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Special Issue on Engineering Ecosystems in Africa

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Special issue: Engineering ecosystems and the development of engineering skills in Africa – Editorial

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After many months of hard work, we are delighted to present this special issue to the SJEE community. Thank you to the authors, our tireless reviewers and the SJEE Editorial Team for making this possible.

As a professional field of study, engineering education operates in a dynamic relationship with educational institutions, industry and the makers of policy that influence how engineering functions in society. Each actor emphasises in different ways the knowledge, skills and purpose of the profession. The relative emphasis of engineering education and the characteristics of institutions that define and deliver it, can vary enormously across different contexts. This special issue explores this interconnectedness with the aim of strengthening engineering education in different contexts, especially the Global South (Matemba, 2022). To do so, it draws on the notion of engineering ecosystems (Klassen & Wallace, 2019), which offers a potential framework on which to build, and which can evolve. There are many ways of depicting an ecosystem; this special issue draws out a range of visualisations and conceptualisations.

The first article by Arnesh Telukdarie and Inderasan Munien illuminates challenges and observations related to engineering education at the level of TVET (Technical and Vocational Education and Training) institutions. *Leveraging the engineering ecosystem to prepare TVET graduates that the South African manufacturing industry needs* reports on a study that investigated whether TVET graduates meet industry requirements (as employees). The authors recognised the disjuncture between what is provided by TVET institutions and the needs of the labour market in the context of higher education (HE) more broadly. Given the scarcity of published data about the relationships between these actors, a primary objective of the article was therefore to address the gap in the literature 'specifically related to the business–HEI–TVET institution nexus as key constituents of the engineering ecosystem' (p. 12) and to identify the factors that businesses in the manufacturing sector view as central to improving the usefulness of TVET graduates to business success. The article makes use of a systems dynamics model to identify points of intervention – or leverage points – in systems that could transform the big picture if robustly implemented. The usefulness of the article extends to other countries in the Global South as far as relative similarities in challenges and general contexts are detected. Overall, the article provides a good case for how engineering education at HE and TVET institutions are interlinked, as far as engineering ecosystems are concerned, and why they should be treated as such when addressed in industry contexts.

The second article also investigates the possibility of leverage points in the relationship between HE and industry, but shifts focus to four countries in East Africa. Written by a team of researchers – Gussai Sheikheldin, Musambya Mutambala, Bitrina Diyamett, Bavo Nyichomba and Umaru Wali – the article explores the potential of the strategy of student industrial secondment (SIS) activities and programmes in addressing the problem of engineering graduates' employability limitations resulting from competence deficit. As a strategy, SIS is understood as being an intervention with the potential to improve competence within the engineering ecosystem, which includes industry partners, academia (within Higher Learning Institutes [HLIs]), policymakers and funding mechanisms.

The article makes a general comparison between the approach to SIS in Tanzania, Rwanda, Uganda and Kenya, and a pilot study involving four SIS students in Tanzania and Rwanda. Compared to conventional SIS programmes, the pilot study was of longer duration, the students were given employee-level responsibilities and payment was included. While the results of the pilot study indicate improved employability skills and increased student confidence levels, the authors downplay these successes, instead using the project as a springboard to reflect on the different ways of conceptualising the engineering ecosystem, including using a systems dynamics model. Part of this involves exploring the notion of a 'regional engineering ecosystem (p. 55) that exists alongside national ecosystems. This is a novel contribution.

The theme of this special issue has been agreeably extended with a third article. Written by Australian author James Trevelyan, it includes research from another region of the Global South, which provides a thought-provoking counterpoint. *Engineering practices observed in South Asia* builds on the finding that 'socio-technical interactions… form the dominant components of engineering practice' (p. 69) and argues that these components of practice are location-dependent. It then draws on extensive fieldwork observations in India and Pakistan to identify location-dependent aspects of engineering practice – such as trust in strangers, language and financial awareness – providing compelling evidence for considering how such factors influence engineering practice in Africa.

The article provides some suggestions for how engineering educators might be able to incorporate these insights into the development of employability skills in formal training, where they are seldom addressed. It also challenges our understanding of engineering ecosystems in terms of the influence of location-dependent factors on the diversity of actors, policies and hierarchies that typically make up such ecosystems. Would these factors, for example, affect how we might conceive of regional engineering ecosystems, the notion suggested by Sheikheldin et al. in the previous article?

The fourth article by Paul Dipitso explores work readiness in the mining sector in South Africa. Entitled *Employers' perspectives on employability skills and attributes of mining engineering undergraduates in South Africa*, the article examines the university–industry relationship within the engineering ecosystem. What makes this article a useful contribution is how it draws on Kolb's experiential learning theory as an analytical lens to understand the acquisition of employability skills when students are placed in a formal industrial secondment programme. Apart from the finding that employers are important in terms of fostering employability skills, the article also provokes us to consider how other theoretical frameworks might be used alongside the conceptual framing of engineering ecosystems.

The final article, returning the focus to East Africa, is entitled *Learning to build institutional capacity through knowledge-based partnerships between universities and industry: lessons for engineering ecosystems from computing in Kenya*. In this piece, the authors, Matthew Harsh, Ann Kingiri, Ravtosh Bal, Ann Numi and Samuel Mibey, explore how linkages between universities and industry might be strengthened through the activity of research. The article deals with a case of computing and information technology in Kenya, analysing a three-year project which created and evaluated industrial studentship and fellowship programmes. It explores how mechanisms of institutional capacity include mechanisms to support acquisition of funding, personal academic support and structures that enable researchers to balance research and teaching. Their findings reveal that while some of these capabilities are weak or missing in the Kenyan computing ecosystem, 'intermediary organisations can act as knowledge brokers to build linkages and facilitate learning between universities and industry' (p. 123).

We hope that you enjoy the valuable contribution of these articles to engineering education research in general but particularly to the growing corpus of literature in and about the Global South.

References

Klassen, M., & Wallace, M. (2019). Engineering ecosystems: A conceptual framework for research and training in sub-Saharan Africa. Proceedings: 7th African Engineering Education Association international conference, Lagos, Nigeria.

Matemba, E. (2022). Redefining the dominated power position in global engineering and in globalization studies in engineering education. SEFI editorial. www.sefi.be/2022/02/02/redefining-the-dominated-power-position-in-global-engineering-and-in-globalization-studies-in-engineering-education/

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Leveraging the engineering ecosystem to prepare TVET graduates that the South African manufacturing industry needs

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This study investigates the claims in literature that South African TVET (Technical and Vocational Education and Training) colleges, a key component of the engineering ecosystem, fail to produce graduates who meet industry requirements. A Likert-scale questionnaire was developed and deployed to manufacturing businesses in South Africa. The results confirm the proliferation of negative perceptions of TVET graduates in South Africa. Advanced statistical analysis and simulation techniques applied to the data confirm the key latent variables impacting the sector as graduate capability, technology, curriculum innovation, technical skills, soft skills, business performance, employability, and graduate turnover. Furthermore, a systems dynamics model was developed based on the causal relationships of observable variables constituting the university–TVET–industry nexus of the engineering ecosystem. The simulation results reveal significant potential for growth in new business activity and employment for TVET graduates. This could be achieved by facilitating collaboration across the engineering ecosystem. Thus, business input into curriculum development would be increased, universities would contribute to curriculum innovation and evolution, and soft skills would be enhanced for both new and existing graduates.

Keywords: TVET, engineering ecosystem, systems dynamics, employability, food and beverage sector, skills

Introduction

Research indicates that technology evolution is a key driver of skills requirements for occupations, impacting new entrants to the labour market and mature workers (Bandura & Grainger, 2019). According to Bandura & Grainger (2019), existing education systems in many countries across the world are failing to adequately prepare the global workforce to contend with change. Consequently, a disconnect continues to grow in terms of academic and technical curricula and requisite skills for occupations with education outcomes and employer requirements (Bandura & Grainger, 2019). A rich and extensive literature analysis indicates

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that the skills development landscape in many countries across the world, South Africa included, is characterised by policies that are not in alignment with the demands of their economic sectors (Brown & Slater, 2018). TVET (Technical and Vocational Education and Training) systems fail to respond to rapid technological advancement, soft skills, and other competencies. In South Africa, the incongruity between supply and demand for skills is intensifying. The existing literature indicates that many young people in the country are languishing in poverty and unemployment arising from an absence of relevant work experience, underdeveloped or inadequate skills, and poor career guidance (Asmal et al., 2020). The TVET system is a critical component of the engineering ecosystem, functioning as a conveyer belt. It creates links between the education system and the labour market. The engineering ecosystem, being complex, depends on all its components to function optimally to generate the requisite outcomes which are to enable, support, and evolve the practices of the engineering discipline wherever they may be relevant or required.

Asmal et al. (2020) find that the unemployment rate among graduates with TVET qualifications has almost doubled from 312 000 in 2013 to 555 000 in 2019. This suggests that there is little or no linkage between TVET institutions and industries, as the skills obtained through these qualifications are not aligned with a developing economy, and fail to produce graduates equipped with the skills demanded by employers. Studies highlight the importance of collaboration between elements of the engineering ecosystem to ensure that students gain the knowledge, skills, and capabilities that employers require (Bandura & Grainger, 2019).

In South Africa, the ineffectiveness of the TVET system is well documented (Badenhorst & Radile, 2018) and characterised by ever-declining uptake rates, low employer satisfaction ratings, and indifference to TVET graduates in the academic sector (Asmal et al., 2020).

Literature review

An overview of the South African TVET sector

TVET played a central role in democratic South Africa's efforts to address persistent unemployment caused by a weak economy. However, the structure, purpose, and accountability of the TVET sector have been significantly altered and transformed by several policy initiatives instituted after the advent of democracy. Currently, there are 677 FET (Further Education and Training) colleges (50 public and 627 private) that operate under the authority of the Department of Higher Education and Training (Needham, 2019).

Public TVET colleges compete with private providers in the marketplace. They are also mandated to provide occupational qualifications, whose funding and quality assurance reside with the Sector Education and Training Authorities (SETAs). To resolve the misaligned technical competence of TVET graduates and to transform the mediocre programmes, which lacked alignment with industry requirements, the government replaced the National Accredited Technical Education Diploma (NATED) qualifications with the National Certificate Vocational (NCV) qualifications (Needham, 2019). The change reduced interest in technical TVET enrolment and the industry failed to support the programme with artisan training. Ultimately the NATED qualifications, with unchanged curricula, were re-introduced into the TVET colleges in parallel with the NCV qualifications, further diminishing the responsiveness of the TVET colleges to the demands of an advanced economy (Terblanche, 2017).

Kraak (2013) likened the South African vocational education system to that of the United Kingdom; both nations adopted a statist and centralised approach lacking industry endorsement and consequently poor employment rates among graduates. The current South African system, according to Allais (2012), contains centralised elements (standards, service delivery regulation, accountability) and decentralised elements (curriculum development, management) which fail to deliver entry-level skills comparable to coordinated systems functioning in Germany and Scandinavia. Studies on skills have found that the South African school and training system has failed to deliver the skills required in the advanced South African economy. McGrath et al. (2019) also found that a TVET qualification offered no advantage in the employment market compared to secondary school leavers. These problems are compounded by high attrition rates in TVET colleges; reports show student attrition of 72% for National Certificate (Vocational) courses offered in TVET colleges (Terblanche, 2017).

Efforts post-1994 were focused on aligning the design and curricula of the TVET colleges to the requirements of the emerging economy. Despite a variety of policy changes, the sector remains besieged by low throughput and poor assimilation of learners into industry. Further, the Human Resource Development Council of South Africa found that funding requirements and uncertainty associated with employment conditions weakened the institutional capacity within the sector to effectively surmount the long-standing challenges, resulting in the TVET colleges persisting with curricula that were acknowledged to be outdated 25 years ago (HRDC, 2014). The diffusion of innovation, which is enabled by institutional investors, is stymied by the absence of agility and relevance in TVET colleges (Vona & Consoli, 2014).

Relationship between the TVET system and employment

Studies have been conducted on employers' views about TVET graduates' employability to determine whether the TVET curriculum is compatible with employers' needs (Kintu et al., 2019). Employers' requirements include a relevant curriculum (implying a process to constantly update and add to the curriculum) and minimal (or zero) nett cost obligations arising from remuneration and training expenditure (Kintu et al., 2019).

Papier et al. (2016) conducted a study across the engineering, retail, wholesale, hospitality, and service sector. They examined employer perceptions of TVET programmes and the graduates produced. The results are quite detailed and demonstrate dissatisfaction among employers with graduate work readiness and attitude. Also, employers in the engineering industry sector highlight an absence of sufficient competence in basic academic knowledge among TVET graduates and maintain that there is a lack of will to remedy the disparity (Papier et al., 2016). Overall, the study found that resolving the following skill gaps is crucial to improving employers' perceptions of TVET graduates across sectors:

- Basic theoretical and practical knowledge;
- Communication skills;
- Computer skills;
- Customer service skills;
- Ability to take initiative;
- An ethic of hard work;
- Self-management skills;
- Willingness to learn;
- Truthfulness/ethics;
- Accountability/taking responsibility;
- Being presentable or well-groomed;
- Respectful attitude;
- Resilience to cope with long hours;
- Punctuality;
- Interviewing skills;
- Professionalism;
- A positive attitude;
- Telephone (mobile phone) etiquette;
- Discipline; and
- Teamwork skills.

The authors reduced these skills to five factors:

- Professionalism;
- Communication skills;
- Workplace understanding;
- Values and ethics; and
- Application of college learning to the workplace.

The authors developed a generic programme and implemented this curriculum enhancement programme in collaboration with selected colleges, SETAs, and employers. The project outcomes revealed that students and employers valued the intervention and showed a positive impact on both employer and graduate experiences and perceptions (Papier et al., 2016).

Conventional ecosystems are biological communities interacting on multiple levels. Applying the analogy to the field of engineering requires an expansion incorporating the interactions between the institutional actors possessing a common interest in the field and the hierarchical relationships between the diverse actors (Klassen & Wallace, 2019). Klassen and Wallace (2019) identified the key challenges confronting higher education institutions (HEIs) within this framework:

1. Pressure to enrol more candidates;
2. Desire to increase research outputs;
3. The oversupply of degreed engineering graduates; and
4. Difficulties of engaging with the private sector due to cultural differences or complex bureaucracies.

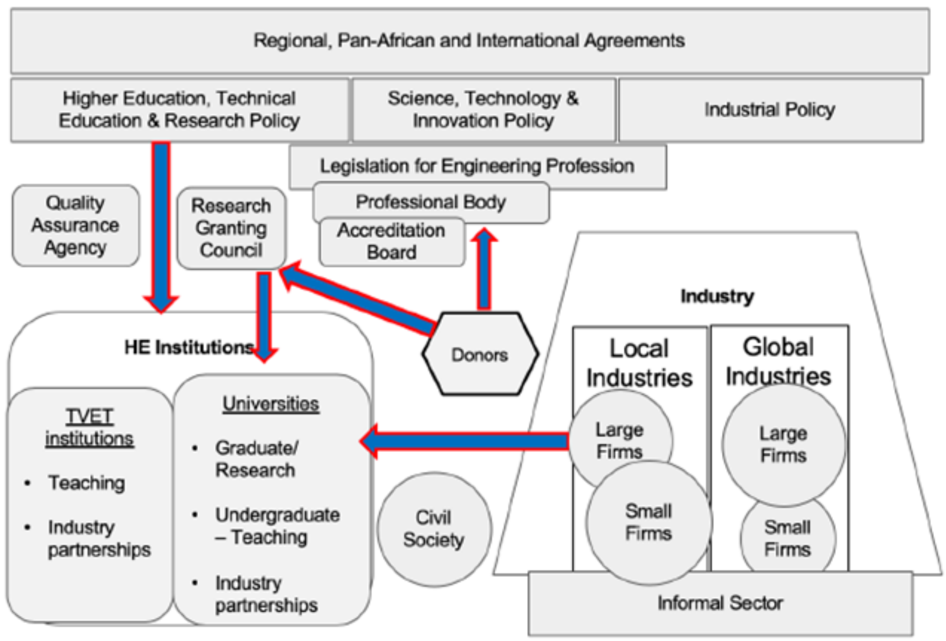

Figure 1: *Engineering ecosystem framework (Klassen & Wallace, 2019)*

Teis (2021) highlighted new challenges for future labour markets initiated by industry digitisation and automation. In response to rapid digitisation, education, and training institutions are now preparing students for evolving and emerging industries instead of outdated occupations. As a result, there is now a concerted effort to align curricula to generate the advanced skills needed for the 4IR. This ongoing effort ensures that students are equipped with the knowledge and skills needed to succeed in the rapidly changing economy of the present and future.

Vocational Education and Training (VET) in the United Kingdom began with a reluctance from the government to participate in the programme, and after a brief period of intervention after World War II when a levy and grant system was legislated, VET in the UK was an employer-led voluntary system. During the 1980s the UK system, being employer-led, was concentrated on company-based skills acquired via National Vocational Qualification skills rather than more generically applicable skills throughout a sector (Terblanche, 2017). The system oscillated between demand and supply control until the present, with the current structure shown in Kraak (2016). The occupational qualification pathway is only followed by 10% of early school leavers. This is primarily due to social and institutional perceptions relating to the prestige and status associated with VET in the UK.

The TVET system in the Netherlands was restructured by merging colleges, adopting outcomes-based education, implementing a National Qualifications Framework, and instituting performance management. Employers play a leading role through sector skills councils in the Netherlands. These councils identify and communicate requirements to an umbrella body which is translated into curricula approved by the government. Employers, who are accredited by sectoral body officials, are the primary training providers in the system. As opposed to the UK system, the Netherlands system is characterised by an institutional alignment between engineering ecosystem actors.

Like the Netherlands, the German system is aligned between the supply and demand components within the engineering ecosystem. The German system consists of a compulsory four years of primary schooling and five years of secondary schooling. Thereafter, learners have the option to enter a dual system, which provides training that alternates between vocational schools and employer sites, and which is accessible to any learner completing the compulsory nine years of education. After three years of vocational training, graduates can enter employment. The German system is facilitated by the government and predicated on stakeholder consensus, including collectively constructed qualifications that enjoy broad recognition (Terblanche, 2017).

Policy variation in South Africa has resulted in institutional instability (Kraak, 2016), which detracts from the objectives of the TVET system to reduce unemployment, inequality, and the burden on institutions of higher education. Buthelezi (2018) found that TVET graduates in South Africa struggle to find employment and rarely create entrepreneurial activity. Employers have no confidence in the TVET system, primarily due to non-inclusive processes, while Buthelezi (2018) opines that TVET graduates 'have unintentionally been used by the system as subjects for experimentation'.

Currently, obtaining vocational education and training is achieved via NC(V) programmes, NATED programmes, learnerships and apprenticeships, technical schools, and occupational qualifications (Badenhorst & Radile, 2018). Statistics South Africa (2014) reported shortages of artisans, technicians, and engineers, and Field et al. (2014) posit that youth unemployment results from a mismatch between skills and employment opportunities. Recently, the International Institute for Management Development ranked South Africa 61st out of 64 countries for skilled labour availability (IMD, 2023).

Marock et al. (2016) reported that a colleges improvement project conducted in the Eastern Cape and Limpopo provinces between 2011 and 2014 suggested that campus improvement initiatives require broad engagement from all stakeholders (college management, learners, employers, teachers, financers and government) and a focused improvement on teacher development and student support (tutorial programmes). Gewer (2016) posited a framework to effect TVET transformation.

Fannon et al. (2019) propose that TVET lecturers be subjected to mandatory industry-based placements to improve practical skills and comply with a continuous professional development plan to facilitate knowledge transfer. Field et al. (2014) suggested that improvements to the South African TVET system must include: resolving the confusing extant architecture to provide clear vocational pathways; linking the provision of vocational training with employer needs; reviewing skills funding policy and framework; improving teacher and management capacity; and focusing on completion and transition.

The HEI landscape and engineering outcomes

Yokogawa (2021) shows that the extent to which an industrial entity is automated varies between human-controlled processes and technology-mediated collaborative ecosystems operating autonomously. This transition from manual to automatic depends on the availability of skills and knowledge generated by HE ecosystems in their entirety. The engineering outcomes necessary in today's technology-driven economy are determined by the quality of candidates emerging from the HE system. In acknowledgment of the criticality of the quality of the skills and knowledge supplied to a transitioning economy, Teis (2021) noted the South African government's prioritisation of an industry-aligned curriculum presented by lecturers with industrial experience. Further, the Minister of Higher Education, Science and Innovation highlighted the central role of industry in generating the requisite competencies by investing in infrastructure and providing experiential training. The HEI ecosystem remains the primary factor determining engineering outcomes driving technological evolution in the industry.

Kraak (2016) accentuated the importance of the HEI ecosystem to the engineering discipline by pointing out that industrial growth drives innovation evolution, and that work-ready graduates enable growth. The perpetual interplay between these two forces drives the development of the proximal engineering discipline as technology inevitably involves the influx of cutting-edge knowledge in materials, systems, processes, and design.

The gap in the existing literature

Whilst the literature indicates that there seems to be a disjuncture between what is provided by TVET institutions and the needs of the labour market, there is a scarcity of published data peculiar to the South African engineering ecosystem on the topic. The current body of literature identifies several challenges facing the South African TVET system, including a lack of coherence, resulting in fragmentation in the system. According to Badenhorst & Radile (2018), the fragmented TVET system often causes disengagement by students, lecturers, and eventually prospective employers. This is supported by academic scholarship on TVET and skills development that illustrates that generally, TVET institutions are failing to respond to the needs of the labour market effectively (Kruss et al., 2017).

Research illustrates that it is important to provide students with the skills needed to meet the demands of the changing industry (Asmal et al., 2020). Badenhorst & Radile (2018) suggest that TVET colleges' administrative and corporate service functions must be strengthened to enhance performance. One of the important findings emerging from the existing literature is that the strategies and mechanisms put in place for training and skills development to address the TVET system such as work-based learning, centres of specialisation, the Lead SETA–TVET Project, and TVET College Improvement Project (Kruss, et al., 2017), among others, have failed to achieve the desired results. The extant literature does not address the perspective of manufacturing businesses specifically, nor does it evaluate the potential implications of instituting business-generated reforms on TVET curricula on the wider engineering ecosystem, of which TVET institutions form an integral part.

The primary objective of this study is to address the gap in the literature specifically related to the business–HEI–TVET nexus as key constituents of the engineering ecosystem by identifying the factors businesses in the manufacturing sector view as central to improving the utility of TVET graduates to business success. This is attained by:

- investigating the key insights relating to the TVET system as part of the engineering ecosystem in the manufacturing sector;
- examining the integration of the TVET system into the engineering ecosystem in terms of the adequacy and alignment of TVET outcomes with the needs of the system; and
- evaluating the impact of these integration strategies on the growth of new businesses in the sector using modelling and simulation.

In pursuit of the stated objective, the research addresses questions relating to the adequacy of the contemporary curricula pertinent to the Food and Beverage SETA strategy, the potential for absorption of TVET graduates upon improved integration into the engineering ecosystem, and the key tenets of any new SETA outreach programmes aimed at expediting knowledge evolution in a pervasive manner throughout the food and beverage industry.

Research methodology

Study framework and questionnaire development

The study adopted a mixed methods approach which combines both quantitative and qualitative methods to provide a broader and more complete vision of the problem (Almeida, 2018). A comprehensive global review of existing literature was conducted, and a nationwide (SA) sector-specific research questionnaire, predicated on the literature review and employing

Likert-scale questions, was deployed. A detailed analysis of the questionnaire results was conducted to analyse the current South African food and beverage status. This aimed to provide a current benchmark.

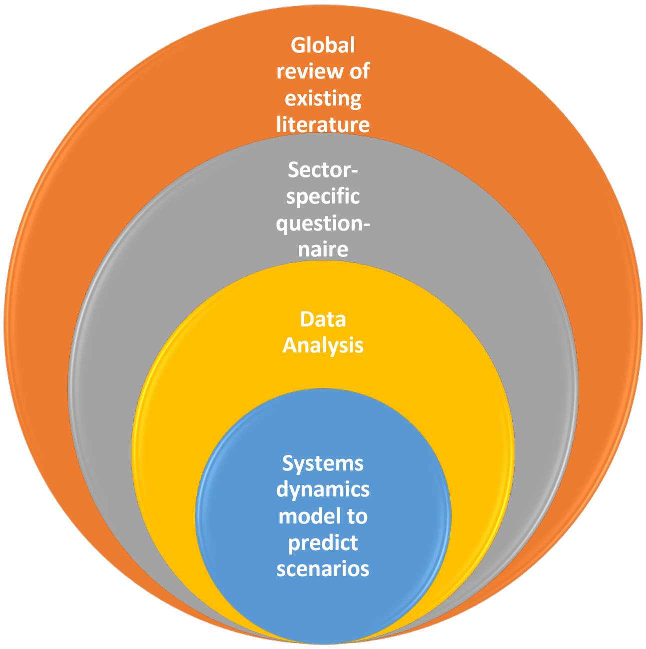

Figure 2: *Research framework*

The literature was also reviewed to determine requirements in terms of skills required for employment, and different TVET curriculum models. The results of the literature review were used to design a questionnaire to determine whether the TVET curriculum in South Africa was appropriate to the skills needed by the food and beverages manufacturing sector.

The themes identified in the literature were analysed into questions designed to validate the findings in the literature and, more importantly, to obtain a detailed understanding of the specifics related to each theme. For example, the need for engineers to be equipped with soft skills was a finding pervasive in the literature. Soft skills are non-technical transferrable skills, and a series of questions was included to validate this finding and to understand the importance that the industry placed on this suite of skills.

Research sample and questionnaire administration

The target population for this study was the 13 987 companies in the South African food and beverages manufacturing sector. The study used probability sampling to ensure that the characteristics of the sample size reflected those of the larger population. Contact details of all small, medium, and large companies (levy-paying and non-levy paying) were extracted from the SARS Levy Database (2020). In total, a sample size of 2 628 companies (email addresses extracted from the database) was drawn for the population. All the companies selected for the survey were manufacturing companies whose products can be categorised as baked goods, cereals, confectionary, snacks, beverages, dairy, food preparation products, or processed meat or vegetables. As manufacturing businesses operating in a competitive marketplace, those selected are in a race for productivity, driven primarily by technology and operational improvements. Both technology and operational excellence are enabled by the engineers delivered from the higher education system, which combines with industry in a critical linka in the engineering ecosystem.

The online questionnaire was sent to all the 2 628 companies together with an email explaining the purpose of the study and inviting recipients to click on a link to complete the questionnaire. Following this, reminder emails were sent to those who had not completed the questionnaire to improve the response rate. Moreover, telephonic questionnaires were also conducted to further increase the response rate. 207 responses were received. Responses were received in a format that could be transferred to Microsoft Excel for analysis.

Development of the systems dynamics model

Systems dynamics is uniquely adapted for understanding social, environmental, and systemic interactions due to a top-down, macro focus and a limited need for assumptions (Muravev, 2019). Further, the emergent behaviour arising from complicated cause-and-effect interactions is readily reproduced by systems dynamics models (Nielsen, 2018). Klassen and Wallace (2019) viewed the engineering discipline as being part of a complex ecosystem evolving under the influence of dynamic forces including technological change and knowledge and skills

Current studies encounter the persistent challenge of predicting the impact of systemic and other changes on improvement initiatives. To remedy this shortcoming, the research team developed a systems dynamics model predicated on the qualitative survey feedback. The questionnaire responses were evaluated using confirmatory factor analysis to establish the latent impact of the following five constructs on the integrated engineering ecosystem:

- TVET training qualifications;
- SME uptake;
- Industry uptake;

- SETA;
- Higher education; and
- External factors.

These factors were selected based on the study objectives, together with Klassen & Wallace's (2019) engineering ecosystem framework, and the various causal loops were integrated to form a coherent systems structure commensurate with extracts from international best practices. The factor loadings quantified the impacts of the key constructs on the system and generated the dynamic profiles of the system variables resulting from the complex reciprocal interactions over time.

The integrated systems structure (see Figure 7) was evaluated using algorithmic techniques to establish the long-term impacts of various scenarios on the engineering ecosystem and its constituent systems.

Results

The research identifies the key facets for prospective engagement between operating entities in the food and beverage sector in South Africa and the TVET institutions which exist to deliver skills to the industry. The key parameters necessary for the appraisal of a TVET system as elucidated in the literature were the relevance of the curriculum, the familiarity of graduates with contemporary technology, the hard and soft skills, the employability of graduates, and perceptions of industry actors regarding the prospective value of TVET graduates.

The research instrument (questionnaire) was developed to specifically illuminate the key issues accentuated in the literature and to address the gap in the literature relating to identifying perceptions necessary to leverage the engineering ecosystem in service of manufacturing in South Africa. Importantly the literature review and subsequent questionnaire were structured to align with a systems approach. This is detailed in the methodology above, with the systems focusing on the SETA, skills, and business cycles. The results from the questionnaire are presented below followed by the systems construct and the systems dynamics model. The research study was structured to deliver on the individual variables affecting skills delivery, the factoring of these variables into systems, and finally the interaction of the collection of systems as an ecosystem.

The profile of the sample was established based on two categories: size, and SETA chamber. The respondents submitted the requisite information with the data (shown in Table 1) showing the comparable participation levels between the different categories of business in the sector.

Table 1: *Participation levels in business category*

Respondent business category	
Large	42%
Medium	31%
Small	27%

The distribution of respondents among the five chambers of the food and beverage manufacturing sector is shown in Table 2. The majority of the respondents are from production, processing, and preservation of meat, fish, fruit, vegetables, oil, and fats (28%), followed by the manufacture of food and preparation products (25%).

Table 2: *Response rate of the various chambers*

To which food and beverage SETA chamber does your business belong?	
Manufacture of Breakfast Products	15%
Beverage Manufacturing	17%
Dairy Manufacturing	15%
Manufacture of Food Preparation Products	25%
Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetables, Oil, and Fat	28%

The first section of the questionnaire focused on industry perceptions relating to the ability of the TVET system to fulfil the skills requirements of the food and beverage industry sector. Various researchers have alluded to a skills mismatch between industry and TVET graduates, and the questionnaire was designed to investigate this perception within the food and beverage sector in South Africa. The responses (as shown in Figure 3) highlight a general dissatisfaction with the graduates' capabilities in all disciplines relevant to the manufacturing sector, with the best response achieved by administration TVET graduates (30% of respondents dissatisfied).

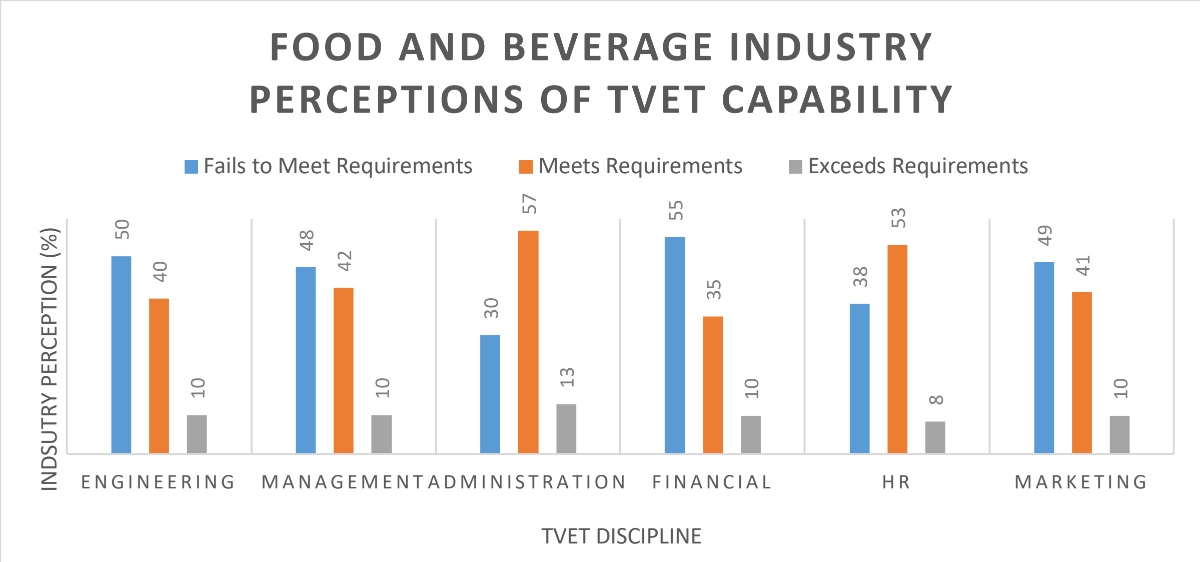

Figure 3: *TVET graduate capabilities as viewed by the employers*

The results indicate that all qualifications assessed by respondents had large proportions failing to meet industry requirements. 50% of engineering graduates from TVET institutions failed to meet employer requirements. This is similar to the perceptions relating to TVET graduates undertaking other fields of study. This result confirms the disconnect between the two key components of the engineering ecosystem, highlighted extensively in the literature, namely industry and TVET institutions.

In the literature, the failure of the South African TVET system to respond to the need for soft skills is cited as a key limitation. This research investigated the perceptions within the food and beverages (FoodBev) employer community relating to soft skill requirements amongst TVET graduates in the South African food and beverages sector. Figure 9 in Appendix A illustrates that the overwhelming majority (84%) of employers in the food and beverages sector indicated that soft skills should be included in the TVET curriculum with the need expressed as ‘moderate’ amongst 48% of the respondents, ‘major’ amongst 18% and as ‘must have’ amongst 19% of the respondents.

The employers were requested to propose the portion of the TVET curriculum that should be dedicated to soft skills. Figure 10 in Appendix A illustrates that 29% of employers indicated that a ‘significant’ portion of the curriculum should be devoted to soft skills, 9% indicated major and 45% indicated minor. The inclusion of soft skills in the TVET curriculum is thus supported by 83% of employers, including 29% indicating that a ‘significant’ portion of the curriculum should be devoted to soft skills (see Figure 10, Appendix A). In addition, 88% of the sample of food and beverages employers believed that soft skills would improve graduate effectiveness in the workplace, with 36% predicting a 'significant' improvement and 9% anticipating a 'major' improvement.

Pervasive in the literature (Terblanche, 2017) is the culpability of the antiquated curriculum in generating graduates lacking acceptable levels of proficiency in technology-related disciplines. Respondents in the food and beverage sector concurred with the literature that TVET graduates' proficiency in engineering and technology-related disciplines is lacking, as demonstrated in Figures 4 and 5.

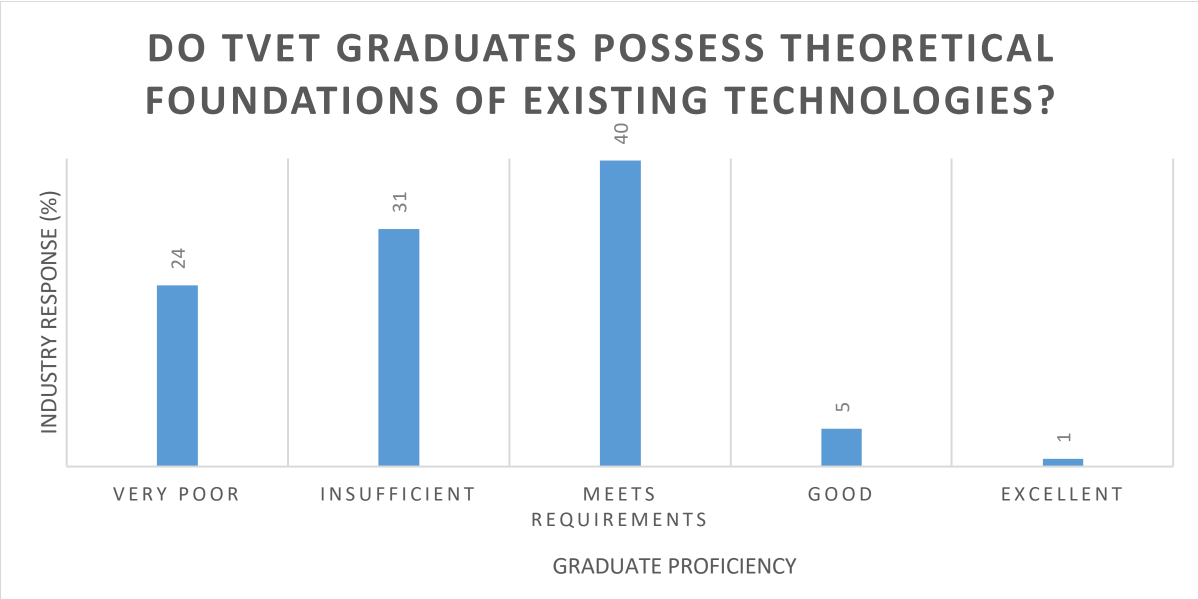

Figure 4: *TVET graduates' theoretical foundation in technology-based disciplines*

A minority (39%) of food and beverage sector respondents were satisfied with TVET graduates' theoretical foundations. Only 5% rated TVET graduates' engineering and technology proficiency as 'good' and 1% as 'excellent'. The majority of respondents (55%) rated the TVET graduates either as 'very poor' (24%) or 'insufficient' (31%) concerning technical knowledge. As an integral component of the engineering ecosystem, the levels of dissatisfaction with TVET engineering graduates reflect the lack of cohesive and integrated action within the engineering ecosystem and highlight the necessity for coordinated action amongst higher education, industry, and government policy to ensure the smooth functioning of the entire ecosystem. The implications of such coordinated action are investigated in subsequent sections.

As the proliferation of innovative technologies driven by the Fourth Industrial Revolution (4IR) increases in the food and beverage sector specifically and manufacturing in general, the capacity of TVET graduates to work with innovative technologies becomes critical to the sector's ability to remain competitive in a globalised economy.

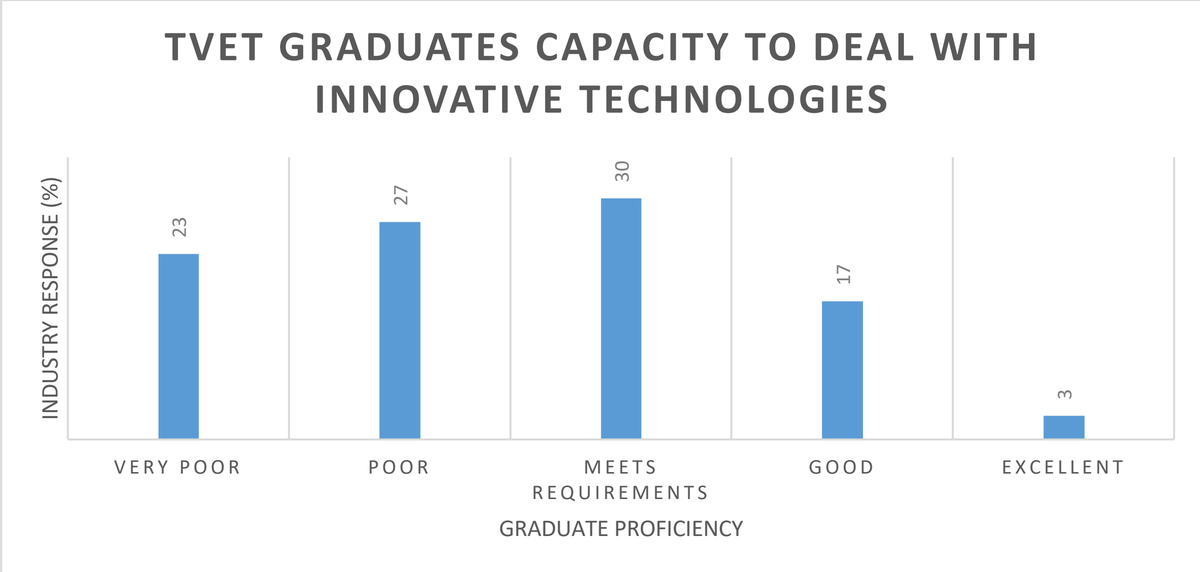

Figure 5: *TVET graduates proficient with innovative technologies*

Only 50% of respondents rated current TVET graduates as capable of meeting the challenges of the 4IR, of which the majority (30% of the total sample) indicated that the graduates just 'meet requirements'. The remaining respondents rated the TVET graduates' ability to contend with innovative technologies as either 'poor' (27%) or 'very poor' (23%). Having been identified as central to South Africa's competitiveness going into the future, industry initiatives to implement 4IR strategies are constrained by the availability of the requisite skills in South Africa. The response from this questionnaire suggests that the majority of industries in manufacturing in South Africa have poor confidence in TVET graduates' capability to give effect to 4IR investments, thus minimising commitments to 4IR strategies in South African manufacturing. Here again, the imperative of coordinated action from all components of the engineering ecosystem is shown to be critical to achieving strategic outcomes essential to ensuring the sustainability of the South African economy.

The vast majority of respondents (81%) indicated that appropriately skilled TVET graduates would positively affect business performance, with 46% anticipating a 'significant' improvement and 19% expecting a 'major' enhancement in business performance (refer to Figure 11, Appendix A). As per the literature (Papier et al., 2016), TVET-trained employees can significantly contribute to businesses. The ongoing disjuncture between the key elements of the engineering ecosystem manifests in material losses for the manufacturing sector. The extremely high proportion of responses indicating significant and major improvements that would arise from properly skilled TVET graduates highlights the lost opportunities which are ultimately borne by society at large.

Further, nearly all the respondents (96%) indicated that they would increase their complement of TVET graduates if the graduates were appropriately skilled, with 45% of business projects employing an additional 6 to 10 TVET graduates (refer to Figure 12, Appendix A). The total potential for employment exclusively restricted to the cohort of respondents (n = 202) at the low, midpoint, and high levels within the ranges reported suggest additional opportunities for 1 009 (low end of the range), 1 516 (midpoint of range) or 2 235 (high end of the range) TVET graduates. That the overwhelming majority of respondents would increase the uptake of suitably skilled TVET graduates is a strong indicator of the immediate need for TVET skills, the opportunity cost currently being suffered by the economy, and the imperative for coordinated action from the engineering ecosystem. The results also suggest a potent opportunity for employment and economic growth within the food and beverage sector if the sample projections are extrapolated to the population.

The perception that the TVET programme curriculum should be improved by evolution innovation is affirmed by 84% of the respondents from the Dairy Manufacturing Chamber and 93% of the respondents from the Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetable, Oil and Fats Chamber. In the beverage manufacturing chamber, only 26% of respondents believe that innovation evolution should constitute a 'major' portion of the TVET curriculum renewal (Figure 13, Appendix A).

Figure 6 illustrates that 81% of respondents from the Manufacture of Breakfast Products Chamber and 98% of respondents from the Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetables, Oil, and Fat Chamber believe that innovation evolution content would improve TVET graduate workplace performance. A full 60% of the respondents believe that inclusion of innovation evolution in curriculum development will have either a 'significant' or 'major' impact on TVET graduate workplace performance. Innovation evolution is best affected by high levels of integration between the components of the engineering ecosystem as well as higher levels of knowledge dissemination between the universities, which are research-focused institutions operating at the leading edge of knowledge, and the TVET colleges.

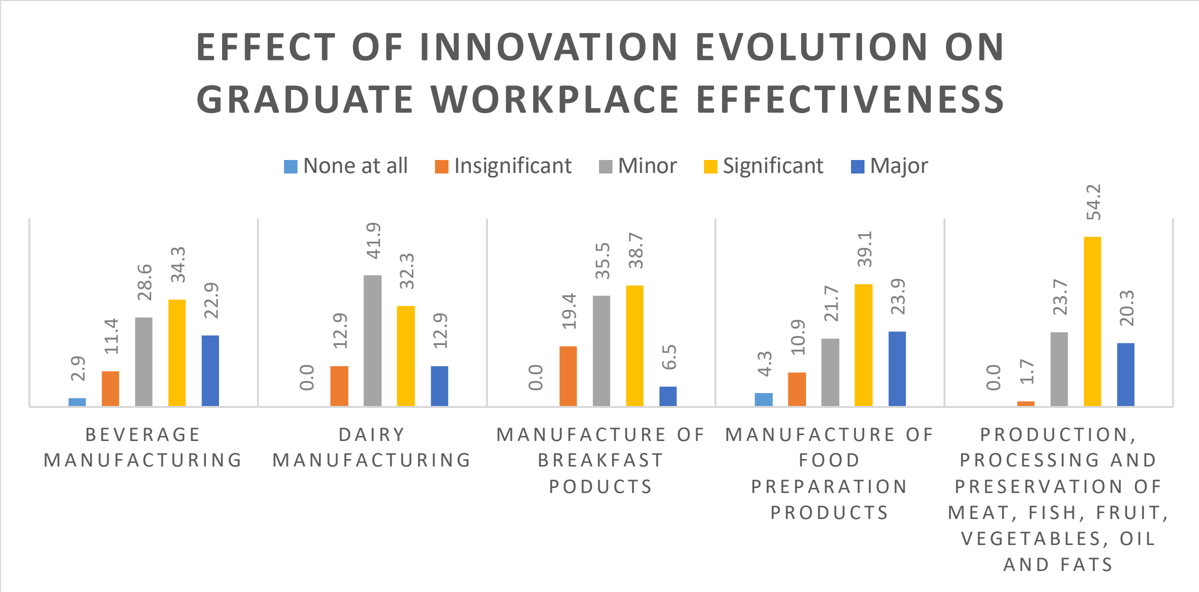

Figure 6: *Innovation evolution and workplace effectiveness*

The results presented in this section confirm that respondents' in the food and beverage sector experiences of TVET graduates are compatible with the findings in the literature, primarily about the skills gap, and the respondents' expressing a strong sentiment that sector involvement in curriculum development and soft skills education will have a transformative impact on TVET graduate workplace effectiveness. A distinctive finding from the sample is the strong expression of the need to incorporate innovation evolution as a critical component of the curriculum development process.

Systems modelling

This investigation ultimately evaluated the implications of enhanced cooperation strategies between the elements of the engineering ecosystem, with government policy represented by the FoodBev SETA. The key variables evaluated were:

- Curriculum innovation evolution;
- SME maturity;
- Employment;
- Impact of technologies;
- Soft skills;
- Hard skills;
- Graduate turnover within the sector.

Questions intended to ascertain perceptions relating to each of the aforementioned parameters were included in the questionnaire and the appropriateness of the questions to the related magnitudes was evaluated using confirmatory factor analysis (CFA) conducted with the Quantec Stata statistical package. The results of the factor analysis confirm the correlation of the observable variables with the aforementioned dimensions, thus confirming the validity of the questionnaire.

Quantification of the Likert scale raw data obtained from the measuring instrument was used on all questions to facilitate statistical analysis and comparison. A Cronbach coefficient alpha of 0.911 demonstrated a strong alignment of the questions to the factors being measured and the internal consistency of the data. The sample consisted of 207 randomly selected respondents from a population of 1 000 businesses. The margin of error for the data was calculated to be 6.2%, validating the samples representative of the population.

A systems dynamics model was created based on the investigation dimensions verified by the CFA, using the relative factor loadings. The model arises from the structure of the causal relationships inherent in the integrated TVET and food and beverage system and is constituted of the observable variables identified in the questionnaire. The integrated causal loop diagram developed in Figure 7 is based on Klassen and Wallace's (2019) engineering ecosystem framework. The pool of graduates in the system (Graduate Pool in the model) is a key response variable in the system together with the FB New Business Growth and Entrepreneurial Activity.

The various sub-systems account for the education and qualification of graduates into the system, ingress of graduates in the food and beverage sector from other industrial sectors, movement of graduates out of the system, and SETA-mediated industry input into TVET curricula upskilling of graduate soft skills and hard skills, and insemination of innovation evolution into the TVET programme.

The questionnaire feedback and the results arising from the subsequent statistical analysis provided the input quantities to define the key dimensions of the model. The integration of the various reinforcing and balancing loops produced by the component systems was effected by linking the common variables between the systems. The selection of the variables and constituent systems was guided by Klassen and Wallace's (2019) engineering ecosystem framework.

The accumulation variables in the integrated system were formulated to provide insight into the key aspects under investigation in the system of systems. A key benefit of systems dynamics is that the temporal profile of the variables was obtained in a manner that included the reciprocating effects of the variable on the elements within the system, and the effect of the system on the variable. As such, dynamic equilibria and unconstrained growth of accumulated quantities provide insight into the fundamental structure of the model during the validation and calibration processes.

The system crucially includes the implications of curriculum improvement on graduate workplace effectiveness and the corresponding implications for food and beverage business performance. The combination of the entrepreneurial activity in the sector and the manifestation of the system structure on business performance is presented as New Business Growth in the model. The model accommodates the feedback loops inherent in the system, providing a more realistic representation of the TVET–FoodBev system.

The model provides the predictive capacity to establish the effects of changes to the observable variables on the research dimensions and the key response factors within the food and beverage industry sector, viz., workplace efficiency, TVET graduate uptake, the pool of TVET graduates available to the sector, food and beverage business performance, and new business growth in the sector. The emergent characteristics inform decision making and resource allocation in constrained environments.

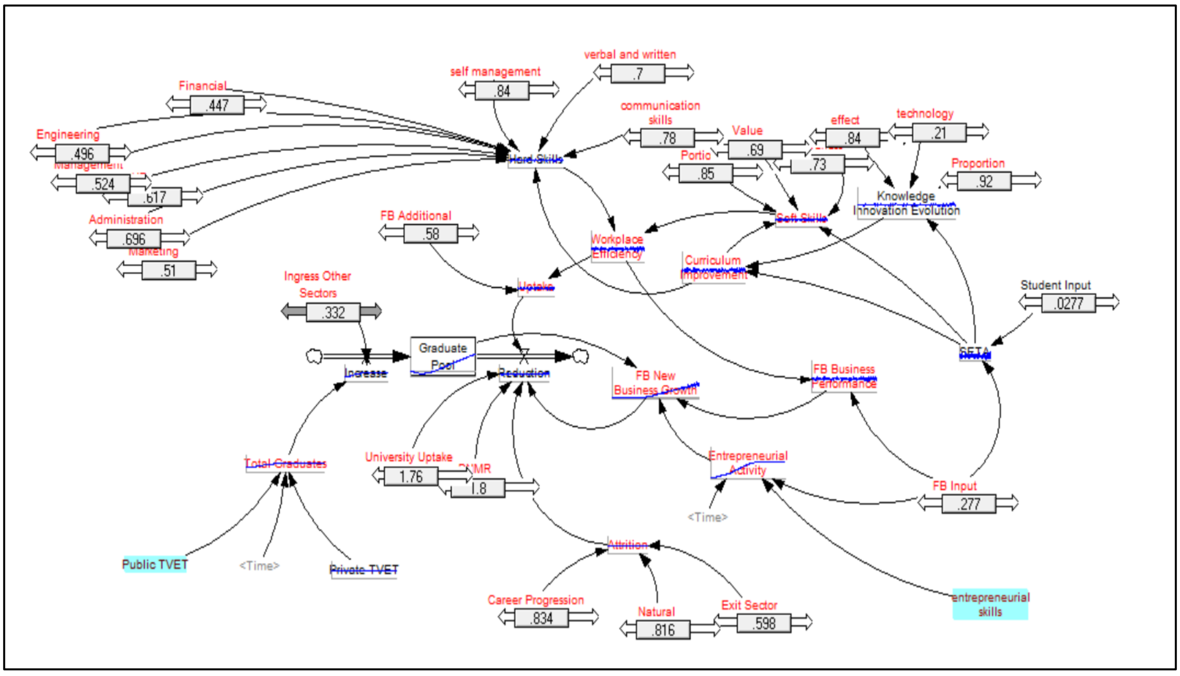

Figure 7: *Systems dynamics model*

The systems dynamics model (Figure 7) developed following the questionnaire data indicates that any TVET curriculum improvement propelled by innovation evolution will improve the hard and soft skills of TVET graduates, resulting in increased graduate effectiveness in the workplace. This will contribute in turn to improved food and beverage business performance, ultimately leading to growth within the sector. The growth of business will deplete the pool of graduates which will constrain growth until the pool is replenished at higher levels from the TVET system and other industrial sectors refuelling the cycle of growth. The model facilitates strategy development by evaluating the deployment of initiatives on the key variables driving growth in the sector. The key value of the model is in using the systems dynamics methodology to simulate integrated inputs with feedback mechanisms to predict tactical and strategic outcomes.

The baseline model was set up on Vensim, a specialty systems dynamics simulation software package. Systems dynamics models reflect systems behaviour at a strategic level which manifests over extended periods; hence the model was set up to run over 240 months (with monthly iteration intervals). The structure of the model was laid out as per the causal relationships discussed above. The baseline scenario (Figure 14, Appendix B) was established on the results of the questionnaire feedback and the relative interactions between the observable variables within dimensions was obtained from the confirmatory factor analysis. The mathematical relationships between the variables were designated following the relative interaction between the variables, as obtained from the measurement questionnaire and the CFA results indicating the relationship between the system dimensions. The results obtained from the baseline simulation were used to ascertain the impacts of changes in observable variables on the two key response variables in the system, the Graduate Pool and New Business Growth. Graduate Pool is the only accumulation variable in the system, and it monitors the changes in the pool of available graduates over time. The baseline inputs for each variable are shown in Figure 14, Appendix B.

The baseline model reflects the hypothetical scenario constructed exclusively from FoodBev sector respondents' perceptions of the impacts of observable variables which are primarily related to TVET graduate quality and the impact of curriculum changes on the overall TVET–FoodBev system. The model was first run to illustrate the baseline scenario which served as the basis for comparison for subsequent changes enacted to investigate specific scenarios. The results obtained for the two key response variables in the baseline scenario are shown in Figure 14, Appendix B. The comparisons with the data in the subsequent scenarios were conducted based on indexes, with Graduate Pool initially at an index value of 100 and FB New Business Growth at a value of 0. In the figure, the Graduate Pool shows an initial decline arising from the increase in demand for graduates stimulated by the improved curriculum. The system does not initially possess the capacity to supply the required number of graduates; however, lower graduation reduction rates allow the accumulation of a pool of graduates over the system requirements.

The Graduate Pool and FB New Business Growth variables reached maximum index levels of 1 200 and 0.15 from initial values of 100 and 0 respectively. The Graduate Pool achieved a minimum value after 58 months, while the FB New Business Growth reached a minimum value after 45 months. In terms of the model, the baseline profiles of the variables were driven by the improved curriculum creating demand for more graduates. These graduates had a significant positive impact on company performance due to improved workplace effectiveness, ultimately driving new business growth in the food and beverage sector (FB New Business Growth).

To investigate the effect of the food and beverage sector input into the TVET curriculum, the level of FB Input into the TVET curriculum development was doubled to 0.6, from the baseline value of 0.3 in the first scenario (Figure 15, Appendix B). The Graduate Pool assumed a similar profile as the baseline profile of the variable; however, the maximum value reached was 688, almost half the final graduate pool relative to the baseline. The FB New Business Growth variable also reached a final level double that of the baseline value. The number of graduates in the pool declining indicates higher employment rates arising from the twofold increase in new business growth in the sector. This result shows that if the system behaved in accordance with respondents' perceptions, input from the food and beverage sector into the curriculum development could translate into proportionate new business growth in the sector.

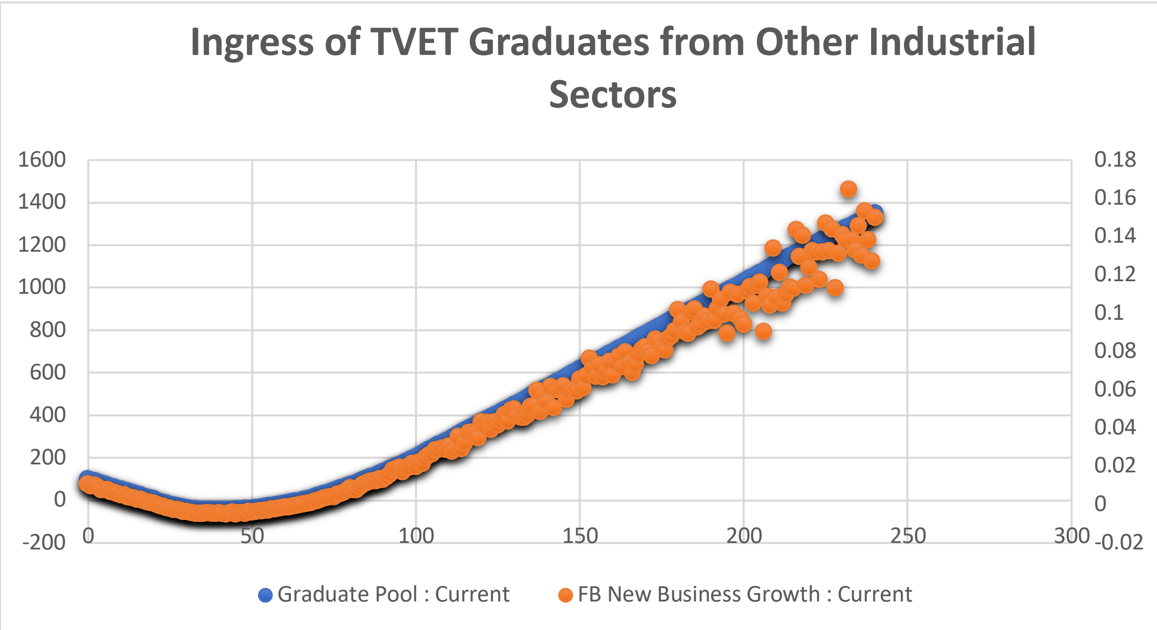

Figure 8: *System dynamics model ingress of graduates*

The minimum levels reached by the Graduate Pool when the number of TVET graduates from other sectors into the food and beverage sector doubled was higher than the baseline minimum value for this variable. However, at 1 348, the Graduate Pool surpassed the baseline maximum, demonstrating that graduate ingress is not a desirable situation. An excessive accumulation of graduates leads to unemployment and dissatisfaction in the sector. Irrespective of the availability of graduates in the available pool, the New Business Growth remains at the same levels as the baseline conditions. This result indicates that well-qualified graduates possessing the requisite skills to function effectively in the workplace obviate any need for inter-sector movement of TVET skills.

In Figure 16, Appendix B, the effect of doubling the attrition rate of graduates from the FoodBev sector on the Graduate Pool and New Business Growth is shown. The deficit in the Graduate Pool (–162) does not exceed the deficit achieved when the food and beverage sector provides input in the TVET curriculum development (–177). FB New Business Growth only reaches a maximum of 0.09, which was the second lowest maximum in the scenario analysis. Losing key skills through attrition has a severe impact on business performance to the extent that business growth is significantly subdued.

The results presented in this section are based on the hypothesised impacts on the observable variables of the respondents' perceptions as predicted by a systems dynamics model of the system. The severity of outcomes on the Graduate Pool and the New Business Growth could also be interpreted as the importance with which the industry representatives view the effect of an escalation of the TVET failure rate and loss of graduates to universities. Also, the impact on the system of returning graduates with improved qualifications is not considered.

It is evident from the results that innovation evolution affected by technology updates and skill requirements from industry and research from universities will increase graduate effectiveness and growth in the sector. The mechanisms facilitating innovation evolution across the engineering ecosystem is an area for future study. However, curriculum improvement through innovation evolution is shown to be a significant medium to integrate the knowledge across the engineering ecosystem.

Conclusion

The results obtained from the deployment of a measuring instrument (questionnaire) to random businesses from the five chambers constituting the Food and Beverage SETA confirm the findings from the literature (Terblanche, 2017) relating to the skills gap between employer expectations and TVET graduates entering the marketplace. Except for graduates pursuing administration qualifications, the industry response showed that 50% of TVET graduates from fields relevant to the FoodBev SETA in South Africa failed to meet industry requirements. Further, also supporting the literature (Papier, 2016), 84% of respondents highlighted a need for the inclusion of soft skills education in TVET curricula, and a greater proportion of respondents, 88%, felt that soft skills will improve graduate workplace performance.

The respondents also articulated dissatisfaction with the graduates' technical knowledge, and the point is highlighted by a strong expectation amongst 96% of the cohort of respondents that graduate employment in the sector would improve considerably should this shortcoming be addressed. The respondents are most concerned about issues relating to innovation evolution, employment, business performance, and technology capacity of graduates, which are well correlated with findings in the literature.

A key finding in this study is the respondents' prominent consideration of innovation evolution as critical to the success of devising a successful TVET curriculum, with 60% of the respondents across all the chambers indicating that innovation evolution will have a 'significant' or 'major' impact on graduate workplace effectiveness. This suggests that research-based knowledge from universities and technology skills from industry are important inputs to the TVET curriculum.

The respondents in this study have clearly articulated dissatisfaction with the existing TVET outputs; and the research identifies opportunities for improvement and presents a systems dynamics model capable of evaluating system impacts when changes are introduced into the food and beverage and TVET integrated system.

The contention that the TVET institutions are a key element of the engineering ecosystem is supported by research findings showing the extent of latent growth potential in the manufacturing sector attributed to inadequately skilled TVET graduates, and the industry responses establishing an absence of cohesion between the engineering ecosystem elements. The respondent's eagerness to employ graduates deemed suitable by industry standards exposes the cost currently being suffered by the economy at large by the poor quality of TVET graduates. The results indicate that the graduate quality issue is an outcome of a poorly integrated engineering ecosystem. The systems dynamics modelling shows that in all scenarios, the outcomes for business and employment in the sector are significant when the components of the engineering ecosystem, as articulated by Klassen and Wallace (2019), function in a coordinated manner to generate a defined outcome.

The higher education–policy–industry nexus has proven incapable of resolving the crisis in technical skills befalling South Africa, with each element pursuing an agenda in isolation. The findings of this research show that the necessary outcomes to realise the 4IR in South African manufacturing emerge from the engineering ecosystem in its entirety, functioning as a single system operating with constant feedback between the components. Innovation evolution is a key attribute of the engineering ecosystem which is made possible by the guidance of industry facilitated by policy and with intensive engagement between the universities and TVET institutions.

Further innovation evolution facilitated by TVET curriculum alignment predicated on industry and research institution input was found to be a key factor in integrating the disparate components of the engineering ecosystem to deliver growth. This could be accomplished by producing graduates with the skills required by industry. The results show that integration of the engineering ecosystem could facilitate innovation evolution by the transfer of knowledge and skills through reinforcing and balancing feedback mechanisms characteristic of an integrated ecosystem.

Most importantly, this study emphasises the interdependent nature of the engineering ecosystem and demonstrates that fulfilling the objectives of the economy cannot be achieved with singular action by individual components within the engineering ecosystem. Delivering the objectives of the economy necessarily entails integrated action from the various sub-systems constituting the engineering ecosystem. This result also accentuates the principle that the engineering ecosystem is not a figurative construct, but an essential system required to deliver outcomes that are unavailable from either its components or other systems within the economy. The emergent properties arising from the integration of the components of the engineering ecosystem are vital to the economy and society in general.

References

Allais, S. M. (2012). Will skills save us? Rethinking the relationship between vocational education, skills development policies, and social policy in South Africa. *International Journal of Education Development*, 32(5), 632–642. https://doi.org/10.1016/j.ijedudev.2012.01.001

Almeida, F. (2018). Strategies to perform a mixed methods study. *European Journal of Education Studies*, *5*(1), 137–151.

Asmal, Z., Bhorat, H., Culligan, S. Hofmeyr, H., Monnakgothla, J., Oosthuizen, M. & Rooney, C. (2020). *Skills supply and demand in South Africa.* Labour Market Intelligence Partnership, Human Sciences Research Council.

Badenhorst, J. W. & Radile, R. S. (2018). Poor performance at TVET colleges: Conceptualising a distributed instructional leadership approach as a solution. *African Education Review*, 15(3), 91-112. https://doi.org/10.1080/18146627.2017.1352452

Bandura, R. & Grainger, P. (2019). Rethinking pathways to employment: Technical and vocational training for the digital age (pp. 55-63). In *Realizing education for all in the digital age*. Asian Development Bank Institute.

Brown, E. K. & Slater, L. (2018). *The future of work in Africa: Implications for secondary education and TVET systems*. African Centre for Economic Transformation.

Buthelezi, Z. (2018). Lecturer experiences of TVET college challenges in the post-apartheid era: A case of unintended consequences of educational reform in South Africa. *Journal of Vocational Education & Training*, 70(3), 364-383. https://doi.org/10.1080/13636820.2018.1437062

Department of Higher Education and Training. (2019). National Skills Development Plan 2030. *Government Gazette, No. 43390*, 2 March.

Fannon, A. M., Pop, C. & Pretti, J. T. (2019). A review of South Africa's draft curriculum framework for industry-based and work-related work-integrated learning in TVET teacher education (pp. 31-40). In K.E. Zegwaard & M. Ford (Eds.), *Refereed Proceedings of the 3rd International Research Symposium on Cooperative and Work-Integrated Education, Stuttgart, Germany*. World Association for Cooperative Education (WACE).

Field, S., Musset, P. & Álvarez-Galván, J. (2014). *OECD reviews of Vocational Education and Training: A skills beyond school review of South Africa*. OECD Publishing.

Gewer, A. (2016). Unfinished business: Managing the transformation of further education and training (pp. 23–46). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

HRDC. (2014). *Strengthening & supporting TVET colleges for expanded access & increased programme quality - A synthesis report*. Pretoria: Human Resource Development Council of South Africa.

International Institute for Management Development (IMD). (2023, November 21). *World Talent Ranking 2023*. https://www.imd.org/centers/wcc/world-competitiveness-center/rankings/world-talent-ranking/

Kintu, D., Kitainge, K. M. & Ferej, A. (2019). An exploration of strategies for facilitating graduates' transition into the world of work: A case of vocational, technical education and training graduates in Uganda. *International Journal of Vocational Education and Training Research*, 5(1), 1–9. http://41.89.164.27:8080/xmlui/handle/123456789/634

Klassen, M. & Wallace, M.L. (2019). Engineering ecosystems: A conceptual framework for research and training in sub-Saharan Africa. *7th African Engineering Education Association International Conference. Lagos, Nigeria.* https://www.researchgate.net/publication/336681167_Engineering_ecosystems_A_conceptual_framework_for_research_and_training_in_sub-Saharan_Africa

Kraak, A. (2013). State failure in dealing with the NEET problem in South Africa: which way forward? *Research in Post-Compulsory Education*, *18*(1–2), 77–97. https://doi.org/10.1080/13596748.2013.755819

Kraak, A. (2016). Three decades of restructuring in further education colleges: Divergent outcomes across differing global vocational education and training systems (pp. 1 –22). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

Kruss, G., Petersen, I., Fongwa, S., Tele, A., & Rust, J. (2017). *Synthetic analysis on the skills development and economic responsiveness of education and training institutions in South Africa: towards an integrated public private partnership strategy for skills development in the TVET college system*. Labour Market Intelligence Partnership, Human Sciences Research Council.

Marock, C., Hazell, E. & Bina, A. (2016). What will it take to turn TVET colleges around? Evaluation of large-scale college improvement programme (pp. 103–120). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

McGrath, S., Ramsarup, P., Zeelen, J., Wedekind, V., Allais, S., Lotz-Sisitka, H., & Russon, J. A. (2020). Vocational education and training for African development: A literature review. *Journal of Vocational Education & Training*, *72*(4), 465–487. https://doi.org/10.1080/13636820.2019.1679969

Muraveva, D., Hu, H., Rakhmangulov, A., & Mishkurov, P. (2020). Multi-agent optimization of the intermodal terminal main parameters by using AnyLogic simulation platform: Case study on the Ningbo-Zhoushan Port. *International Journal of Information Management, 57,* 102133. https://doi.org/10.1016/j.ijinfomgt.2020.102133

Needham, S. (2019). TVET policy in South Africa: Caught between neo-liberalism and privatisation? *Journal of Vocational, Adult and Continuing Education and Training, 2*(2), 82–101. https://hdl.handle.net/10520/EJC-1ba524e12a

Nielsen, H.E., & Nielsen, S. (2018). System Dynamics Modelling, its concept of causality and particular relevance for providing the Balanced Scorecard thinking with a dynamic analytical framework. https://pure.au.dk/ws/files/129904811/SDMcausalityDOC_final_WP_July_2018.pdf

Papier, J., Needman, S., Prinsloo, N. & McBride, T. (2016). Preparing TVET Graduates for the workplace: Employers' views (pp. 83–1 02). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

Statistics South Africa. (2014). *National and provincial labour market: Youth. Statistical release P0211.4.2.* http://beta2.statssa.gov.za/publications/P02114.2/P02114.22014.pdf

Teis, N.J.P. and Els, C.J. (2021). Knowledge, competencies and dispositions of lecturers in technical engineering in the context of advancing 41R technologies. *Journal of Vocational, Adult and Continuing Education and Training, 4*(1). https://hdl.handle.net/10520/ejc-jovacet_v4_n1_a6

Terblanche, T.E. (2017). Technical and Vocational Education and Training (TVET) colleges in South Africa: A framework for leading curriculum change. PhD thesis, University of Stellenbosch, Stellenbosch.

Vona, F. & Consoli, D. (2014). Innovation and skill dynamics: a life-cycle. *Industrial and Corporate Change*, *24*(6), 1393–1415. https://doi.org/10.1093/icc/dtu028

Appendix A

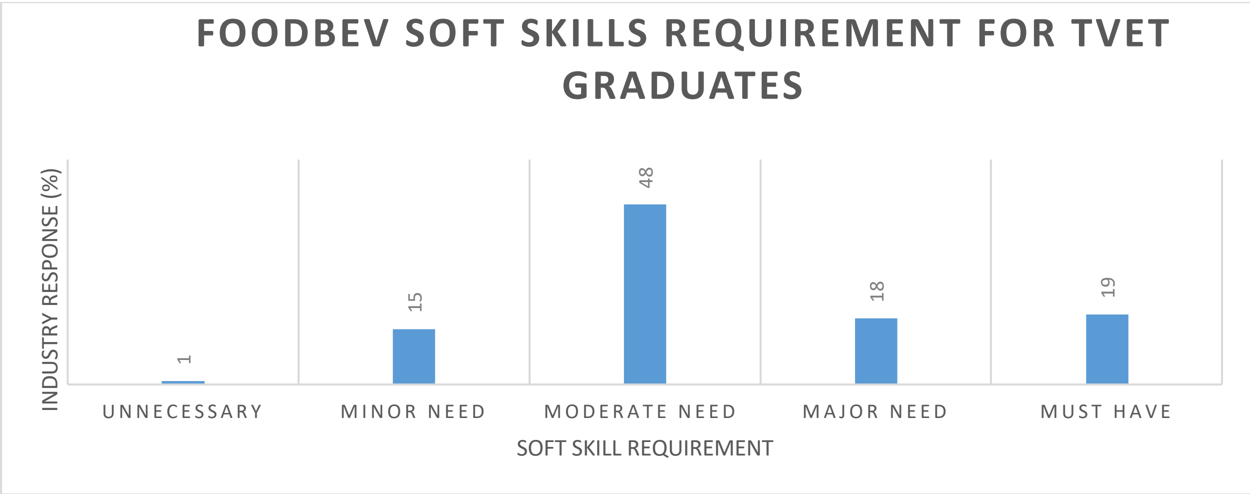

Figure 9: *Soft Skills requirement for TVET curriculum*

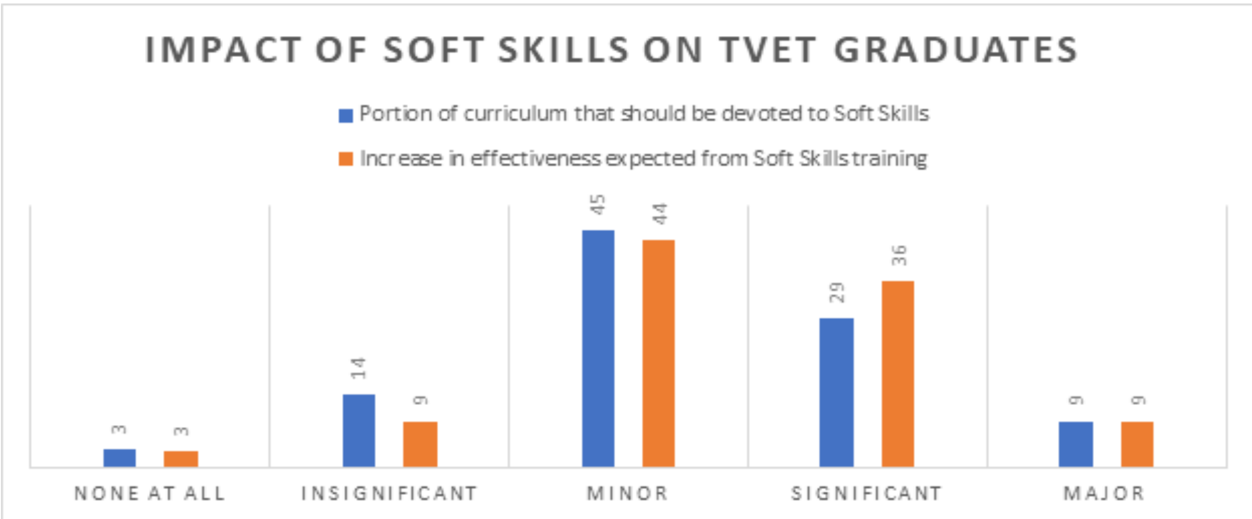

Figure 10: *Soft Skills training input and impact*

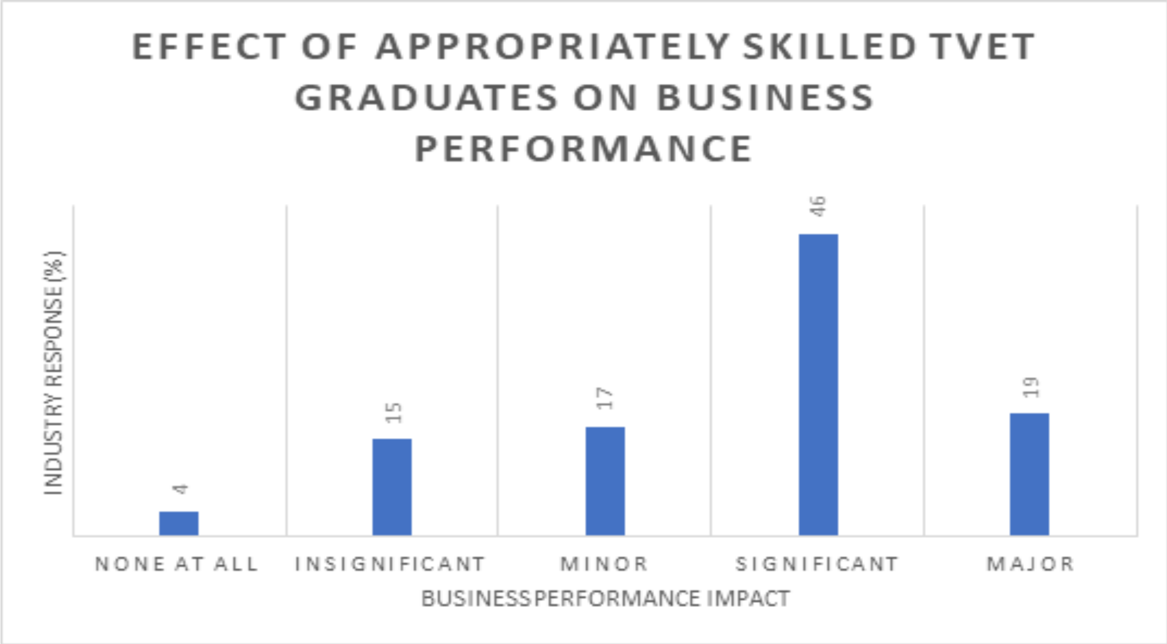

Figure 11: *Impact of appropriately skilled TVET graduates on business performance*

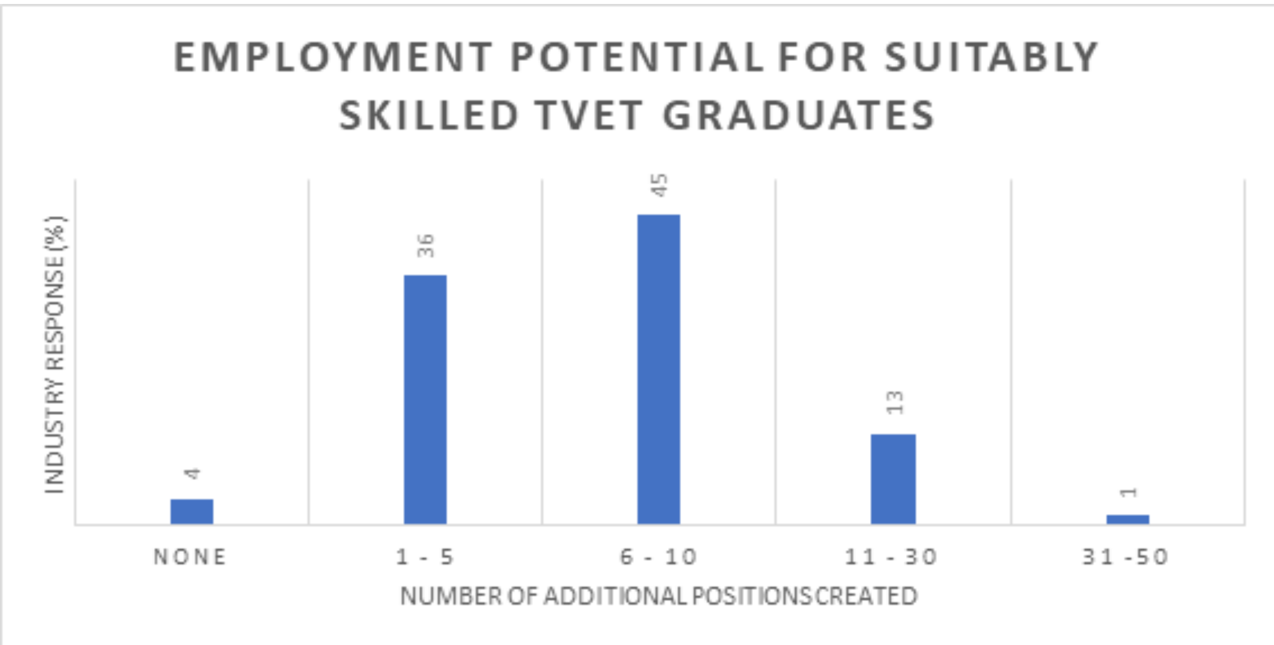

Figure 12: *Employment potential of appropriately skilled TVET graduates*

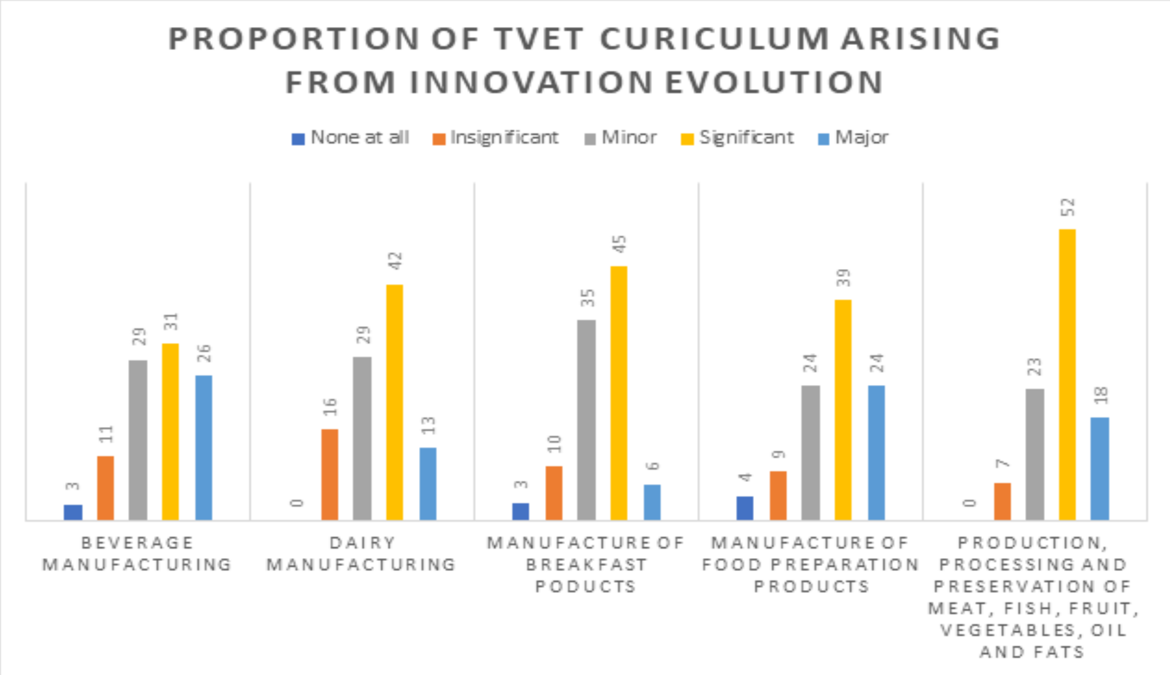

Figure 13: *Respondents recommendation for TVET curriculum proportion of innovation evolution.*

Appendix B

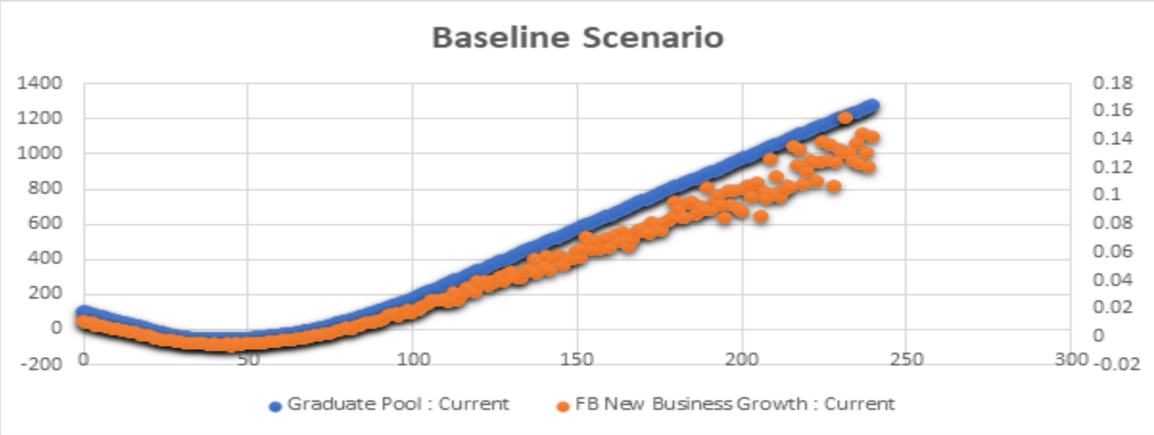

Figure 14: *Systems Dynamics baseline scenario*

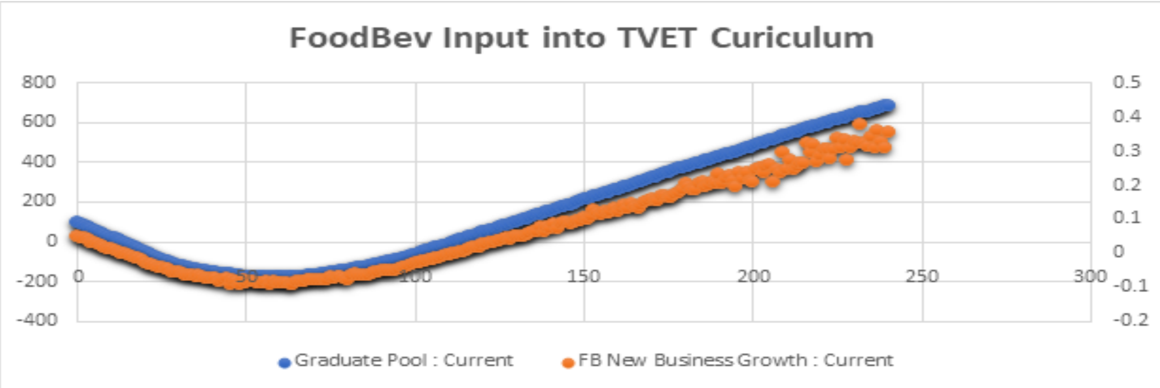

Figure 15: *Systems Dynamics FoodBev input into curriculum*

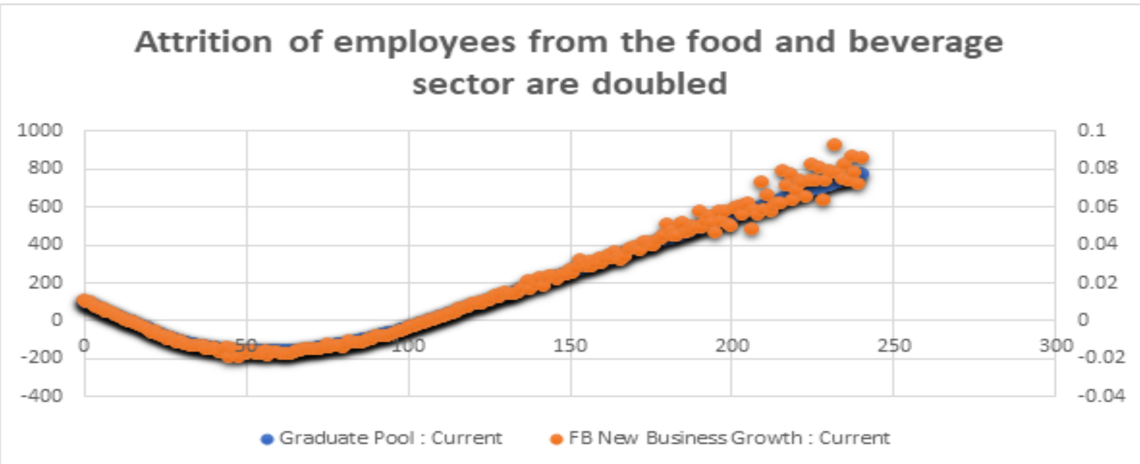

Figure 16: *Systems Dynamics model attrition of graduates*

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Leverage points in engineering ecosystems: student industrial secondments in East Africa

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While the relative shortage of engineering practitioners in Africa has been reported as a major obstacle on the road to development, a significant number of existing engineering graduates still find it difficult to find employment in engineering fields. This dichotomy may be partially explained by the inability of local industries to absorb more skilled labour; a relative deficit (real or perceived) in the competency of local graduates in the ever-advancing areas of science, technology, engineering and mathematics (STEM); and/or a scarcity of opportunities to hone and demonstrate their competency to employers. To address the challenge of competency deficit, this study postulated that promoting effective engineering student industrial secondment (SIS) activities can be a leverage point in the engineering ecosystem by strengthening the linkages between engineering education, practice and employability. The study surveyed the history of engineering practical training in Tanzania, Kenya, Uganda and Rwanda, complemented with a pilot study of four long-term, employment-like SIS placements in Tanzania and Rwanda. The main objective was to observe closely, trial potential models, and learn from and synthesise effective SIS experiences. The study found similarities across the countries regarding experiences with student practical training models, their challenges, and the perspectives of stakeholders. Findings also support that longer durations of SIS placements than currently practised help increase the employability of engineering students. However, in view of the small number of placements, further evidence is called for.

Keywords: student industrial secondments, engineering ecosystem, East Africa, graduate employability

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Introduction

Improving the status of engineering endeavours in Africa in research, training, employment, standards, etc., is positively related to sustained economic development as defined by the Sustainable Development Goals (SDGs) 8 (Decent Work & Economic Growth) and 9 (Industry, Innovation & Infrastructure), particularly for its contribution to strengthening the capacity of the industrial sector which is critically needed to sustain economic growth. The same endeavour would also contribute to achieving SDG 4 (Quality Education), which is aimed at ensuring that all learners acquire the knowledge and skills needed to promote sustainable development. Looking at engineering from the angle of economic growth, we find correlations between GDP per capita and the number of engineering practitioners (EPs) per 100,000 persons in countries. Countries that have a larger number of EPs also happen to be those with higher GDP/capita (see Table 1). A global study in 2016 found a strong, positive link between engineering strength in a country (measured according to the engineering index (Ei) index, comprising the size and quality of digital infrastructure, engineering industry, infrastructure, knowledge, labour force, and safety standards) and both GDP/capita and investment/capita (Cebr & Royal Academy of Engineering, 2016). The study quotes Prof Calestous Juma: 'you cannot have an economy without engineering…' (p. 10).

Table 1: *Correlation between countries' GDP/capita and EPs per 100,000 persons*

Country	Approx. GDP/capita US$	Approx. EPs/100,000 pop
Seychelles	14,000	500
Mauritius	11,000	400
Botswana	7,500	275
South Africa	6,000	200
Eswatini	3,500	140
Zambia	1,700	75
Tanzania	1,000	70
Mozambique	500	35

Source: SADC, 2019; Mohamedbhai, 2021

While there is a relative shortage of engineers in Africa in general (SADC, 2019; UNESCO, 2010), there are also many graduate engineers who do not find employment in their fields. It is also common that foreign/international agencies involved in engineering-related activities in the region resort to hiring expatriate engineers rather than employing local engineers, citing as reasons lack of competency and knowledge of industry standards among local engineers, particularly among early-career ones. A study on local technological capabilities and foreign direct investment in Tanzania indicated that weak linkages between local firms and multinational enterprises operating as foreign direct investment firms arise partly from concerns among the latter about the limited capacities of local firms to engage in activities that transfer technological capabilities (Diyamett et al., 2012). A logical question arises from these two realities: if significant numbers of the existing graduates have difficulties finding engineering-related employment, how can it be concluded that African economies require more engineering graduates for their development? What is responsible for this dissonance?

Knowledge deficits – quantitative and qualitative – in science, technology, engineering and mathematics (STEM) in Africa have been observed (Beaudry et al., 2018; Mohamedbhai, 2015a). One practice that has a positive contribution in preparing engineering students for employment is student industrial secondment (SIS) programmes. SISs (under various names) are temporary placements of post-secondary students in relevant industries where they receive direct on the job training with actual work responsibilities. Besides having the opportunity to apply what they have learned in classes and laboratories, thus honing their theoretical attainment with practical experience, SISs allow students to gain tacit knowledge and an appreciation of additional important employability skills not often taught in academia (e.g., teamwork, professional communication, performing under real world pressures, dealing with operational and logistical constraints, and meeting industrial standards). Globally, some correlations have been found between engineering SIS programmes and increased employability of STEM graduates (Friel, 1995; Hackett et al., 1998).

In light of the above, a study was initiated to explore best practices in running robust engineering SIS programmes coordinated between universities and industries. In this paper, a literature review of engineering education in East Africa and experiences of SIS in Africa and other parts of the world is presented. The paper then outlines the design of the study and its implementation, followed by the findings from the study, then discussion, and conclusions.

Engineering education and practical training in East Africa

Engineering education in East Africa at tertiary level was introduced later than other disciplines such as social sciences, especially after political independence from colonisation. The formation of the East African Community (EAC) in 1967 helped unify the education systems across the EAC countries (Despres-Bedward et al., 2015; Kumar et al., 2004). At the time, engineering students from Tanzania and Uganda used to study at the University of Nairobi, Kenya, which was the sole engineering school in the EAC (Kumar et al., 2004). Since then, the number of engineering schools and engineering graduates has increased, but not in concert with the increasing need for qualified engineering practitioners (Nganga, 2014). In the 1980s, the Structural Adjustment Programmes promoted by the World Bank and the International Monetary Fund (IMF) affected higher education in African countries (Case et al., 2015) in ways that led to countries mitigating the effects by increasing classroom size, introducing cost-sharing with student families, and cutting budgets on items such as maintenance of laboratories and curricula updates.

The required number of engineering practitioners in any developing society is an educated guess that takes into consideration the average number of engineers for any population size of a modern, developed society, and the conventional ratio of engineers-to-technologists/technicians, as well as differences between engineers and incorporated engineers (or engineering technologists) on average (Mohamedbhai, 2017; UNESCO, 2021). In 2013, the UNESCO Director-General mentioned in a speech that 'in Namibia, Zimbabwe and Tanzania, there is one qualified engineer for a population of 6,000 people – compared to one engineer per 200 people in China'. The ratio is also said to be 1:311 in the UK and 1:227 in Brazil, while the desired global average is 1:770 (Barugahara & Sebbale, 2016). Table 2 shows the number of registered professional engineers in East Africa in 2021-2022. There is, however, a particular dissonance in the status of engineering in Africa: if there is a significant shortage of engineers compared to the need, then it follows that the recent engineering graduates should quickly find relevant employment. However, that is not the case.

While there are some exceptions, East African countries in general report that a significant number of local engineering graduates have difficulty finding engineering employment (Matthews et al., 2012; Mohamedbhai, 2015b; Confederation of Tanzania Industries, 2018). The competency of engineering graduates has been called into question by some studies and reports. A survey in

2014 by the Inter-University Council for East Africa (IUCEA), which regulates higher education in East African Community countries, reported that in Uganda at least 63% of graduates did not demonstrate sufficient skills for the job market; while in Tanzania, 61% of graduates fitted the same description. In Burundi, Rwanda, and Kenya, 55%, 52%, and 51% of graduates respectively were perceived to be in need of competency building (Nganga, 2014). A 2012 Royal Academy of Engineering study (Matthews et al., 2012) concluded that engineering academic staff in sub-Saharan Africa, although qualified, 'had very little exposure to engineering practice [in industries and public works]'. It also pointed out the teaching style adopted in most academic institutions in the region could be described as 'chalk and talk' as opposed to problem-based-learning (PBL) and more practical/engaging styles of teaching and learning. Relatedly, an observed practice in most African countries is that there is heavy reliance on engineering practitioners brought from outside Africa to work on engineering projects and in industries, making opportunities of employment limited for local practitioners.

Table 2: *Number of registered engineers in East Africa*

Country	**No. of registered engineers**	**Population (millions)**	**Population per registered engineer**
Uganda	1,406	43.0	30,714
Kenya	2,586	55.4	21,425
Tanzania	7,610	62.1	8,158
Rwanda*	1,482	13.6	9,202
Burundi	15	12.4	825,264
South Sudan	—	11.4	—

Source: Alinaitwe, 2021 *Updated August 2022, from the Institution of Engineers Rwanda

It can be speculated, therefore, that this problem with engineering ecosystems in Africa is twofold: the relative deficit (real or perceived) in competency of engineering graduates in ever-advancing areas of STEM, and the limited opportunities to hone and demonstrate such competency in the labour market.

With the combination of poor institutional infrastructure, limited use of new teaching and training techniques and equipment at engineering schools, weak industry-academia linkages, and the challenges with accreditation and registration of engineers and technologists described above, there is little question that engineering education in Africa needs improvement (SADC, 2019; Sheikheldin and Nyichomba, 2019; Kraemer-Mbula et al., 2021). In general, there is a shortage of reliable EPs to meet local engineering needs (of local industries, public sector, training, consulting, etc.). The challenges are both quantitative (i.e., of size of workforce) and qualitative (i.e., quality of training).

Engineering education has been observed to yield more favourable results when practical training, being an important bridge between theory and practice, is integrated in various ways. One noticeable approach is co-curricular activities that include applying what is learned in class by working to solve real-world problems. These co-curricular activities include industrial training/attachments of students while at school, internships with industries right after graduation (or during times off school), voluntary activities related to the field of study (such as community service or development projects), and joining clubs or organisations that include activities that engage students with the larger environment and society (Burt et al., 2011). Studies from North America and Europe on the outcomes of co-curricular activities in engineering education – especially co-operative training (or industrial secondments) and industrial attachment programmes – converge on several conclusions. One conclusion is that, 'When engineering students are involved in co-curricular experiences, they exhibit greater leadership skills, are more thoughtful about their ethical decisions, and can articulate how involvement influences their ethical development' (Burt et al., 2011, p. 1). Another conclusion is that with good preparation, students perform well in co-operative training/attachments to levels that satisfy both the student and the employer (Friel, 1995; Hackett et al., 1998). In addition, while such programmes and internships may cause students to graduate later than their peers who do not undertake the same co-curricular activities, their employability upon graduation tends to be higher, as well as their starting salaries (Friel, 1995; Kotys-Schwartz et al., 2011). Furthermore, some studies showed that companies that engage in well-structured co-operative programmes tend to praise the experience, and refer to both qualitative and quantitative benefits of these programmes, for example that these programmes reduce training costs of newly-hired graduates because they already know a good deal about the company and operations from their previous experience; and that SISs help in diversifying future employees as well as easing them into the work environment. Friel (1995) concludes his study on the topic by saying, 'It appears that cooperative education develops a graduate that is better prepared for permanent work and helps a company identify potential new hires prior to the graduation date that may require less training' (p. 6). Other studies – in Europe and Africa – focus on curriculum design that delivers much of the same benefits of co-curricular activities, or complements them, in ways that aim to produce competent, work-ready engineering graduates. Context-based curriculum design (Case et al., 2015) and problem-based learning (PBL) (Aalborg University, n.d.) are important ideas and practices in that vein.

East African countries, and African countries at large, have had their share of implementing SIS programmes. Tanzania, Uganda and Kenya have had SIS programmes for decades, and Rwanda has recently joined them. In Zimbabwe, for example, industrial attachment programmes (IAPs) – another name for SISs – for students in Higher Learning Institutes (HLIs) have been practised since the 1980s (Dondofema et al., 2020) with reported classical benefits to students, HLIs and industries, as well as reported challenges. The latter include an overload of students relative to available industries for IAPs, mismatch of skills between students and industries, weak linkages between HLIs and industries, and difficulties of HLIs in coordinating IAPs for large numbers of students (Munyoro et al., 2016). Similar benefits and challenges to those IAPs in Zimbabwe are evident in other countries such as Ghana (Adjei et al., 2014; Nduro et al., 2015). Nigeria has the largest higher education system in Africa and has the Students Industrial Work Experience Scheme (SIWES) in which almost all universities participate, aimed at all students that study in STEM and related programmes. SIWES requires 24 weeks as the minimum duration of an IAP for engineering students to be recognised, and according to Oyeniyi (2012), it has been a relative success in increasing students' skills and utilising them in industrial development.

Yet all the above does not sufficiently explain what is missing in our understanding (and attempted remedies) of the twofold problem mentioned above. We may need to understand the contexts better through more information, observation, and synthesis.

Approach and methodology

The study was carried out in three main phases: (I) surveying some SIS best practices in East Africa and other developing countries; (II) action research by piloting long-term SIS placements; and (III) synthesising the findings and widely disseminating the results to stakeholders. This was to be a study of best practices to produce evidence-based and evidence-informed policy recommendations in establishing and running robust engineering SIS programmes coordinated between universities and industries – and perhaps with support from the public sector – to serve both the industries and students. While there are currently sporadic cases of SIS placements in various university programmes, clear, broad and standardised programmes with visible outcomes are yet to be found.

The main objectives of the study included: (a) gaining reliable knowledge and understanding, through policy learning, of the potential of tertiary SIS programmes in strengthening engineering ecosystems in East Africa, and (b) examining selected best practices in SIS pedagogical approaches, through initiating, monitoring and evaluating SIS placements. In general, the study aimed to shed light on the problem of dissonance between the recorded shortage of engineers in Africa, on the one hand, and prevalent unemployment (and underemployment) of engineering graduates on the other, and to improve our understanding of peculiarities and possible remedies for the purpose of advancing the sustainable development goals.

The study's approach was based on a lens of inquiry that strengthening the linkage between engineering study, practice and employability is a 'leverage point' in the engineering ecosystem of a country or region. Leverage points are places of intervention in a complex system where change has a significant ripple effect throughout the entire system, influencing many components that have not been touched directly (Meadows, 2010, 2012). The research team postulated that promoting engineering SIS programmes can be a suitable approach to strengthening the linkage between engineering study, practice and employability. If such an outcome is achieved – through curriculum change and policy support – it can, in turn, increase student enrolment in engineering schools, as a response to increased employability of engineers after graduation. From an engineering ecosystem perspective, it is critical to understand that engineering academic programmes and engineering jobs in local industries are tied together by the flow of information and technology, through human resources as well as knowledge, including economy/market feedback. We understand these relations as feedback loops that influence each other's own dynamics through information flow, rules and connections of the whole system. This type of system is a 'technosocial system', where people and technologies work in combined efforts that form functional wholes (Woodhouse & Patton, 2004). The study's objectives followed a theory of change illustrated in Figure 1.

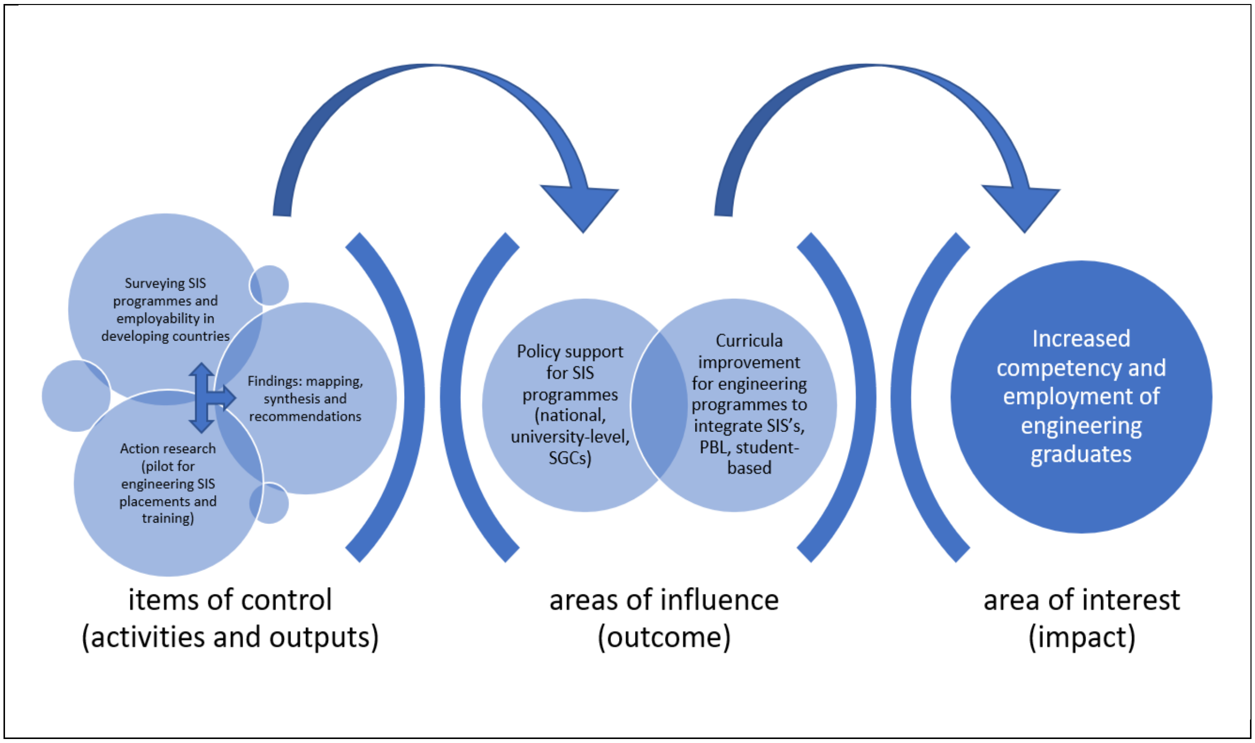


Figure 1: *SIS Project theory of change*

In phase I of the study, we carried out two complementary activities. The first activity was a survey of the four East African countries of Tanzania, Kenya, Uganda and Rwanda in terms of previous and current experiences of engineering, undergraduate SIS programmes, and any of their visible outcomes, and identifying best practices among such programmes (if existent within East Africa), as well as other comparable and relevant best practices known in other countries from the economic South. The third activity was to identify partner universities for the pilot phase and finish selecting students. For phase I we used key informant interviews (using semi-structured interview guides) with academics, industry associations and policymakers (such as science councils and engineering boards). We also consulted public documents (published by industries, academia and government), such as tracer studies of engineering graduates and annual reports from industry confederations. We were able to collect information with more depth from Tanzania (interviewing key informants from engineering-related industries in Dar es Salaam, Arusha, Mbeya and Morogoro, four universities, the Confederation of Tanzania Industries, the Commission for Science and Technology and the Engineering Registration Board) while we had to stop at general meetings with academic deans and science council representatives in Uganda and Rwanda, as well as with (not very) publicly-accessible information. In Uganda, we had general meetings with Makerere University's engineering faculty, and with senior staff at the National Council of Science and Technology, in which we were provided reliable and documented information and public reports such as the Ugandan tracer study of engineering graduates (Barugahara & Sebbale, 2016). In Rwanda, we were also able to rely on publicly available information acquired through general meetings with faculty staff from the University of Rwanda (UR) and personnel of the National Council for Science and Technology, especially as one of the co-authors of this paper is an engineering faculty member at UR and was a partner in phase II of the project, and because Rwanda has a number of public reports covering most of the information we were looking for. In Kenya, colleagues at the Africa Centre for Technology Studies, a partner research organisation, were able to collect relevant data on our behalf since they are operational in Kenya and the scope of the study was relevant for them.

In phase II (the pilot study), four students were selected from two partner universities in East Africa: the University of Dar es Salaam (College of Engineering and Technology) and the University of Rwanda (College of Science and Technology). Faculty advisors from each college selected two students for SIS placements for one year in engineering entry-level or apprenticeship positions in suitable industries. The students had just completed their junior year (i.e., one year left to graduate). SIS placements included stipends (comparable to salaries of entry-level engineering graduates in their respective countries). Of the four selected students, three were female and one was male. The SIS placements differed from the usual practice in the region. They were to be long-term – almost one academic year – and they were to be with employee-level responsibilities. Each university received a budget from the project funding that covered student stipends and administrative costs.

Findings

There appears to be consensus that existing SIS programmes in East African countries are not only similar but also do not work well, and for the same reasons – mainly insufficient industrial attachment periods, the overwhelming number of students compared to the number and size of industries available to place them, and the mismatch of skills and work in SISs.

General findings from phase I

Similarities were observed across the four countries regarding experiences with student industrial training programmes and initiatives (the models, the challenges, and feedback and perspectives of stakeholders). The SIS models are the same and have been so since engineering departments were established in most of the East Africa region. According to academic interviewees, these programmes worked well in the past, with a limited number of engineering students and effective involvement of the public sector in securing relevant SIS experiences. Currently, the circumstances have generally changed, but the models have remained the same. One reason is that the number of students has increased dramatically, and many university colleges (non-engineering or 'professional degrees') began to seek industrial training for their students as well, thus overburdening industries as they did not increase in number and capacity in proportion to the increase in student numbers. Overall, however, it must be noted that there was weak documentation of past and present SIS programmes (or industrial training/attachment programmes), which made the study rely more on qualitative data and observations than originally intended. Most of the stakeholders we met could not offer more than verbal information, and occasionally basic documents.

The overall findings from phase I are: (a) all four countries are technically familiar with SIS programmes, except that they have not changed over time as the environment changed, especially in terms of the increase in the number of engineering students without a corresponding increase in local industries; (b) and partly due to (a), it became more difficult to manage SIS programmes for both university faculty and industry supervisors, which eventually led to SIS programmes with weak structure and limited hands-on training; (c) most stakeholders (academia, industry, government, students) are generally aware that current SIS programmes have significant shortcomings that markedly minimise their potential benefits; and (d) the unavailability of, or weak access to, documentation of SIS experiences to date made it a challenge to perform a rigorous investigation to make informed decisions that could improve the status quo.

Tanzania. In Tanzania, annual practical training periods of eight weeks, except for the final year, are standard in all Tanzanian HLI engineering schools. Industries are required by the state to accept students for these periods. After the first year of engineering study, students undergo their first practical training period as artisans (i.e., with tasks at artisan levels); after the second year as technicians; and after the third as engineers. These placements that progress the expected skill levels were designed to enable the engineering students to experience, hands-on, the various, connected, and important levels of engineering practice. However, criticism is emerging from faculty, students and industries, with high consensus, that few students and industries benefit from such training due to overcrowding (as even other schools/disciplines have practical training programmes around the same period) and the short period of training. On average, 2,500 students from Dar es Salaam Institute of Technology (DIT), and 1,800 students from University of Dar es Salaam (UDSM) do practical training annually, all spread across about 200 industries, public and private; however, normally not all students get placements, so on average around 120 industries participate each year. The number is overwhelming, and the capacities of industries are both limited and spread thin. Another constraint is that all other non-engineering final-year students (from business, management, earth sciences, etc.), or students from other fields from other universities, also attend practical training placements and at the same time of the year, resulting in even more crowding. Table 3 (in the appendix) provides feedback from industry partners about the current state of SIS programmes in Tanzania.

In the past, UDSM had the only engineering programmes in the country. Engineering students were few and the main industries known. Besides, most graduates were recruited for jobs, or further studies, before graduation. Smaller classroom size and relatively fewer industries allowed for focus and enabled decision makers to place almost all the graduates, who were also fully funded. Also, at UDSM, from the 1980s to early 1990s, students were allocated employers (state-owned enterprises or parastatal organisations) by their third year, where they would go for their eight-week practical training and where they would work after they graduated. Today, Tanzanian registered engineers form 63% of registered engineers operating in all of East Africa and they work all over the East African Community (EAC) (Barugahara and Sebbale, 2016, p. 41). This could be seen as a testimony to Tanzania's engineering education and certification quality compared to the rest of the region. However, Tanzania has about 60 engineering practitioners per 100,000 persons, a low number among the Southern Africa Development Community (SADC) countries (SADC, 2019). Yet in 2015, activities involving engineering contributed as much as 63.8% to total GDP. Activities involving engineering include agriculture, construction, manufacturing, electricity, gas, water, mining operations, transport and communication (SADC, 2019, p. 8). That means that engineering-related activities are important for the Tanzanian economy, and that improvements to the national engineering ecosystem would be desirable for overall economic development.

Rwanda. Rwanda has recently embarked on enhancing the STEM capacity of the country at large, with most public funding being directed towards STEM institutions, and it has also invited many international institutions to establish educational and research posts in the country (UNCTAD, 2017). That focus also includes providing practical training opportunities for engineering students as well as implementing policies to normalise workplace training for TVET level graduates. At the University of Rwanda, engineering students are provided practical training in their workshops as part of the curriculum (e.g., machine tools, welding, carpentry, electronics, appropriate technology) in addition to an industrial attachment programme that is a compulsory credit-rated module for every specified degree programme at the College of Science and Technology. This industrial attachment is typically assigned after the student completes the third year and it lasts for 10 weeks, quite similar to practical training and field attachment placements in Tanzania and Uganda, with some variations. Challenges of the industrial attachment programme also seem to be similar to those in Tanzania and Uganda, and they include difficulty in finding proper industry placements for students, problems with funding and students' welfare during attachment periods, constraints in finding time and resources to monitor and supervise students sufficiently, and students' lack of motivation in maximising learning benefits from the attachments. Table 4 (in the appendix) presents a general comparison of the status of SIS programmes in Tanzania and Rwanda's principal universities: UDSM and UR.

A 2014 tracer study of graduates from HLIs in Rwanda found that 'graduates from Economics and Business, Education and Arts and Social Sciences are over-produced vis-à-vis other fields like Medicine, Engineering, and ICT' (Republic of Rwanda, 2015, p. ix). In 2014, based on data from 2012, a World Economic Forum Executive opinion survey ranked Rwanda as number 74 (out of 148) in the world in terms of the availability of scientists and engineers, and the country ranked 125 in objective measurements of enrolment in tertiary education (UNESCO, 2015). Between 1996 and 2013, 6,180 students graduated from HLIs in Rwanda with an engineering degree. Overall, the country had a 15% unemployment rate, and 'there appear[ed] to be lack of sufficient formalised synergies and partnership between public and private employment agencies with HLIs. As a result, relevancy of internships and acquired skills to the labour market were rated weak' (UNESCO, 2015, p. 114). Weaknesses were also noted by employers among graduates in the areas of hard skills in areas of research and problem-solving skills. According to UNCTAD (2017, p. 21), 'each year, 1,400 engineering students successfully graduate. In [2016] 300 had found a job in government structures and 200 in the private sector, while the others are searching for a job, and this in spite of an unresolved skills gap.'

Uganda. In Uganda, and contrary to other East African countries, a tracer study of engineering graduates showed that most of them end up working in their field (or related to their field). For Uganda, it seems that studying engineering remains a good choice for graduates in terms of employability (Barugahara & Sebbale, 2016).

> Most engineering graduates (74.6%) found their first job less than a year after graduation. This could be because 61.9% searched for engineering related jobs, three years prior to graduating. In this survey, 78.8% of engineering graduates were employed while 3% and 0.6% were either unemployed or inactive respectively [while] 72% of engineering graduates described their current occupation as being "closely related" to their undergraduate training (Barugahara and Sebbale, 2016, p. iii).

These findings shed a positive light on the status of engineering education and employment in Uganda. Yet problems in the industrial training programme persist. Similar complaints to those in Tanzania, of fatigue in the programme, where students, faculty and industry are not sure of its benefits, show that industrial training works on paper as a requirement that has to be fulfilled, while a fair assessment may reveal an unfavourable situation. In the past, Makerere University had the only engineering programmes in the country. Just like UDSM in Tanzania, engineering students were few and the main industries were known, and most graduates were recruited for jobs or further studies before graduation.

Other aspects require revisiting, however. For example, 91.7% of the engineers were not formally registered, according to the tracer study: 'The number of registered engineers in Uganda is still low compared to the other countries in the East African Community (EAC). Kenya has a register of 1,400 engineers which is twice that of Uganda. (By 2015, Uganda had a register of 772 engineers of whom 494 were in practice.)' (Barugahara and Sebbale, 2016, p. 41). The main reason cited was that they lacked minimum requirements for registration. Far fewer females in particular were registered engineers. The value of registering, and how it pushes engineering practitioners further in their engineering careers, may need to be promoted, the tracer study adds, since it is required for being considered in many engineering jobs and responsibilities. And like Tanzania, although there are higher numbers of engineers in the population, 'Uganda still has one of the smallest per capita ratios of engineers per population' (one engineer per 53,000 people)' (Barugahara & Sebbale, 2016, p. iv). Moreover, fewer engineers were involved in traditional mechanical/manufacturing and agricultural fields, which are critical fields for national industrial development.

Kenya. In Kenya, and like Tanzania and Uganda, engineering colleges and universities also conduct students' practical training through placements and attachments. The time allocated for the field attachment is between eight and twelve weeks, depending on the course programme. University curricula require the second-year students to go for internal (in-school) hands-on training for two weeks and third year and fourth year students to go for external placements. Several challenges in industrial training programmes have been identified in Kenya. Although students are evaluated by industries as having strong hard engineering skills, they complain that students lack soft skills (such as effective communication and teamwork). Secondly, supervision is limited in following up students' performance, and the decrease was explained by the increasing number of students to supervise. The University of Nairobi, for example, registers around 290 students who go for placements per year against 20 supervisions at different student placements. Similarly, the number of industries cannot comfortably accommodate the increasing number of students in Kenya.

4.2. Findings from phase II (SIS placements)

In summary of phase II findings and observations, students, industrial supervisors and academic supervisors reported a positive return from the SIS placements that took place in this study. The highlights from the student reports, with faculty and industrial supervisors' comments, show similarities in two aspects: a) increase in employable skills: all reports highlighted an increase in hands-on skills and understanding of practical/work environments; and b) increase in confidence: comparing the level of confidence in their skills from the point when they began the SIS placement to the point when they finalised their placement, reports showed that the students had gained significant confidence in their ability to secure employment after graduation, in addition to a similar increase in confidence from their faculty and industrial supervisors. Overall, the students had either secured placements (as soon as they graduated) or were more confident in their ability to find the right channels and approaches to secure employment after graduation. Table 5 (in the appendix) summarises lessons drawn from the pilot study (phase II).

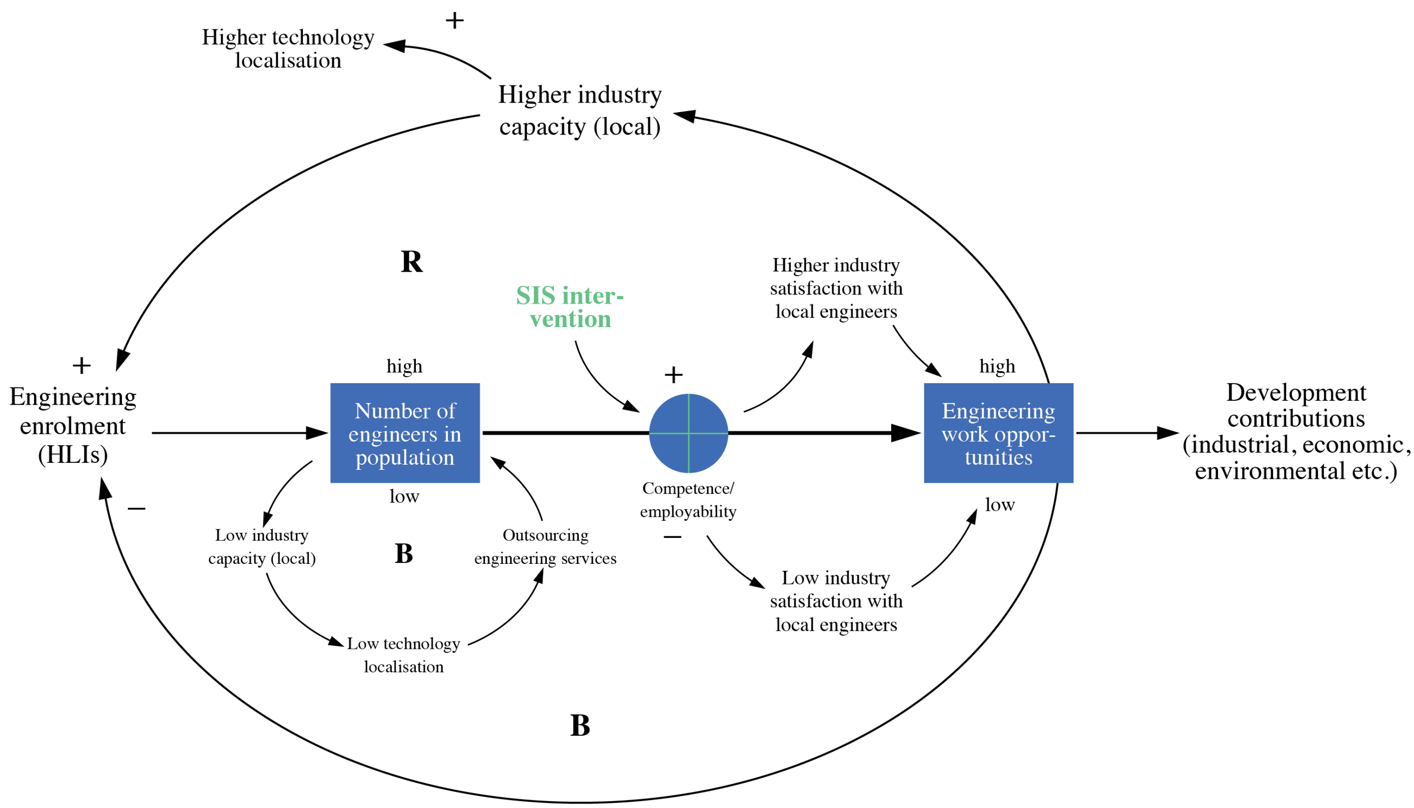
Overall, while the experiences were positive, the fact that they were only pilot placements may have not allowed for experiencing a more structured, systematic and well-planned SIS programme. In these pilot projects the students and their industry supervisors had to fill the SIS experience with work, and they did that well, but it made them think about how it would have been more rewarding and educational if they had been more prepared in terms of specifying the students' tasks and outputs, and in terms of setting a standard SIS programme to follow.

Additionally, some ideas emerged after recognising the benefits of long-term SIS programmes, such as the suggestion by a senior UDSM professor of incorporating longer SIS placements by changing the structure of current practical training/industrial training programmes – for example, combining 3-year practical training periods to make a longer SIS term (a semester or more).

Discussion: engineering ecosystems and leverage points

The problem of dissonance between shortage of engineers and unemployment of engineering graduates, as explained above, can be traced to gaps in capacities and policies. A way of looking at the problem is to approach it with the frame of 'engineering ecosystems' (Klassen & Wallace, 2019; Sheikheldin & Nyichomba, 2019). The notion of 'ecosystem' implies things such as multiple actors with interdependency between them and the important role of systems aspects such as communication channels, feedback loops, timeframes, unintended consequences, and so on. We can consider engineering ecosystems as technosocial systems that are broad and interlinked.

The four East African countries share many similarities, in history and in current challenges in university-industry interlinkages, making them a good example of a 'regional engineering ecosystem' that exists alongside national ecosystems. Considerable evidence exists for the existence of systems phenomena, such as feedback loops, system delays, and possible leverage points. In this study, cases were observed of systems delays in response to changes in the engineering scene. For instance, changes in the number of engineering graduates did not change old SIS policies, and also there were delays in policies regarding absorption of engineering practitioners in the job market and adjusting to new needs and numbers. We can also expect that changes in curricula, or training of instructors in PBL, will only show outcomes some years after implementation. Several feedback loops could be identified as well, demonstrated in Figure 2 below.



Legend:
– arrow with +/- sign: increasing or decreasing influence/impact
– arrow without +/- sign: qualitative influence or fluctuating correlation
– **B**: balancing/negative feedback loop **R**: reinforcing feedback loop

Figure 2: *A systems dynamics diagram (stock and flow + feedback loops) of relations between the number of engineers and work opportunities in a country, with competence/employability being the regulator or bottleneck of flow between the two.*

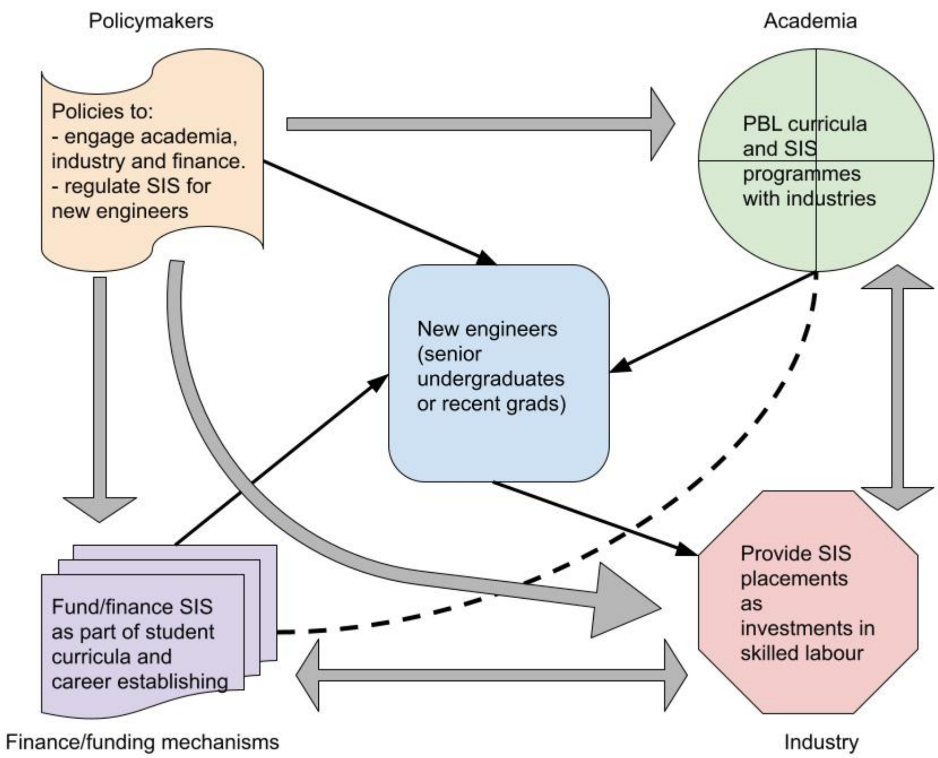
Combining two systems modelling tools (stock and flow diagrams, and feedback loop diagrams), Figure 2 portrays reinforcing and balancing relations between several elements and processes, as they relate mainly to the flow between two stocks: the number of engineers in the population and limited engineering work opportunities. With competence/employability being the valve, or bottleneck, of that flow, as proposed in this paper, the relations can change with the intervention of SIS and similar programmes as a leverage point in the system, as also proposed by the paper.

It is important to note, from the outset, that the diagram has limitations of representation. First, such diagrams emphasise change over time, which implies delays in the effects (of any interventions) that are not captured with precision in the diagram. Second, it focuses on what SIS can bring in change to the system, as a leverage point, but it does not cover other aspects that influence work opportunities and number of engineers, such as economic investment in engineering education and engineering projects, for example.

Other leverage points may exist in policies: standardising long-term, hands-on SIS placements across the triple helix (state-academia-industry) could lead to strengthening the local engineering ecosystem (i.e., advancements in industry, registration of engineering practitioners, and technology localisation). Yet there might be bigger leverage points, at the level of paradigms – perhaps such research points to bigger issues of perceiving engineering practice in developing countries. We can rethink academic engineering training as parallel to the development level of the country, instead of thinking of engineering training as only relevant when up to standards of industrialised, technologically advanced, countries (as is the case now). The four main influencers/actors of engineering ecosystems (policymakers, universities, industries, and financing/funding mechanisms) could introduce new, more conducive paradigms.

Figure 3 (below) provides another visualisation: that of the main actors and connections of the engineering ecosystem if new engineers (i.e., senior undergraduates or recent graduates) are taken as the centre of attention. The visualisation was developed over the project's period, based on the literature, survey and pilot, but it is still in need of further examination and consultation. In this ecosystem, policymakers play a critical role, and they include regulatory bodies for engineering practice as well as other actors from the state or from regional bodies (such as science councils). Academic institutions also play a major role, particularly when they choose to innovate and tailor their programmes to include more PBL and SIS activities. Industries play a critical role as well, particularly when they realise that providing and organising well-structured SIS placements is an investment in future skilled labour that they need to grow and innovate.

Finance/funding mechanisms play a crucial part in the ecosystem because they can be catalysts that invest in proper engineering training to get returns in the form of more capable engineering practitioners (in quality and quantity) who advance and improve the ecosystem at large, for sustainable development goals.



Legend:

↗ from-to inputs (bolder lines between institutional actors)
---- inter-influence (various relations)
↔ indirect influence (through policy or relation)

Figure 3: *Engineering ecosystem influencers/actors and employability of new engineers*

Employability – for engineers and others – can be generally understood as having the set of knowledge, skills, understanding and attributes to gain and sustain fulfilling work. With such understanding/definition in mind, all existing evidence supports the argument that SIS programmes (and co-curricular activities in general) increase the employability of students. Yet there are supporting approaches that should be implemented – for example, linkages with industries should be a reality, not an aspiration, and pedagogical approaches such as PBL are instrumental in realising these linkages.

In summary, we may think about it in simplified terms: if the competency of engineering graduates in Africa is increased through enhancing and strengthening engineering education, then the employability of those graduates would likely increase, thus making an engineering degree more attractive for incoming college students, eventually leading to an increase in the number of engineers. Finally, a general understanding is growing that policy is the catalyst of possibilities. To have broad and long-lasting impacts on engineering education in Africa, for the sake of sustainable development and growth, solutions should be articulated as policies – formulated, implemented, embedded and supported.

Conclusions

General characteristics and patterns were revealed through this study about the challenges of university-to-employment transition for engineering students in East Africa. The four East African countries of Tanzania, Rwanda, Uganda and Kenya share similarities in history and current challenges and interlinkages, making them an example of a regional engineering ecosystem that exists alongside national ecosystems. There is consensus that the short-term (8-12 week) industrial attachments currently practised do not allow most students to have the in-depth industrial experiences that enhance their employability skills. In addition, industries tend to receive more students in each training period than they can give tailored attention to, resulting in the latter completing industrial attachments with little experience and only fulfilling formal requirements to graduate. Weak coordination between universities/colleges and industries also contributes to a general mismatch of placements and miscommunication about how SISs can be improved to increase the employability of engineering students. Stakeholders – faculty, industry supervisors and students – agree that long-term SIS placements (for example, 6-12 months) help increase the employability of engineering students, but further evidence is needed (more scale SIS placements and more tracer studies). While long-term goals lie in the increased number of industries that require skilled employment, short-term mitigations may lie in universities giving existing industries room by arranging SIS programmes at different time periods.

A systems approach points towards a need for recognising feedback loops and delays in engineering ecosystems as they respond to a twofold problem: the relative shortage of engineering practitioners and the limitations to employability for current practitioners. Pedagogical approaches that foster strong academia-industry linking, such as SIS and PBL, may resolve such dissonance (i.e., possible leverage points in the ecosystems), and can be effected through policies that act as change catalysts.

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References

Aalborg University. (n.d.). *Problem Based Learning (PBL)*. Aalborg University, Denmark. PBL.AAU.DK

Adjei, N. A. K., Nyarko, D. A., & Nunfam, V. F. (2014). Industrial attachment in polytechnic education: An approach to polytechnic-industry nexus in human capital development of selected polytechnics in Ghana. *Journal of Education and Practice*, *5*(33), 33. https://ssrn.com/abstract=2518991

Alinaitwe, H. (2021). *Dynamics of demand and supply of engineering professionals – making our engineers work for industrialization in Africa*. In Workshop: engineering education capacities-how engineering ecosystems are preparing students in Africa for employment, Dar es Salaam, December (Vol. 1).

Barugahara, I., & Sebbale, S. (2016). *Tracer study of engineering graduates in Uganda: An expedition from university to work*. Uganda National Council for Science and Technology (UNCST).

Beaudry, C., Mouton, J., & Prozesky, H. (Eds.). (2018). *The next generation of scientists in Africa*. African Minds.

Burt, B., Carpenter, D., Finelli, C., Harding, T., Sutkus, J., Holsapple, M., Bielby, R., & Ra, E. (2011). *Outcomes of engaging engineering undergraduates in co-curricular experiences*. American Society for Engineering. https://deepblue.lib.umich.edu/handle/2027.42/86117

Case, J., Fraser, D., Kumar, A., & Itika, A. (2015). The significance of context for curriculum development in engineering education: A case study across three African countries. *European Journal of Engineering Education*, *41(3)*, 279-292. https://doi.org/10.1080/03043797.2015.1056103

Cebr & Royal Academy of Engineering. (2016). *Engineering and economic growth: A global view*. Royal Academy of Engineering.

Richard, R. (2018). *Identification of the skills gap for innovation and successful industrial development in Tanzania*. Confederation of Tanzania Industries.

Despres-Bedward, A., Ibrahim, N., & Newfield, K. (2015). *Engineering education for sustainable cities in Africa*. Proceedings of the Engineering Education for Sustainable Development Conference (4-7 September 2016, Bruges, Belgium).

Diyamett, B., Ngowi, P., & Mutambala, M. (2012). *Foreign Direct Investment (FDI) and local technological capabilities in the manufacturing sector in Tanzania.* (Policy Brief 2-2012.). STIPRO. https://stipro.or.tz/wp-content/uploads/2018/11/Foreign-Direct-Investment-Manufacturing.pdf

Dondofema, J., Mwenje, J., & Musemwa, L. (2020). The Industrial Attachment Programme - history, benefits, challenges and its adoption in Zimbabwe: A review. *Asian Journal of Education and Training*, *6*(3), 412–420. https://doi.org/10.20448/journal.522.2020.63.412.420

Friel, T. (1995). Engineering cooperative education: A statistical analysis of employer benefits. *Journal of Engineering Education*, *84*(1), 25–30. https://doi.org/10.1002/j.2168-9830.1995.tb00142.x

Hackett, R. K., Martin, G. R., & Rosselli, D. P. (1998). Factors related to performance ratings of engineering students in cooperative education placements. *Journal of Engineering Education*, *87*(4), 455–458. https://doi.org/10.1002/j.2168-9830.1998.tb00379.x

Klassen, M., & Wallace, M. (2019). Engineering ecosystems: A conceptual framework for research and training in sub-Saharan Africa. Proceedings: 7th African Engineering Education Association international conference, Lagos, Nigeria.

Kotys-Schwartz, D., Besterfield-Sacre, M., & Shuman, L. (2011). *Informal learning in engineering education: Where we are – Where we need to go.* Proceedings of the Frontiers in Education Conference, 12-15 October. https://doi.org/10.1109/FIE.2011.6142836

Kraemer-Mbula, E., Sheikheldin, G., & Karimanzira, R. (2021). Southern Africa. In S. Schneegans, T. Straza, & J. Lewis (Eds.), *UNESCO science report: the race against time for smarter development* (pp. 534-573). UNESCO.

Kumar, A., Ochieng, A., & Onyango, M. (2004). Engineering education in African Universities: A case for internationalization. *Journal of Studies in International Education*, *8*(4), 377–389. https://doi.org/10.1177/1028315304269136

Matthews, P., Ryan-Collins, L., Wells, J., Sillem, H. & Wright, R. (2012). *Engineers for Africa: Identifying engineering capacity needs in Sub-Saharan Africa*. A summary report. Royal Academy of Engineering.

Meadows, D. H. (2010). Leverage points: Places to intervene in a system. Meadows, D. H. (2010). Leverage points: Places to intervene in a system. https://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/.

Meadows, D. H. (2012). *Thinking in systems: A primer*. London: Earthscan

Mohamedbhai, G. (2015a). Engineering education in Sub-Saharan Africa: Quest for quality. *International Journal of African Higher Education*, *2*. https://doi.org/10.6017/ijahe.v2i1.9259

Mohamedbhai, G. (2015b). Improving Engineering Education is Sub-Saharan Africa. International Higher Education, 80, https://doi.org/10.6017/ihe.2015.80.6155.

Mohamedbhai, G. (2017). The importance of polytechnics for Africa's development. *International Higher Education*, *88*, 30–31. https://doi.org/10.6017/ihe.2017.88.9695

Mohamedbhai, G. (2021). *Engineering practitioners in Sub-Saharan Africa: Demand, supply, capacity and quality*. In Workshop: engineering education capacities – How engineering ecosystems are preparing students in Africa for employment, Dar es Salaam, December (Vol. 1).

Munyoro, G., Nyandoro, Z., & Musekiwa, M. (2016). An evaluation of the Student Industrial Attachment Programme in Zimbabwe: A case study of Chinhoyi University of Technology. *IMPACT: International Journal of Research in Business Management (IMPACT: IJRBM)*, *4*(8), 1–16.

Nduro, K., Anderson, I. K., Peprah, J. A., & Twenefour, F. B. K. (2015). Industrial training programmes of polytechnics in Ghana: The pertinent issues. *World Journal of Education*, *5*(1), 102-113. https://doi.org/10.5430/wje.v5n1p102

Nganga, G. (2014, May 23). Survey finds most East African graduates 'half-baked'. *University World News*. https://www.universityworldnews.com/post.php?story=20140523130246934

Oyeniyi, A. A. (2012). *Students' industrial work experience scheme (SIWES) and the incidence of occupational misfit in Nigeria*. Industrial Training Fund. https://files.eric.ed.gov/fulltext/ED533330.pdf

Republic of Rwanda. (2015). *A tracer study of graduates from Higher Learning Institutions (HLIs) and employers' satisfaction of graduates' competences*. Higher Education Council.

Sheikheldin, G., & Nyichomba, B. (2019). Engineering education, development and growth in Africa. *Scientific African*, *6*, e00200. https://doi.org/10.1016/j.sciaf.2019.e00200

SADC (Southern African Development Community). (2019). *Engineering numbers & needs in the SADC region*. The Southern African Development Community Secretariat.

UNCTAD (United Nations Conference on Trade and Development). (2017). *Science, technology and innovation policy review: Rwanda.* UNCTAD/DTL/STICT/2017/8. UNCTAD.

UNESCO (United Nations Educational Scientific and Cultural Organisation). (2010). *Engineering: issues, challenges and opportunities for development*. UNESCO. CSIR https://researchspace.csir.co.za/dspace/handle/10204/5055

UNESCO. (2015). Mapping research and innovation in the Republic of Rwanda. G. A. Lemarchand & A. Tash (Eds.), *GO→ SPIN Country profiles in science, technology and innovation policy, vol. 4*. United Nations Educational, Scientific and Cultural Organization.

UNESCO. (2021). *Engineering for sustainable development: Delivering on the sustainable development goals*. UNESCO.

Woodhouse, E., & Patton, J. W. (2004). Introduction: Design by society: Science and technology studies and the social shaping of design. *Design Issues*, *20*(3), 1–12. JSTOR.

Appendix

Table 3: *Summary of feedback from industry partners about current state of SIS programmes (Tanzania)**

Organisation	TANELEC (electric equipment)	Confederation of Tanzanian Industries (CTI) (Richard, 2018)	TEMDO	CAMRTEC
SIS/internship existence	Yes	Yes	Engineering students are supervised by engineers at TEMDO. They are introduced to TEMDO (orientation), and then they are assigned their jobs and supervisors. The same training as UDSM (first year artisan, second year technician, and third year engineer).	When students come here, they feel estranged and challenged. Making the students deal directly with the technological creation work takes them away from the classroom environment to face real-world challenges. More of that is required.
Students received for training (annually)	About 12–15 every year	N/A (but with members of CTI)	Sometimes we get more than 10 students every year (roughly) from all the PT levels. They come from UDSM, SUA, ATC, DIT, etc.	Every year, over 50, but they usually come in groups of 20s or so per season.
Are some students employed after PT with the same organisation?	Yes, currently [we] have three students from UDSM (graduates) as our employees.	Yes, experiences of member industries that take students as interns after they graduate, for about a year – some are employed.	— (employment through public sector)	— (employment through public sector)
General assessment of current state of SIS (problems/challenges and university-industry linkages)	- Some students are useful to have, but some students are a burden. - Our resources and capacity limit the number of students we can receive. - Many of the students find our work here quite new and interesting.	Currently, there is a skills development levy of 4.5% of basic pay of all employers (higher than most countries around), so the industries feel that they are already contributing to skills development in the country and without benefit.	Staying longer (in the SIS) will make the student learn more. At 2nd and 3rd year they need to be guided to understand how to deal with design challenges and be more accurate.	Not enough time for them to actually master any part of the process. They end up covering a little of everything, making them versed in nothing. Also, teaching them is a challenge, because there is a lot that they do not know.

*Information drawn from survey that included public documents and semi-structured interviews with leaders/representatives from each organisation.

Table 4: *Status of SIS programmes in Tanzania and Rwanda's principal universities**

Institute	CoET (College of Engineering and Technology) University of Dar es Salaam	CST (College of Science and Technology) University of Rwanda
SIS/internship existence	Practical training every year for 8 weeks (1st, 2nd and 3rd year degrees – artisan, technician, engineer).	Currently, both students and faculty have mandatory industrial attachment placements, coordinated and executed with industries.**
Overall number of graduates	Graduates of CoET are on average 600 a year. On average CoET has 2,400 students enrolled (all years) every year.	600 to 1,000 graduates every year (engineering)***
Students in training (annually)	Average 1,800 per year	Average 500-1000 students per year
Industries involved with institute	Over 200 industries, but normally not all would get placements every year, so on average around 120 industries per year.	Ministry of Infrastructure: there is a clause for all foreign companies to include students and faculties for industrial training.
Problems/challenges with existing industrial SIS programmes	(1) Industries have little time to help PT students with questions. (2) PT students are not given proper protective equipment, or are given used ones (which is unhealthy). (3) On PT 3rd year, the student has to write a project on a practical problem, but one cannot have a well-executed project in only 8 weeks of placement. (4) Small allowances.	(1) Not enough industries, especially willing industries. (2) Student welfare during Industrial Attachment (IA) is minimal. (3) Budgetary constraints for staff to supervise IA student participation. (4) Guaranteeing student professional behaviour during IA requires close supervision.

*Information drawn from public records, shared by respective university faculties.
** Students at CST used go for industrial attachments after completion of 3rd year for 10 weeks. Curriculum was reviewed and now, starting from academic year 2019-2020, 2nd year students also do 10 weeks.
*** On average the School of Engineering of CST has 2,000 to 2,500 students enrolled (all years) every year, while CST has 5,000 to 6,000 students enrolled.

Table 5: *Summary of lessons and recommendations from pilot SIS placements**

	University of Dar es Salaam		University of Rwanda	
	Student 1	Student 2	Student 3	Student 4
Specialisation and year	Chemical engineering, 3rd year completed	Civil engineering, 3rd year completed	Electronics & Telecommunication Engineering programme, 3rd year completed	Civil Engineering, 3rd year completed
Industries joined (with time)	Kilombero Sugar Company Limited (November 2019 – October 2020)	Cost Plan Group (November 2019 – July 2020) and Karanga Leather Factory (August - November 2020)	Liquid Telecom Rwanda (LTR) (January 2020 – December 2020)	Rwanda Housing Authority (RHA) (January 2020 – December 2020)
Lessons for university (from student reports)	(1) Collaborate with industries (organisations and production companies). (2) More funds should be raised for sustaining the programme and engaging more students.	Get involved in identifying gaps by analysing what the university teaches and what the industry offers, and then design capacity building.	(1) Improve collaboration to facilitate students' industrial placement. (2) Pay visits to students or arrange for virtual meetings to understand what is going on. (3) Ensure that students receive their stipends timeously.	Ensure that the allocated funds for students reach them on time.
Lessons for industries (from student reports)	Need to collaborate with support institutions (e.g. SIS programme and universities). This assists in student placement and also serves as a ground for engineering graduates' mentorship and recruitment.	(1) Raise awareness of the programme; and meet students to understand their challenges. (2) Financially, invite more donors to sponsor the programme. (3) Join the SIS programme, meet the students and make clear what they expect from them.	Work in collaboration with the university in running the programme; collaborate with other industries in finding and facilitating industrial placements.	Ensure that regular supervisions are undertaken; strengthen partnership with universities and industries to facilitate the internship programme.
Lessons for SIS programme coordinators	(1) Provide information on SIS programme to more students; (2) SIS should serve as a way to advocate for reshaping the university engineering programme.	Financially, invite more donors to sponsor the programme, preferably industry to get involved in providing support.	—	Sponsor more students; work together with industries to ensure availability of placements.

*Commentaries drawn from approved student reports. Academic and industrial supervisors either commented generally or simply approved the student's report.

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Engineering practices observed in South Asia

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The development of engineering skills in Africa could be improved by learning from experiences in South Asia where research has exposed significant weaknesses in the engineering education ecosystem. Research has shown how socio-technical interactions that involve collaborations with other people dominate the work of professional engineers. In contrast to wealthy, developed countries, societies in the Global South are often characterised by complex patterns of social behaviour where perceived reputation, socio-economic status, caste, tribal identity and language strongly mediate power structures and hence collaborative performances such as engineering. In addition, several environmental factors such as the local economy and business practices, labour market, education, weak social security, low trust in strangers, climate and geography all influence the ways that engineers practice in their firms. These factors, coupled with pragmatic responses within firms, and knowledge gaps such as incomplete perceptions on labour costs, make it much harder for engineers in South Asia to generate similar levels of performance as in wealthier countries. Engineers' salaries and the cost of engineered goods and services of equivalent performance and quality may serve as objective indicators of engineering performances. This paper concludes with suggestions for engineering educators in the Global South to help a greater proportion of engineering graduates to become competent novice engineers in local enterprises with these socio-cultural and economic complexities.

Keywords: engineering practice; social culture; development studies; engineering education; Global South

Introduction

Engineering is critical for social and economic development, to provide goods such as energy, water supplies, sanitation, transport, communications, fertilizers, and food processing. The development of improved engineering skills in Africa is critical to meet rising expectations across the continent.

Echoing observations in Africa (e.g., Senzanje, 2003), South Asian[1] engineers are struggling to meet these expectations despite increased investment in engineering education

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[1] South Asia includes India, Pakistan, Bangladesh, Sri Lanka, Nepal, Sikkim, Bhutan, and the Maldives.

over the last few decades. The cost of engineered goods and services of equivalent performance, quality, durability and reliability tends to be higher than in wealthier countries (Trevelyan, 2014). Engineered artefacts should enable people to be productive, to do more with less effort, time, materials, energy, uncertainty, health risk and environmental disturbances. However, even though productivity in India has improved more rapidly than other countries in the Global South, Indian productivity is still less than a quarter that of wealthier countries[2], despite the widespread availability of new technologies (Manyika et al., 2015). Furthermore, a large proportion of South Asian engineering graduates, as high as 80% by some estimates, are considered unemployable as engineers (Tilak & Choudhury, 2021). Those who find employment mostly earn about 15% of the starting salaries for engineering graduates in Australia (Kaspura, 2019; Tilak & Choudhury, 2021). These significant differences in outcomes raise questions about the effectiveness of engineering education, and efforts to improve education outcomes in Africa may – depending on the context – benefit by learning from South Asian experiences.

Engineering education curricula are largely standardised globally, using similar if not identical texts, often in English rather than in the local national languages. So far, 29 countries have ratified the Washington Accord that prescribes attributes of professional engineering education programmes and many more use similar criteria to accredit their education programmes (International Engineering Alliance, 2021). Such broad standardisation reflects an implied assumption that the knowledge required by engineers is universally applicable. However, the differences in outcomes suggest that this assumption is questionable.

As Figure 1 suggests, even a superficial visual comparison can challenge the assumption of universality in engineering practices. Widely reported difficulties encountered by engineering workers who migrate from one country to another can also lead one to question the validity of this assumption (e.g., Friesen, 2011; Shan, 2012; Trevelyan & Tilli, 2010). If engineering practice were substantially similar between countries, engineering workers would readily gain employment after migrating. However, the objective performance indicators mentioned above, coupled with research observations from the Global South, help demonstrate significant differences between engineering practices there compared with those in higher-income countries such as Australia.

[2] http://wdi.worldbank.org/table/2.4.

Figure 1*: Residential construction in Melbourne (left) and Islamabad (right), November 2022. (Photos by author)*

In this paper, I argue that critical aspects of knowledge required by engineers are location dependent. Even though the available evidence is limited, there is enough to justify further research on local engineering practices in different countries and settings and to start adjusting some aspects of professional engineering education programmes.

While South Asian engineers mostly succeed as migrants in countries like Australia, in their home environment their counterparts struggle to achieve similar performance levels, as evidenced by the high costs of engineered services such as safe drinking water, construction, electricity and manufacturing (Trevelyan, 2013, 2014). Costs of engineered goods *of equivalent design, quality, durability, performance and reliability* tend to be higher in South Asia than in Australia, a significant impediment holding back economic and social development. For example, safe drinking water can cost 10 times more than in Australia because it mostly has to be manually transported because water distribution pipes in most cities are contaminated with faecal bacteria. Electricity, at the point at which it performs useful work, can cost four times more (Trevelyan, 2013), because of the need for generators and other backup power sources to maintain supplies through frequent interruptions to the grid supply and also appliance inefficiencies. One notable exception is telecommunication services which can be less expensive than in wealthier countries while providing comparable service quality (Trevelyan, 2013). Similar observations have been made by Sachs and others, for example commenting on the relatively high cost of engineered agricultural inputs such as fertilisers (Sachs, 2005).

Some readers might argue that manufacturing centres established in India (in particular) by large multinational firms contradict the observations on the cost of engineered goods. Would these firms invest in India if the cost of their business was higher than in wealthier countries? Certainly, many firms in wealthy countries have outsourced parts of their engineering operations to India and other countries where certain activities such as drafting can be performed at lower cost because of the low hourly cost for hiring drafters, programmers, finite element mesh designers, and other specialised technical workers. However, the costs and difficulties are often underestimated (Leonardi & Bailey, 2008). Such investments may also be strategic, for example to establish a foothold and gain first-hand experience in what is widely expected to be a rapidly growing market in the future. Indeed, many of the observations reported in this paper came from such a manufacturing centre, a firm established with significant offshore investment which has been recognised as one of the leading firms of its kind in India. Yet the same challenges influencing the high cost of engineered goods were also present in this firm.

Several unanswered questions motivated two decades of research on engineering practices by my students and myself in Australia and South Asia, including the following. Can the performance difficulties experienced by engineers in their home countries be part of the explanation for the relatively high costs of engineered goods and services? Do engineering performance difficulties mainly arise from environment factors beyond their control? Is it possible that engineers could respond to these factors with significantly improved results?

From 2003 onwards, my students and I have interviewed and observed engineers in India and Pakistan with the aim of comparing their observations with detailed descriptions of engineering practices in wealthy countries from the research literature. We expected that this would expose differences between South Asian engineering practices and those in other countries. However, as Barley (2005) wrote at the time, little was known about technical work. Only about 20 detailed observations were available (e.g., Bucciarelli, 1994; Lam, 1997; Vinck, 2003; Zussman, 1985), and substantial effort was needed to find them (Trevelyan & Tilli, 2007). Therefore, the scope of investigation had to be widened to include engineering practices in Australia and other relatively wealthy countries.

Subsequently, many researchers have begun to address the significant weakness in our knowledge of varying international engineering practices (see Jesiek, 2018; Mazzurco et al., 2020). However, we still have only a few research observations of engineering practices from the Global South (Coelho, 2004; Domal, 2010; Kusimo & Sheppard, 2019; Matemba, 2020; Nan & Bocong, 2018; Trevelyan, 2013, 2022; Zhu, Hu, Li, Zhang, & Li, 2021; Zhu, Hu, Zheng & Li, 2021). Several of these represent substantial and detailed research contributions. The paper draws on these contributions to show that engineering practices in South Asia differ significantly from practices in Australia and other wealthier countries. Furthermore, even this limited evidence base helps to explain the outcome differences described at the start of this paper and how African engineering might be reshaped in future.

Through a chance encounter with an importer of specialised high-value engineering equipment, I identified a small number of expert engineers in South Asia who were readily distinguished by high salaries, comparable with salaries for engineers in wealthy countries. Since remuneration can be a sensitive topic, this information usually emerged from casual conversations after formal interviews had concluded, being a more conducive atmosphere for sharing confidential information. Not every participant felt they could share their remuneration details.

The importer's engineering customers recognised that his American products provided substantially greater value than competitors because superior technology enabled superior performance with easier operation and maintenance. These engineers had managed to persuade their employers to purchase the more costly American products. As in many countries, procurement is a specialised function within an engineering firm: procurement staff know how to obtain the best possible purchase terms, and usually the decision is based almost entirely on purchase price. Even senior engineers may have little or no influence over their decisions (Domal, 2010). One the importer's customers explained how he influenced the purchasing department in his firm:

> I asked the supplier to draft a purchase specification that would exclude the competing products, and the purchase department accepted that: they did not have sufficient knowledge to question it. Then they could confirm for themselves that the US-made equipment that I had recommended was the only product complying with our requirements (interview by author).

Another attribute characterising these engineers was their ability to think about their contributions to the firm in terms of commercial value. For example, this engineer reflected on the relative cost and contributions of his product development team.

> It is nowhere near what I am saving them. I think there is a factor of 50 there … This was a very novel concept within the company. But I use the same concept on myself: if I am being paid that much, that's how I must perform. I do these things internally for myself, for my own justification, for my own ego, but nobody asks me to do that (interview by author).

The reason for their high salaries became evident once their contributions to their firms were identified. These engineers had become critical to their respective firms' success and therefore they were paid sufficiently well that they would not have any financial incentive to relocate to a wealthier country where engineers could expect higher remuneration.

Finding these expert engineers was a significant development in the research because it exposed the relevance of the marginal product theory of wages from labour market economics. This well-supported theory predicts that remuneration will reflect value generation. Engineers who earn more do so because their firm perceives that they generate more economic value (Trevelyan & Williams, 2018). Therefore, salary levels can help us assess the relative economic contributions of engineers, an objective performance measure for engineers in different firms and countries. We can therefore conclude that Australian-based engineering graduates generate more economic value than their Indian counterparts.

This does not imply that Indian engineers are less capable or intelligent than their Australian counterparts. Instead, it tells us that engineers in Australia, including South Asian migrants, are more able to generate economic value for their firms because engineering practices are different. Indian-born and educated engineers migrate to Australia and other wealthier countries in substantial numbers, and after a period of adjustment perform comparably with local engineers because they follow similar practices. The fact that the expert engineers in South Asia were earning salaries comparable or higher than engineers in Australia tell us that they somehow managed to work out practices that enabled them to generate comparable economic value in their home environments. Their firms were able to supply goods and services equivalent to the best imported alternatives.

The relative cost of engineered goods and services of equivalent design, quality, performance, durability and reliability may offer another objective outcome measure that can indicate relative levels of engineering performances. If we can understand how these cost differences are related to engineering practices, it might be possible to help firms and utilities reduce these costs. By reducing the costs, engineers can generate greater value and, ultimately, will benefit from higher remuneration. Studying local engineering practices could also fill knowledge gaps among engineering educators, most of whom lack recent experiences of commercial engineering practices (see Cameron et al., 2011).

Therefore, this paper first reviews what we have learned from research observations about socio-technical interactions between engineers and others that form the dominant components of professional engineering practice. These are also the main aspects of practice that are location dependent. Next, the paper identifies environmental factors affecting engineering practices that cannot easily be changed. Several research observations help to identify location-dependent aspects of engineering practices and help to identify knowledge gaps and practices that might be changed. Observations of expert engineers provide evidence that engineers can change local practices and acquire the knowledge needed to provide engineered goods and services equivalent to imported equivalents. Finally, the paper speculates on ways that engineering educators might be able to help graduates benefit from these expert engineers' experiences.

The literature describing engineering practices based on workplace research studies still consists of a relatively small body of knowledge, perhaps a few hundred books and articles. It is small in relation to engineering education research as a whole. Further, there are very few research studies on engineering practices from the Global South. Even so, these accounts raise many relatively complex issues spanning business, finance, anthropology, economics and psychology. A single journal article only permits space for references to a small selection of relevant literature, so the reference citations in this paper should be regarded as starting points for reading rather than a definitive list.

Socio-technical aspects of engineering practice

There are aspects of engineering with universal applicability relying on knowledge derived from science and mathematics such as the properties of materials and calculation methods that predict the behaviour of engineered artefacts and systems. Engineers frequently use computer software that makes it easier to use such knowledge in their daily practice. This knowledge and the related computer software are universally applicable, explaining why engineering education curricula are largely standardised worldwide, and with similar texts.

Implicit and tacit knowledge, such as tightening nuts and bolts appropriately, making reliable soldered electrical joints, pouring reinforced concrete, debugging memory leaks in software, and implementing earthing and lightning protection, largely untaught, is equally universal and applicable anywhere.

However, another major aspect of engineering practice is not as universally applicable. A growing body of research evidence reveals how socio-technical interactions between people enacting a range of collaborative performances lie at the core of engineering practice. For example, informal technical coordination, gaining willing and conscientious collaboration from others with an agreed time schedule and without relying on organisational or other authority, appears to constitute a significant proportion of the work of professional engineers (Anderson et al., 2010; Blandin, 2012; Jesiek et al., 2019; Trevelyan, 2007; Vinck, 2003, 2019). One explanation for the relative prominence of this activity derives from the distributed nature of expertise: knowledge is distributed across numerous participants, both engineers and others (Trevelyan, 2010a). Professional engineers frequently engage with others across organisational and discipline boundaries (Asplund & Flening, 2021; Jesiek et al., 2018; Jesiek et al., 2021) and also adopt persuasive communication practices to secure resources and advocate for particular interpretations of evidence (Coso Strong et al., 2022). At the same time, many engineers regard this socio-technical activity as 'non-technical' or 'not real engineering', even as an interruption to their 'real engineering' work (Bailyn & Lynch, 1983; Perlow, 1999; Perlow & Bailyn, 1997). Trevelyan (2007) noted that even highly experienced engineers might not be consciously aware of coordination activity. Engineers, at all stages of their careers, are constantly building and maintaining their networks of personal contacts – suppliers, customers and clients, sources of technical expertise, regulators, people who know where to find experts, and so many others. Neither the network nor the social and cultural skills needed to create it and navigate it successfully are easily transferrable to a new country, even a new firm or industry.

Quantitative estimates of the proportion of time that professional engineers spend on socio-technical interactions with other people, including face-to-face, telephone and teleconferencing, through text, and through human-readable data in information systems, vary between about 40% and 90% (e.g., Tenopir & King, 2004; Trevelyan & Tilli, 2008; Williams

& Figueiredo, 2010). In other words, socio-technical interactions with other people dominate professional engineering practice. Seeking human-readable information is another significant component, typically 5 to 10%, and might also be considered as a form of socio-technical interaction (Tenopir & King, 2004; Trevelyan & Tilli, 2008). Therefore, it would be surprising if such interactions were not influenced by the culture(s) of the host society and organisation. In contrast, so-called 'technical' work, solitary cognitive performances that require interactions with abstract objects, usually mediated by information systems, form a relatively much smaller component of practice. Engineers typically spend 5 to 20% of their time on this activity, including design, calculations and modelling and most spend a negligible proportion of their time interacting manually with physical objects (Trevelyan & Tilli, 2008; Williams & Figueiredo, 2010).[3]

Therefore, the central part of engineering practice, socio-technical interactions with other people, is neither easily transferrable nor relies on universally applicable skills. This can explain why engineering practice is not universal, but may be highly specific to a particular country, industry or firm.

Other aspects of engineering practice are also specific to a particular location or setting. As Latour (2005) has explained, localised knowledge, much of it embodied in the physical infrastructure of a workplace, is usually more important in creating workplace competence than the particular competencies of an individual. For example, operating a profitable business in a traditional street market requires implicit knowledge acquired through years of experience, most likely passed on from parents to children. On the other hand, a supermarket has many levels of established structure: the layout, shelves, barcodes, packaging, labels, price tags, checkout terminals and the back-end logistics and information systems that instantly create competence among young workers who may not have even finished school. In the same way, engineering firms provide physical and virtual infrastructures, IT systems and tools (mostly as software) that enable competence among engineers (Petersen & Buch, 2016). As we shall see, it is the combination of socio-technical skills, access to knowledge and expertise through professional networks, business processes, infrastructures, IT systems and tools that distinguish engineering workplaces in India from those in wealthier countries, and these enable engineers based in wealthier countries to generate far more economic value.

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[3] The video 'What do I do as a mechanical design engineer?' (https://youtu.be/pX03H1oeyN0) provides an entertaining explanation supporting this finding.

Environmental factors

Many factors influence the practice environment for engineers and cannot easily be changed. They shape pragmatic responses by engineers, some of which will be explained later in the paper. They include national and organisational culture, geographic location, climate, labour market and education, governance, and the local economic environment which is itself shaped by other firms responding to similar local and international influences. In contrast, engineers can influence practices implemented within a particular firm or organisation.

At a superficial level, the work of engineers in South Asia can seem much the same as in any other country. A typical working day involves email correspondence, phone calls, meetings, site inspections, and some solitary technical work, most often through sketches, drawings or computer information systems. Examination through a research lens developed in one country can attenuate, even hide the influence of another country's culture, geography, language and economic environment (e.g., Zhu, Hu & Zheng et al., 2021).

Many have argued that the cultures of the host society and firm strongly influence economic performance. However, since we are constantly immersed, culture can be challenging to observe, primarily by noticing differences between cultures. Cultural influences on firm performance have been extensively researched since the 1980s.

However, Chatman et al. (2016) recently argued that studies of organisational culture, in particular, need to be reconsidered because they have lacked construct validity, and researchers have drifted from academic enquiry towards lucrative industrial consulting. Some have even argued that observing culture is 'inherently subjective and requires a researcher to have extraordinary sensitivity an almost preternatural capacity to think, feel and perceive like a native' (Chatman & O'Reilly, 2016, p. 8). Writers have confused the concepts of 'organisational climate' (shared perceptions on policies, practices and rewards); 'social culture' as underlying assumptions and beliefs (conscious and unconscious); norms and values about appropriate behaviours; artefacts reflecting these (such as clothing, language, symbols); and organisational practices. There is still only loose agreement among scholars on what constitutes culture.

Hofstede (2011) and Trompenaars & Hampden-Turner (2021) both proposed measures that can differentiate national cultures, yet both approaches have been criticised, citing weaknesses stemming from data sets accumulated in the course of business consulting work, mainly with managers working for larger companies (e.g., Jacob, 2005). For example, neither considered the influence of religion except to assert that some religions place a different emphasis on the need to change or improve the conditions under which people conduct their lives. However, both schools of thought have provided ideas that can help distinguish the influences of host cultures on engineering practices. Tellis et al. (2009) studied the influences of national and organisational culture, government policy, labour and capital on the wealth of firms and nations, concluding that organisational culture was the most decisive influence. Their paper (Tellis et al., 2009) reflects, in part, the interests of their audience, marketing researchers and practitioners. Also, reflecting earlier observations by Chatman et al. (2016), Tellis et al. (2009) chose organisational culture measures that include attitudes and practices such as willingness to cannibalise profitable assets for higher future profits (an attitude), and empowering product champions (a practice).

Tellis et al. (2009) also recognised, though relatively simplistically, the influence of geography on regional GDP in terms of distance from the equator. Mellinger et al. (1999) devised a more comprehensive quantitative model to account for geographic influences on regional GDP, including factors such as proximity to the sea and climatic zones. For example, after correcting for purchasing power, they assessed the average GDP in temperate coastal regions as 18 times higher than non-temperate zones far from the nearest coastline. The influence of geography is particularly relevant for the economic development in the Global South, explained qualitatively in some detail by Kamarck (1976) in his report for the World Bank. For example, human muscles release heat energy that has to be transferred to the environment. At higher ambient temperatures, heat transfer is slower in the absence of air conditioning, imposing finite limitations on physical exertion (e.g., Zhu, Wang, Zhang & Wang, 2021). Some economic development impediments in tropical countries identified by Kamarck (1976) have since receded in significance, particularly diseases such as malaria, dengue and trypanosomiasis because of medical interventions and control measures to reduce the prevalence of insect carriers.

A large proportion of South Asian people working in engineering enterprises live in urbanised communities where indoor night temperatures exceed the neutral temperature for human sleep, above which metabolic heat cannot be lost to the environment fast enough to maintain normal body temperature (approximately 30 °C with a fan, 27 °C without a fan (Hansen & Soebarto, 2019; Khosla et al., 2021; Lan et al., 2017)). I have conducted numerous indoor temperature observations in the course of designing novel air-conditioners to provide energy-efficient cooling devices for South Asia. The overwhelming majority of people in South Asia who cannot afford artificial cooling, therefore, may be suffering from sleep deprivation for months at a time, particularly in the monsoon season when water coolers are ineffective. Under these conditions, capacity for work, both physical and cognitive tasks, is significantly reduced (Day et al., 2019), though objective measurements on work capacity are only available from research institutions where participant sleep quality is assured. Many parts of Africa experience similar climate conditions as in South Asia.

Several other challenging environment factors are mentioned below, including levels of trust in strangers, the local business and economic environment, availability of social security and welfare, labour markets, education, governance, and legal systems. When seen in combination, it can be hard to see how all these adverse factors could possibly be overcome. Yet as we shall see, at least a few engineers have successfully managed that.

Research methods

This paper draws on interviews and field studies conducted by my students and myself (Trevelyan, 2016), and also draws on extensive evidence available from other studies, particularly PhD theses based on observations in the Global South. Coelho (2004) studied engineers in an Indian water utility, and Domal (2010) studied mechanical engineers in a leading automotive component manufacturing factory in India, comparing them with similar engineers in Australia. Some data from Africa has recently become available (Kusimo & Sheppard, 2019; Matemba, 2020).

Between 2003 and 2013, my students and I conducted 330 qualitative interviews lasting 90 to 120 minutes each, which contributed data on engineering practices in Australia and South Asia. Ten field studies conducted by students helped to triangulate interview data (details appear in Trevelyan, 2013; 2014; 2022). All South Asian participants identified as male, while a few Australian participants identified as female.

I have also drawn on my experience practising as an engineer in Australia, UK and Pakistan since 1971 and teaching engineering from 1975 till 2016. I have directed a small business enterprise in Australia and Pakistan since 2007, and have gained insights into those countries' economic and regulatory environments. Interactions with other South Asian firms have also helped me understand the similarities and differences compared with Australia. For example, while there are differences in social culture between India, Pakistan, and other South Asian countries, they are minor when comparing with cultural and social practices in Australia. Therefore, this paper refers to 'South Asian' participants and only identifies specific countries when necessary.

Qualitative data analysis followed conventional interpretive methods (Charmaz, 2014; Huberman & Miles, 2002; Miles & Huberman, 1994; Patton, 1990; Strauss, 1987). First-hand experience of engineering practices in Australia, UK and Pakistan and extensive visits to engineering operations in several other countries enabled theory construction beyond the interview and field study data (Charmaz, 2014). For example, frequently occurring patterns of technical coordination to enact distributed expertise in engineering enterprises were not explained by any of the participants (Trevelyan, 2007, 2010a). These concepts emerged from data by repetitive reading and reflection on the data, coupled with personal experiences of practice and living in the respective countries. Subsequent independent research has provided supporting evidence, with some cited above. Several of the students conducting research interviews also have had extensive engineering practice experience. Discussions of the early findings with participants and others, experiences from running businesses in Australia and Pakistan, and literature from organisation science, labour market economics and development economics have helped me further develop the ideas presented in this paper.

Factors affecting engineering practice

Interview data revealed several significant social and cultural factors that influence engineering practices. The following sections describe several factors that seemed to be more influential in making it difficult for engineers in South Asia to generate results that could be expected in Australia and other wealthy countries. While they are described in separate sections, they are all interconnected and their influences cannot easily be untangled.

The data also revealed a wide range of practices within each country. While activities in some engineering firms in South Asia follow practices similar to those in firms in Australia, others exhibit practices that are vastly different. These variations indicate the need for a large number of observations in different settings, industries and countries in order to position practice attributes within ranges that can be encountered within a particular country.

Trust in strangers

On visiting an engineer's office in South Asia, it is not unusual for a researcher to be seated alongside a visitor on a couch or armchair who seems to have no obvious connection with the firm's business. With relatively high social status within the firm, many engineers face a seemingly endless succession of visits during the working day from distant relatives and extended family members seeking employment for sons, daughters or other relatives. They may be people whom the engineer cannot recall, but the mention of certain family members by name means that the visitors cannot be ignored. These visitors may sit silently for hours while the work of the day proceeds, seemingly without reference to the visitors at all. If not in the office itself, the visitors will patiently wait in ante-rooms, or in the immediate vicinity outside (Coelho, 2004).

Mistrust of strangers can help explain this observation. South Asian societies typically exhibit low levels of trust outside family and in-groups (Balliet & Van Lange, 2013; Frevert, 2009; Jacob, 2005; Nadeem, 2013; Ward et al., 2014). In-group membership depends on reputation, socio-economic status, caste, tribal identity and language (Waris & Kokab, 2017). Many firms are controlled by a powerful family, and positions of authority are often reserved for family and in-group members. A 'family' can include non-relatives. Such an extended family is usually based on long-lasting and intimate ties with others who, for all intents and purposes are considered to be family members, even to the extent that males are admitted to female-only parts of the household as if they are brothers from the same father. Therefore, gaining employment may rely more on family connections than qualifications and experience because family membership provides sufficient trust for a measure of delegated authority. Among engineers, a given level of technical competence cannot be presumed. This practice can also promote firm loyalty because of the relative difficulty of securing employment in other firms where family connections may be more tenuous or non-existent. Similar patterns can influence public sector employment below the most senior levels where entry requires high performance in tightly controlled public service examinations. However, in the public sector, support from and loyalty towards powerful local political actors can also be a requirement, whether their party is in office or not.

In contrast, a greater level of trust in strangers in Australia permits recruitment selection based more on personal attributes such as workplace competency and relevant technical experience. However, family and other personal connections also significantly influence recruitment at many Australian firms.

As an example, this South Asian engineer explained his low level of trust in outsiders, especially 'vendors' – small roadside enterprises to which some manufacturing work is outsourced (Domal 2010).

> The people who work directly for me at [this firm], by and large, they are all honest, hard-working people. 60% of my vendors are dishonest! In England you assume that someone is telling you the truth unless proved otherwise. In this country you assume that he is lying unless proved otherwise. I think that's how you start and it's something you have to deal with on a day-to-day basis and it wastes a lot of resources, time. Misrepresentations, false statements, what have you like to call them, it has become a way of life in this country, and I don't see it changing in my lifetime (interview by author).

Social welfare

Another environment factor influencing engineering practice is the availability of social security and welfare. In societies with weak or non-existent social protections, the need for job security can be a more powerful behavioural influence. In South Asia, personal catastrophe may only be a short step away, out of sight around an unexpected corner. Disease or accidental injuries requiring costly medical attention, an unintended insult towards a senior, or simple mistakes arising from ignorance can suddenly terminate employment and the income security that comes with it. Fear of falling, to become one of the vast masses of urban poor, is a powerful emotion that lurks close to the surface of the psyche. Domal (2010, p. 182) described

> ever present, enormous and unresolvable social disparities between the shop floor workers, the day labourers, representing the mass of humanity clutching to a precarious day-to-day existence, on the one hand, and the engineers and managers representing the middle and upper-class social elites. These disparities seem to bring intensity to otherwise ordinary differences of opinion which is seldom experienced in the Australian context. Further, it is possible that the hopelessness of ever resolving the social disparities is reflected in the apparent lack of enthusiasm in Indian engineers to solve issues in the factory which could be resolved.

Losing one's job or acute illness in Australia can still be a traumatic event for many but is rarely a catastrophe because there are strong institutional support structures in Australia including high quality physical and mental healthcare systems coupled with economic support.

The social disparity between engineers and shop floor workers is much less, so much so that shop floor workers can and do make significant contributions to engineering decisions. For example, this Australian engineer explained how his firm ensures that early-career engineers acquire practical knowledge from shop floor supervisors.

> A wise construction boss will make sure that a young engineer has a highly experienced foreman on his site. The experienced foreman will be teaching the engineer how to do the project management, a kind of reverse mentoring. Older foremen with the right skills get a tremendous thrill from doing this kind of thing especially when they're explicitly asked to do it (interview by author).

A reader might suggest that demonstrating superior workplace competence would provide employment security. However, research interviews by the author demonstrate that overt displays of superior work performance can undermine social relationships, disrupting knowledge sharing through social networks, especially in a culture where workplace seniority (duration of service) is valued more highly than competence.

Income supplementation in government service

Government service in South Asia is characterised by significant social responsibilities and low salaries, imposing significant constraints that shape engineers' practices. Coelho described engineering work in a government water utility lurching uncertainly towards a degree of privatisation (Coelho, 2004, 2006), revealing how engineers are not only responsible for managing daily operations but, unlike their Australian counterparts, are also responsible for revenue collection. Interviews by Domal (2010) yielded insights into some of the tactics used by engineers responding to revenue collection targets that can exceed 80%. Engineers may resort to breaking pipe connections to insert flow restrictors to help persuade reluctant customers to pay their bills, as this engineer explained:

> People will be paying electricity bill, cable bill everything but water they won't be paying … until and unless we go there … people will be … sometimes we block the sewage connection also … some of the customer they don't pay even if you disconnect the water supply line they won't pay … so ultimately we have to block their sewage system. (Domal, 2010, p. 220)

In doing so they unintentionally enable sewage contamination to seep into the water pipes through poorly restored joints that are often lying in open sewers alongside urban streets because the water supply pipes are only pressurised for a couple of hours every two or three days. While this is a pragmatic engineering policy (Taylor et al., 2019), one of the consequences is that piped water connections throughout South Asia tend to have faecal contamination, causing a high incidence of stunting, permanent intestinal damage to infants caused by repeated diarrhea episodes (Bain et al., 2014; Cumming & Cairncross, 2016).

Water supplies also affect workers' health, particularly lower-paid clerical and manual workers who may be unable to afford effective water filtration at home. No one can escape occasional gastric infections, but without safe drinking water at home, these are more frequent and debilitating and can cause stunting in children (Cumming & Cairncross, 2016) and significant absences from work, reducing productivity.

Engineers working in a South Asian public service utility face particularly acute dilemmas (Coelho, 2004; Domal, 2010). Accountable to a district engineer, they have to work with many powerful local stakeholders including politicians, business owners and wealthy residents, with occasional delegations or organised protests from less wealthy residents. Their mobile numbers are often widely circulated unofficially, so an endless succession of calls punctuates the working day until late in the evening. Working in a bureaucratic organisation that cannot respond quickly to economic and market shifts, engineers can find it impossible to satisfy demands from powerful actors with allocated labour and official spending constraints. Low official salaries leave no room for flexibility, so many engineers pragmatically respond to urgent service requests from wealthy stakeholders by accepting unofficial payments that some would see as bribes. Some eschew requesting such payments, accepting them only when offered voluntarily. Discovering illegal connections, therefore, can open up significant opportunities to supplement informal funds that can then be used to satisfy requests from other powerful stakeholders who may not offer payment, or may not have the means to pay. Tracing such connections can be challenging (Figure 2) and most are hidden underground. Nevertheless, the pursuit of such connections can open still further difficulties.

> What was interesting to me in this incident was the intense dilemma the engineer was thrown into by the seemingly straightforward problem of an illegal connection. She had to negotiate a labyrinth of plots constituted by rumours, illicit acts and transgressive collaborations in order to enact or exert her own agendas of personal survival, responsibility to her workers and colleagues, and a wider official accountability. She was also caught in the classic bureaucratic conundrum where, as head of the unit, she was also the newest kid on the block with at best a shallow grasp of local geographies and histories of power and collaboration. All these needed to be unravelled in order to act effectively, or at least safely. (Coelho, 2006)

Figure 2: *Urban water connections: some may be illegal. Hyderabad 2009 (Domal, 2010)*

Some 'entrepreneurial' engineers in a government organisation can earn far more than others by manipulating opportunities to their advantage and networking with powerful actors.

> Some assistant engineers make a lot of money … She goes straight to ministers and their PAs by herself and talks to them boldly – she wields a lot of influence! I cannot do that – I don't go anywhere like that without my husband! (Coelho, 2004, p. 237)

From these accounts, we can see how established practices within South Asian government engineering enterprises are remarkably stable, limiting how engineers can respond by adapting their practices. Change comes slowly if at all; for example, the acute water shortages observed by Coelho (2004) recurred in 2019 for the same reasons (Bloomberg, 2021).

Language and the need for constant supervision

Language is a significant issue that magnifies uncertainties, opening large spaces for alternative interpretations. Many engineers in South Asia speak in three or more languages interchangeably: English; the national language (Hindi, Urdu, Bengali, Sinhalese, Nepalese, etc.); their mother tongue (Punjabi, Sindhi, Marathi, Telugu, Malayalam, Bengali, Tamil, Gujrati, etc.); and possibly local dialects as well, jumping from one to another seemingly at random, referred to as 'code-switching' by linguists. An English technical term may have no local equivalent, and while the meaning is familiar for engineers, for others it can temporarily block comprehension as they figure out which language the word might be, resulting in several seconds of missed conversation. In a context where seniority or high social status demands unconditional respect, automatically accorded to engineers in most workplaces, others will be hesitant to ask clarifying questions as that might imply they were not listening in the first instance. Most people lose concentration after a few minutes of uninterrupted speech: code-switching magnifies gaps, uncertainties and misunderstandings (as well as making interview and field note transcription a far more demanding task for a researcher!) (Domal, 2010).

Engineers' directions often reach factory or site workers through multiple verbal translations. Most South Asian engineers are not fluent in local worker dialects, so their instructions will be relayed through supervisors who translate from a mixture of English, Hindi and possibly the regional language to the workers' dialect(s). Any uncertainty in the minds of workers, therefore, results in at least hesitation and clarification with other workers, and mostly pausing the work until a supervisor or engineer provides explicit instructions, relieving the worker of any potential blame for misunderstandings. Expensive machinery stands idle in the meantime. For workers, mistakes can cost their jobs, particularly if they have minimal employment security. Mistakes can ruin expensive materials or machines, so workers may calculate that the consequences of inaction in the presence of any uncertainty are less severe.

From an external viewpoint, workers who work slowly or cease productive work completely in the absence of a supervisor can appear to be lazy or stupid. Yet, from the worker's viewpoint, this could be seen as a rational decision based on their expectations about consequences and the lack of social security.

Even locals can confuse this rational response as laziness or 'lack of attitude' (Domal, 2010). A similar observation from Nigeria (Kusimo & Sheppard, 2019) may reflect the same reasoning by workers faced with ambiguity and reluctance to act without instructions from someone in authority. The consequence for engineers is the continuous need for vigilant supervision.

The need for constant, highly paid supervision where one engineer or foreman supervises as few as three or four unskilled day labourers adds considerable indirect costs (Trevelyan, 2014) that can be many times the salary cost of the worker. Well-intentioned labour market regulations can magnify the need for supervision. In parts of India, for example, day labour can be hired for a maximum continuous period of only six months. So just as engineers have managed to train labourers to reasonable proficiency, they have to start all over again with new labourers (Domal, 2010). Typically, permanent workers have to be paid at much higher rates and benefits.

Lower education standards in South Asia also increase the need for supervision. Technical workers may be unable or unwilling to interpret drawings or written instructions. Therefore, engineers have to be much more vigilant (Domal, 2010) than in Australia to ensure due care and diligence with technical work. In South Asia, the span of control, the number of technical workers who can be supervised by one person, is usually considerably less than in corresponding enterprises in Australia.

Supervising production and maintenance work takes engineers away from their desks for extended periods, making coordination with other engineers and outsiders more difficult and frustrating (Domal, 2010). Mobile phones have helped in some respects, making access to engineers easier, although handling up to 200 calls daily itself is a significant demand on engineers' time (Domal, 2010). It is harder for engineers, therefore, to engage with formal email correspondence and documentation activity than in a more formally organised firm in Australia. Even at an export-competitive factory much of the production supervision work was being performed by relatively inexperienced engineers (Domal, 2010) who lacked the skills that experienced, specialised production supervisors acquire in countries with longer experience of industrialisation (Mason, 2000).

Activities related to supervision such as technical coordination (Trevelyan, 2007) may require frequent follow-up phone calls to keep priority work front-of-mind in an environment with frequent social distractions and other urgent priorities, including domestic matters and fatigue from long commutes, and often a second job to supplement income.

Financial awareness

Unfortunately, indirect labour costs arising from the need for training and supervision seem to be largely invisible to engineers, even many business owners. Arguments about labour costs, whether of engineers or shop floor workers, are usually based only on the hourly salary costs. Therefore, decisions can drift in directions that magnify overall costs rather than reducing them. The expert engineers took a different perspective, recognising the total cost, including training, supervision, machine utilisation, and all the other indirect costs required to achieve a given outcome, where low productivity more than offsets the low apparent hourly cost of labour.

Here is an engineer, also a business owner, being asked about investing in more automation:

> For any product I think labour cost accounts 7 to 9% and I think in those terms. Even if an increase in the labour cost by 20 percent, the total cost will go up from 1 to 2%, that's all. Why should I think too much about it? (Domal, 2010, p. 159)

This participant missed the connection between labour cost and plant utilisation. While the direct labour cost was only 7 to 9%, indirect costs such as opportunity costs from machinery breakdowns were not considered relevant.

My first-hand business experiences in South Asian firms revealed some of the reasons why few engineers have access to detailed financial information that could alert them to indirect costs. Anecdotal evidence from conversations with other business owners reveals that many keep multiple sets of accounts. The tax inspector will see accounts that show minimal if any taxable income. Another set of accounts is needed to persuade the bank that there are sufficient profits to qualify for a loan extension. The shareholders receive accounts that explain why their dividend increase has to be deferred for another year. The owner's working accounts will report his cash position, but few owners appear to account for asset depreciation.

The business owner has to keep all these accounts confidential to prevent other stakeholders from discovering the extent of deceptions. Anecdotal evidence suggests that some tax inspectors, well-educated but with low government salaries compared to the business owner's income, know they are being deceived and negotiate with the business owner to share the benefits from reducing the firm's apparent tax liabilities. Tax inspectors know it is difficult for a business owner to subsequently regularise their tax position without incurring substantial penalties. A banker explained to me that they know that their commercial loans will perform worse than forecast if the business owner does not allow for depreciation. However, at the same time, they know they will lose profitable business customers to other banks who do not insist on allowing for depreciation.

A research interview with a Pakistani engineer responsible for a US$ 250 million process plant revealed that he was unaware of the requirement to take depreciation into account to calculate profitability. The business owner of a semi-government commercial enterprise limited his spending authority to about USD 200. He explained, referring to powerful local stakeholders: 'I have to pay bribes out of my own pocket just to get my trucks carrying product to customers past their roadblocks' (interview by author).

The perceived need by business owners to keep accounts confidential makes it hard for engineers to appreciate financial issues in firms and organisations. Few of the engineers interviewed had any financial responsibilities, significant financial awareness, or authority. In contrast, the few expert engineers had figured out the financial situation of their firms for themselves. However, they still had little or no spending authority delegated to them. It is not uncommon for owners of large South Asian businesses to personally sign and authorise every single payment.

In Australia, most of the engineer participants had significant financial as well as technical accountabilities. While they were not necessarily aware of the day-to-day financial position of their firms, they were required to make recommendations based on financial arguments with significant consequences (Domal, 2010). Most Australian participants appreciated the opportunity costs of equipment failures. At the same time, they had limited appreciation of indirect labour costs, but because direct salaries in Australia are much higher, indirect labour costs are less significant than in South Asia. While Australian engineers are aware of low hourly labour costs in countries such as India and Pakistan, most are unaware of the high indirect costs and low worker productivity.

Formal procedures, information systems

Well-established engineering organisations in wealthier countries like Australia use formalised procedures to help ensure that distributed knowledge reaches people who need it. For example, in a company where the hourly rate for the services of a systems engineer was around three times higher than for small, informally organised firms, this engineer explained how formalised processes help:

> We have very formalised document review systems. For the critical design phases we have actual site meetings and we have checklists of what has to be done at those meetings. We have found that they are very effective. In this project we have probably gone further than just about anyone else has in the world in terms of formalising what previously has been a very informal process. We have checklists for all the major meetings, we have a formal checklist for document review, we have templates for all the major documents, so I think we are very structured in that regard. The client has to check all our conceptual design documents (*i*nterview by author).

He also explained that many clients are reluctant to engage in detailed document checking, but his firm delays project commencement until this has been done. Contrast this with the following field observation at a South Asian engineering consultancy:

> The firm's principal explained their frustration at being unable to win engineering contracts on projects conducted by major international companies and multilateral agencies. 'We have so much local knowledge that they lack. We see them making elementary mistakes just because of that. And we cost far less than their foreign engineers.' Later, while visiting the firm's design office, I saw some large format drawings rolled up on a table and asked if I could inspect some of them. One of the drawings was marked up for a drafter to make changes. I asked about the reasons for the changes. The principal asked one of the drafters to find the documentation detailing the changes. 'Ah sir, only Mohamed would know that, and he is on leave today (author's field notes).

Instead of a formalised system allowing engineers to retrieve information detailing change proposals and approvals, even this large firm had to rely on informal knowledge among its staff instead. Withholding information can also be an apparently rational strategy for workers concerned for their job security or status. We have also seen this phenomenon among maintenance workers in Australia who are reluctant to provide more than the minimum information when interacting with information systems to enter completion reports on their work orders (Gouws, 2014).

Another South Asian engineer at a major process plant explained that there were no formal procedures other than for purchasing: 'I don't have fixed procedures ... each person in this position will institute different procedures to suit himself ... (he) will design the procedures to suit the requirements as he sees fit' (interview with author)

The lack of formality and reliance on memory was also apparent in inventory management practices. At smaller South Asian engineering enterprises, different steel materials awaiting machining lie on the ground with no identification marks. At a major export-competitive factory, inventory management relied on pencilled notes marked on paper records. Unmarked boxes of components were scattered seemingly randomly, awaiting attention from the storeman to be placed in their correct locations. On the factory floor:

> The floor has large potholes and makes it hard to manoeuvre materials handling equipment. It is difficult to read documents and product labels due to inadequate lighting. Inventory is exposed to dirt, water damage, and theft. There is poor housekeeping, often allowing parts to be placed anywhere on the floor, under tables, and behind machinery, making it difficult to

> determine what is supposed to be there and what has been mistakenly placed there (lost). (Domal, 2010, p. 84)

As in the case of the consultancy, critical information relied on fallible human memory. Hourly rates charged to clients for engineers' services, like salaries, reflect value generation. Strong evidence emerged from interviews across firms and countries that formalised information sharing systems and procedures were associated with firms that charged clients significantly higher rates for their engineers. At the same time, especially among younger engineers in Australia, considerable resistance and resentment of these systems was apparent. As one young engineer remarked, cynically: 'Welcome to the firm of 10,000 standard procedures!' (interview with author).

Respect for authority

In South Asia, status is largely ascribed rather than earned through achievement (Trompenaars & Hampden-Turner, 2021), in contrast to a country like Australia, where status arises more from known achievements. Age, seniority, the family name and connections made known during informal conversation, the tone of voice, the use of language, clothing, and even pale skin colour can all convey status and authority, in addition to one's formal position within the firm's hierarchy. Many decades after the end of British colonial rule, white people are still accorded higher respect than locals and are assumed, often incorrectly, to be more honest.

Addressing 'seniors' by their first name is unusual in South Asia, as is speaking out of turn or even at all without being prompted. One avoids raising an issue or asking questions that might expose weakness in one's seniors' thinking or that might conflict with their espoused position. It can be awkward to ask clarifying questions that might expose gaps in one's own listening, memory or comprehension[4] because that might imply failure on the part of one's senior to provide a full and complete explanation. It makes it difficult and possibly risky for subordinates to raise performance difficulties resulting from seniors' earlier directions (Domal, 2010).

However, informal technical coordination activity that underpins the social network enacting distributed expertise in an engineering enterprise relies on being able to work outside

[4] Comprehension gaps arise frequently because of language issues as explained earlier.

lines of authority, whether formal or by attribution (Trevelyan, 2010b), as a construction engineer explained:

> Now, of course officially, there is a line of authority. The engineer can take work to his head engineer who can pass the work to the head draftsman who can direct the drafties what to do. But you don't want to rely on that because it involves too many people and it's too slow. It's quite unwieldy and that's why horizontal interactions are essential. (Trevelyan, 2007, p. 194)

This can be much more difficult in South Asia, as noted by Domal, where authority demands respect. For example, even a minor maintenance problem may require formal approval by a manager to issue spare parts. (Domal, 2010).

South Asian engineers have to work within narrow limits of authority set by their managers and supervisors. Here a senior engineer describes how this limits opportunities for delegation:

> We started a new idea in our assembly plant called a cellular manufacturing system. We organised small cells and the participants were from all levels of the company including executives from different departments like maintenance. [And did it work out?] No, it didn't last long. [Why not?] Because I would say that here the culture is such that people do not like change so they were not receptive to it, and secondly not all departments were involved in it that you needed to execute a job. For example, if there was a problem and the maintenance department had to fix it they would say, 'Okay we have indented the parts and when we get them you would have the thing fixed.' Of course, the indent would have to be processed through the administration department and they would take their own time. Of course, if the cell had been given both responsibility and authority, it would have worked but the authority was not given to them, only the responsibility. That's why it did not work (interview by author).

Informal authority in wealthier countries such as Australia relies more on a visible commitment to general organisational goals (Zussman, 1985), so it is possible for engineers to exert influence informally, outside lines of formal authority, as this engineer explained.

> Now if you work through the traditional lines of authority it's going to take too much time and may even get forgotten. To do this effectively the subcontractor engineer has to develop a relationship with the client engineer and create an understanding in the client engineer that if he signs off on something that turns out to be incorrect then the problem is going to come back to bite him in the end. This kind of situation illustrates why an engineer spends a lot of his time managing up, managing sideways and managing down all at the same time … you need lots of subtle negotiation. Resorting to authority is a total waste of time as it only creates resistance and the lines of authority may not even exist (interview by author).

Within certain limits, and with significant effort, it is possible to change this cultural practice in a South Asian enterprise, as this expert engineer explained:

> It is a one-person company – Ashitosh, he is the expert on everything, even in areas he hasn't a clue about. That in itself is very self-restricting.… You have to provide an enabling environment for people to grow.… You can't have an island of excellence in a sea of mediocrity, you just can't. You know the guys who have gone out from my department, even to marketing, they are doing very, very well. They are the only guys who can stand up to Ashitosh and say, 'No sir, we are going to do it this way, not the way you are saying.' And they can say that. That in itself is an achievement. I'm the only guy here in this firm who calls the chief executive by his first name. Everyone else calls him 'Sir' or 'Sahib' *(interview by author)*.

This engineer, over time, had cultivated a different culture within his product development group, one that encouraged subordinates to ask questions, to raise their own ideas and to subject accepted ideas to analysis and testing by experiments. In making these changes in cultural practices, along with other practices such as inculcating an awareness of the economic implications of engineering work, this engineer had enabled such significant value generation that his firm could compete with imported products (Trevelyan, 2022). Over three decades, this engineer had learned how to create a productive engineering enterprise within the firm. Along with other expert engineers with similar achievements, this shows that it is possible to overcome environmental factors in South Asia, though not without significant effort.

Exposure to sales engineers

Sales engineers perform an influential role in countries like Australia by providing workplace education for engineers about new products, technologies and services that can increase the performance of firms.

Specialist suppliers of engineering products and services, firms that almost always sell their products to other engineers, employ sales engineers to perform marketing functions for the firm. A sales engineer identifies a potential customer and interprets the customer's needs in terms of technical solutions enabled by the specialised products and services offered by the firm. The sales engineer may perform significant technical analysis, create designs incorporating the firm's products, and promote this work in terms of a value proposition for the customer. For example, a firm selling precision linear bearings and servo motors may create a design for a precision positioning table for a firm employing engineers who have limited experience of their own with this technology. The sales engineer anticipates (or hopes) that the customer engineer will be able to persuade his enterprise to issue a purchase order for specialised products supplied by his firm. A sales engineer knows that a significant part of the work is to educate customer engineers about the capabilities of the products supplied by their firm, and also to build a relationship that will persist over time. Sales engineers also participate in trade shows to extend their networks of potential customers (Darr, 2000, 2002).

Engineers in South Asia have less exposure to sales engineers and the education they provide, partly because the specialist engineering supply firms perceive fewer business opportunities, and partly because of the immense number of engineering enterprises in the major South Asian countries. Another factor deterring many specialised suppliers is the tendency of purchasing departments in South Asian firms to prioritise price in their purchase decisions. It takes special knowledge and experience developed by a very small number of engineers to overcome this tendency, as explained earlier in this paper.

Conclusions

The paper presents evidence that there are significant differences between engineering practices in South Asia and Australia. Very little research has been conducted in other countries in the Global South: the evidence we have suggests similar differences. Naturally, there are large practice difference between different firms and government engineering enterprises as well: this paper focuses attention on similar practices observed in several different enterprises. This result raises questions about the validity of an implicit assumption in instruments, such as the Washington Accord, that professional engineering practices are similar worldwide and there is no need to address significant regional variations.

The paper identifies engineering salaries (across a broad range of disciplines) and the cost of engineered goods of equivalent design, performance, quality, reliability and durability as two potentially objective measures of engineering performances. Compared with Australia, South Asian salaries are much lower and the costs of most engineered goods are significantly higher, with some notable exceptions.

Evidence presented in this paper helps to explain the reasons for these differences. There are environmental factors that cannot be changed such as geography, climate, economic environment, labour market, levels of trust in strangers, languages spoken by engineers and others, availability of social welfare, governance and legal systems, access to education, and literacy. There are also factors that can be changed, such as practices showing respect for authority, access to education resources on products and services provided by specialist suppliers, organisational procedures, and financial awareness, particularly of indirect labour costs and machinery downtime opportunity costs.

Limitations

Given the limitations of a journal paper, it is not possible to describe all the factors observed: the paper focuses on factors that seemed more significant. For example, the lack of reliable materials testing laboratories in many parts of South Asia also imposes significant limitations on engineering performances. There were insufficient female participants to draw any findings related to gender. While there may be some similarities in other countries in the Global South, further research is needed before the results can be confidently generalised beyond South Asia. Also, given large variations in practices between different firms and enterprises, it would be unwise to generalise the findings across all enterprises in a particular country or region.

Suggestions for engineering educators

Each of the factors influencing engineering practices described in the preceding sections points to spaces that are seldom addressed in professional engineering education, if at all. Nevertheless, if we are to give our students (and their parents) the best chance to fulfil their dreams to become successful professional engineers in their home countries, education programmes must prepare them to become competent novices in local engineering enterprises.

As explained earlier, research points to socio-technical interactions with other people as being the most critical location-dependent aspects of engineering practice. However, even a casual examination of a typical engineering undergraduate curriculum will reveal hardly any formal instruction devoted to socio-technical aspects of engineering practice. Even courses such as 'project management' usually focus on documents and planning methods and avoid scholarly discussions on human behaviour.

However, education, particularly in engineering, results from socio-technical interactions between faculty, teachers, students, families and part-time employers. Once education is seen as a site where socio-technical interactions between people form the dominant activity, it enables faculty to draw students' attention to the significance of socio-technical interactions in engineering practice and the cultural factors that shape those interactions. Educating professional engineers to be effective teachers could help improve practice because a major part of engineers' daily interactions with others is remarkably similar to collaborative learning in classrooms (Jonassen et al., 2006; Trevelyan, 2010b). With appropriate knowledge of the socio-technical contexts in which engineering is practised locally, faculty can provide students with contextual knowledge so students can learn how universally applicable technical knowledge is actually used in practice. While it is preferable for faculty to have first-hand exposure to practice to acquire contextual knowledge, another way to do this is to arrange for students to observe engineers nearby and write about their observations (e.g., Anderson et al., 2010).

There are several measures that faculty could implement without significant curriculum changes.

1. Perhaps the most important research finding is that engineers in South Asia who learn to generate sufficient commercial value can (eventually) earn salaries least as high as engineers would earn in Australia. Faculty can explain to students that there is no need to migrate to a wealthy country to gain a high salary and income security. However, graduates will need to learn how to work with local people to deliver results in line with expectations.
2. Students who learn that socio-technical interactions will take most of their time will be less likely to experience a mismatch between expectations and the reality of engineering work as engineers. Students can also learn that these interactions are important for their own success. Trevelyan (2020) provides guidance to help students rapidly acquire socio-technical workplace skills.
3. Collaborative learning methods are not only among the most effective classroom techniques, but can also provide a setting in which students can appreciate the significance of socio-technical interactions (Smith, Stirling & Berkhout, 2005). Solitary technical work drawing on knowledge learned in engineering school may comprise a tiny part of engineering practice, and hands-on work even less.
4. A definition that links engineering with productivity can help students understand the economic and social benefits from engineering activities:

> Engineers are people with specialised technical knowledge who conceive, deliver, operate and sustain artificial objects, systems and processes that enable other people to do more with less effort, time, materials, energy, uncertainty, health risk, and environmental disturbances. (Trevelyan, 2020)

5. Faculty can explain some of the environmental factors listed in this paper that influence productivity and engineering practices. Many people in low-income countries imagine that their countries remain poor because of corruption by elites and economic

mismanagement by incompetent rulers. However, as explained in this paper, there are several other factors that impede economic development. Among these are the factors that make it harder for engineers to provide similar outcomes as in Australia.

6. Faculty can help students understand how social-cultural factors such as trust, the need to maintain support networks, and respect for seniors influence the ways that people interact with each other, and how this can influence technical decision-making. For example, a classroom discussion on how to work with a professor who has made a significant mistake in his technical analysis might be helpful for students to appreciate the influence of the social hierarchy.
7. Faculty can help students learn that, as a result of these factors influencing engineering practice, the cost of engineering activity in the Global South is often higher than in countries like Australia, for similar product design, performance, quality, reliability and durability. This will seem counter-intuitive for many, even most faculty. Data on the cost of safe drinking water provided in this paper, easily verified, can help students understand this. The higher costs result from lower productivity. This is also an opportunity: engineers who can reduce costs to levels comparable with wealthy countries will be well rewarded by their firms.
8. Faculty can help students understand the significance of indirect labour costs such as supervision.
9. As noted above, faculty can encourage students to observe practising engineers and interview them to observe socio-technical interactions in practice (e.g., Anderson et al., 2010).
10. Faculty can encourage students to participate in extracurricular activities, particularly part-time work, and reflect on the social interactions that they experience to help them become more observant of human behaviour. Students working as volunteers can learn collaboration and coordination techniques that they will apply in engineering workplaces. Service learning has been shown to facilitate student learning in the USA and has now begun to be implemented in some Indian engineering schools (Dustker, Bandi & Oakes, 2021).

One cannot be sure that improving engineering education will influence what happens in engineering workplaces where organisational culture can overwhelm earlier behavioural influences (Buch, 2016). However, the observations and suggestions in this paper may help engineering faculty staff in the Global South to help prepare a greater proportion of their students for competent practice as engineering novices in local workplaces in their own countries, and not just in Australia, the USA and other wealthy countries.

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References

Anderson, K. J. B., Courter, S. S., McGlamery, T., Nathans-Kelly, T. M., & Nicometo, C. G. (2010). Understanding engineering work and identity: a cross-case analysis of engineers within six firms. *Engineering Studies*, *2*(3), 153–174. https://doi.org/10.1080/19378629.2010.519772

Asplund, F., & Flening, E. (2021). Boundary spanning at work placements: Challenges to overcome, and ways to learn in preparation for early career engineering. *European Journal of Engineering Education*, *47*(1), 50–69. https://doi.org/10.1080/03043797.2021.1889467

Bailyn, L., & Lynch, J. T. (1983). Engineering as a life-long career: Its meaning, its satisfactions, its difficulties. *Journal of Occupational Behaviour*, *4*(4), 263–283.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal contamination of drinking-water in low-and middle-income countries: A systematic review and meta-analysis. *PLoS Medicine*, *11*(5), e1001644. https://doi.org/10.1371/journal.pmed.1001644

Balliet, D., & Van Lange, P. A. M. (2013). Trust, punishment, and cooperation across 18 societies: A meta-analysis. *Perspectives on Psychological Science*, *8*(4), 363–379. https://doi.org/10.1177/1745691613488533

Barley, S. R. (2005). What we know (and mostly don't know) about technical work. In S. Ackroyd, R. Batt, P. Thompson, & P. S. Tolbert (Eds.), *The Oxford handbook of work and organization* (pp. 376–403). Oxford University Press.

Blandin, B. (2012). The competence of an engineer and how it is built through an apprenticeship program: a tentative model. *International Journal of Engineering Education*, *28*(1), 57–71.

Bloomberg. (2021, February, 04). How Chennai, one of the world's wettest major cities, ran out of water. *The Economic Times*. https://economictimes.indiatimes.com/news/politics-and-nation/how-chennai-one-of-the-worlds-wettest-major-cities-ran-out-of-water/articleshow/80680182.cms

Bucciarelli, L. L. (1994). *Designing engineers*. MIT Press.

Buch, A. (2016). Ideas of holistic engineering meet engineering work practices. *Engineering Studies*, *8*(2), 140–161.

Cameron, I., Reidsema, C., & Hadgraft, R. G. (2011, December 5–7). *Australian engineering academe: A snapshot of demographics and attitudes* [Conference presentation]. Australasian Conference on Engineering Education, Fremantle, Western Australia.

Charmaz, K. (2014). *Constructing grounded theory* (2nd ed.). Sage.

Chatman, J. A., & O'Reilly, C. A. (2016). Paradigm lost: Reinvigorating the study of organizational culture. *Research in Organizational Behavior*, *36*, 199–224. https://doi.org/https://doi.org/10.1016/j.riob.2016.11.004

Coelho, K. (2004). *Of engineers, rationalities and rule: an ethnography of neoliberal reform in and urban water utility in South India* [Unpublished doctoral dissertation]. University of Arizona. http://hdl.handle.net/10150/280681

Coelho, K. (2006). Leaky sovereignties and engineered (dis)order in an urban water system. In M. Narula, S. Sengupta, R. Sundaram, A. Sharan, J. Bagchi, & G. Lovink (Eds.), *Sarai Reader 06: Turbulence* (pp. 497-509). Centre for the Study of Developing Societies.

Coso Strong, A., Stockman, T., Heale, T., Meyer, S., & Meyerson, E. (2022). Persuasive communication practices of engineers in cross-boundary decision-making. *Engineering Studies*, *14*(3), 216–238. https://doi.org/10.1080/19378629.2022.2144738

Cumming, O., & Cairncross, S. (2016). Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & Child Nutrition*, *12*(S1), 91–105.

Darr, A. (2000). Technical labour in an engineering boutique: Interpretive frameworks of sales and R&D engineers. *Work, Employment and Society*, *14*(2), 205–222.

Darr, A. (2002). The technization of sales work: An ethnographic study in the US electronics industry. *Work, Employment and Society*, *16*(1), 47–65.

Day, E., Fankhauser, S., Kingsmill, N., Costa, H., & Mavrogianni, A. (2019). Upholding labour productivity under climate change: An assessment of adaptation options. *Climate Policy*, *19*(3), 367-385. https://doi.org/10.1080/14693062.2018.1517640

Domal, V. (2010). *Comparing engineering practice in South Asia and Australia* [Unpublished doctoral dissertation]. University of Western Australia. http://research-repository.uwa.edu.au/files/3224816/Domal_Vinay_2010.pdf

Dustker, S., Bandi, S., & Oakes, W. (2023). Scope of Service-Learning in Accomplishing Objectives of National Education Policy 2020, India – A Conceptual Analysis. *Journal of Engineering Education Transformations*, *36* (Special Issue 2).

Frevert, U. (2009). Does trust have a history? *European University Institute*. https://hdl.handle.net/1814/11258

Friesen, M. R. (2011). Immigrants' integration and career development in the professional engineering workplace in the context of social and cultural capital. *Engineering Studies*, *3*(2), 79–100. https://doi.org/10.1080/19378629.2011.613571

Gouws, L. (2014). *The extent and nature of problems encountered in maintenance: The story behind the text* [Unpublished doctoral dissertation]. University of Western Australia. http://research-repository.uwa.edu.au/files/3407587/Gouws_Leonie_2014.pdf

Hansen, A., & Soebarto, V. (2019, April 7–9). *The epidemiology of health and mortality at extremes* [Conference presentation]. 1st International Conference on Comfort at the Extremes: Energy, Economy and Climate, Heriot Watt University, Dubai.

Hofstede, G. (2011). Dimensionalizing cultures: The Hofstede Model in context. *Online Readings in Psychology and Culture*, *2*(1). https://doi.org/10.9707/2307-0919.1014

Huberman, A. M., & Miles, M. B. (Eds.). (2002). *The qualitative researcher's companion*. Sage Publications.

International Engineering Alliance. (2021). *Graduate attributes and professional competences version 4: 21 June 2021*. World Federation of Engineering Organizations (WFEO). https://www.ieagreements.org/

Jacob, N. (2005). Cross-cultural investigations: emerging concepts. *Journal of Organizational Change Management*, *18*(5), 514–528. https://doi.org/10.1108/09534810510614986

Jesiek, B. (2018). *Research on engineering practice (REP) workshop – Bibliography*. International Network for Engineering Studies (INES). https://inesweb.org/files/REP%20Workshop%20Bibliography%20v2.pdf

Jesiek, B. K., Buswell, N. T., Mazzurco, A., & Zephirin, T. (2019, 10–12 June). *Toward a typology of the sociotechnical in engineering practice* [Conference presentation]. 8th Research in Engineering Education Symposium (REES 2019), Cape Town.

Jesiek, B. K., Buswell, N. T., & Nittala, S. (2021). Performing at the boundaries: Narratives of early career engineering practice. *Engineering Studies*, *13*(2), 86–110. https://doi.org/10.1080/19378629.2021.1959596

Jesiek, B. K., Mazzurco, A., Buswell, N. T., & Thompson, J. D. (2018). Boundary spanning and engineering: A qualitative systematic review. *Journal of Engineering Education*, *107*(3), 380–413. https://doi.org/10.1002/jee.20219

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: lessons for engineering educators. *Journal of Engineering Education*, *95*(2), 139–151.

Kamarck, A. M. (1976). *The tropics and economic development: A provocative inquiry into the poverty of nations*. The Johns Hopkins University Press for the World Bank. https://documents1.worldbank.org/curated/en/775691468780881698/pdf/multi-page.pdf

Kaspura, A. (2019). *The engineering profession: A statistical overview* (14th ed.). Engineers Australia. https://www.engineersaustralia.org.au/publications/engineering-profession-statistical-overview-14th-edition

Khosla, R., Jani, A., & Perera, R. (2021). Health risks of extreme heat [Editorial]. *BMJ*, *375*, n2438. https://doi.org/10.1136/bmj.n2438

Kusimo, A. C., & Sheppard, S. D. (2019, August 18–21). *Manufacturing bowler ability: How resource scarcity hinders team coordination during manufacturing in Nigerian factories* [Conference presentation]. ASME International Design Engineering Technical, Conferences and Computers and Information in Engineering Conference IDETC/CIE2019, Anaheim, California. https://asmedigitalcollection.asme.org/IDETC-CIE/proceedings-pdf/IDETC-CIE2019/59278/V007T06A028/6454036/v007t06a028-detc2019-97820.pdf

Lam, A. (1997). Embedded firms, embedded knowledge: Problems of collaboration and knowledge transfer in global cooperative ventures. *Organization Studies*, *18*(6), 973–996.

Lan, L., Tsuzuki, K., Liu, Y. F., & Lian, Z. W. (2017). Thermal environment and sleep quality: A review. *Energy and Buildings*, *149*, 101–113. https://doi.org/10.1016/j.enbuild.2017.05.043

Latour, B. (2005). *Reassembling the social: An introduction to actor network theory*. Oxford University Press.

Leonardi, P. M., & Bailey, D. E. (2008). Transformational technologies and the creation of new work practices: Making implicit knowledge explicit in task-based offshoring. *MIS Quarterly*, *30*(2), 411–436.

Manyika, J., Woetzel, J., Dobbs, R., Remes, J., Labaye, E., & Jordan, A. (2015). Global growth: Can productivity save the day in an aging world? *McKinsey Global Institute*. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/employment%20and%20growth/can%20long%20term%20global%20growth%20be%20saved/mgi%20global%20growth_executive%20summary_january%202015.pdf

Mason, G. (2000). Production supervisors in Britain, Germany and the United States: Back from the dead again? *Work, Employment and Society*, *14*(4), 625-645.

Matemba, E. E. (2020). *Globalisation of engineers: African professional engineering education perspectives* [Unpublished doctoral dissertation]. Curtin University. http://hdl.handle.net/20.500.11937/82165

Mazzurco, A., Crossin, E., Chandrasekaran, S., Daniel, S., & Sadewo, G. R. P. (2020). Empirical research studies of practicing engineers: A mapping review of journal articles 2000–2018. *European Journal of Engineering Education*, *46*(4), 479–502. https://doi.org/10.1080/03043797.2020.1818693

Mellinger, A. D., Sachs, J. D., & Gallup, J. L. (1999). Climate, water navigability, and economic development. *Working Paper Series 1999.24*. http://nrs.harvard.edu/urn-3:HUL.InstRepos:39403786

Miles, M., & Huberman, A. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage Publications Inc.

Nadeem, S. (2013). Manager-subordinate trust relationships in Pakistan. In P. Cardona & M. J. Morley (Eds.), *Manager-subordinate trust: A global perspective* (pp. 234-253). Routledge.

Nan, W., & Bocong, L. (2018). The entrepreneurs and engineers in China: The situation in the Long 1980s. In S. H. Christensen, B. Delahousse, C. Didier, M. Meganck, & M. Murphy (Eds.), *The engineering-business nexus: Symbiosis, tension, and co-evolution*. Springer Science+Business Media B.V. https://www.researchgate.net/project/Book-project-The-Engineering-Business-Nexus-Symbiosis-Tension-and-Co-Evolution

Patton, M. Q. (1990). *Qualitative evaluation and research* (2nd ed.). Sage.

Perlow, L. A. (1999). The time famine: Towards a sociology of work time. *Administrative Science Quarterly*, *44*(1), 57-81. https://doi.org/10.2307/2667031

Perlow, L. A., & Bailyn, L. (1997). The senseless submergence of difference: Engineers, their work, and their careers. In S. Barley & J. Orr (Eds.), *Between craft and science: Technical work in US settings* (pp. 230-243). Cornell University Press.

Petersen, R. P., & Buch, A. (2016). Making room in engineering design practices. *Engineering Studies*, *8*(2), 93–115. https://doi.org/10.1080/19378629.2016.1200591

Sachs, J. (2005). *The end of poverty*. Penguin.

Senzanje, A. (2003). Problems faced and advances made by agricultural engineers in Southern and Eastern Africa. *Agricultural Engineering International: The CIGR Journal*, *5*. https://hdl.handle.net/1813/10359

Shan, H. (2012). Learning to “fit in”: the emotional work of Chinese immigrants in Canadian engineering workplaces. *Journal of Workplace Learning*, *24*(5), 351-364. https://doi.org/10.1108/13665621211239886

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research policy*, *34*(10), 1491-1510

Strauss, A. (1987). *Qualitative analysis for social scientists*. Cambridge University Press.

Taylor, D. D. J., Slocum, A. H., & Whittle, A. J. (2019). Demand satisfaction as a framework for understanding intermittent water supply systems. *Water Resources Research*, *55*(7), 5217-5237. https://doi.org/10.1029/2018wr024124

Tellis, G. J., Prabhu, J. C., & Chandy, R. K. (2009). Radical innovation across nations: The preeminence of corporate culture. *Journal of Marketing*, *73*(1), 3-23. https://doi.org/https://doi.org/10.1509/jmkg.73.1.3

Tenopir, C., & King, D. W. (2004). *Communication patterns of engineers*. IEEE Press/Wiley & Sons Inc. https://doi.org/10.1007/978-94-010-0397-1_17

Tilak, J. B. G., & Choudhury, P. K. (2021). Employment and employability of engineering graduates in India. *Journal of Contemporary Educational Research*, *5*(3). https://doi.org/10.26689/jcer.v5i3.1825

Trevelyan, J. P. (2007). Technical coordination in engineering practice. *Journal of Engineering Education*, *96*(3), 191–204. https://doi.org/10.1002/j.2168-9830.2007.tb00929.x

Trevelyan, J. P. (2010a). Reconstructing engineering from practice. *Engineering Studies*, *2*(3), 175–195. https://doi.org/10.1080/19378629.2010.520135

Trevelyan, J. P. (2010b, October 27–30). *Engineering students need to learn to teach* [Conference presentation]. 40th ASEE/IEEE Frontiers in Education Conference, Washington, DC.

Trevelyan, J. P. (2013). Observations of South Asian engineering practice. In B. Williams, J. D. Figueiredo, & J. P. Trevelyan (Eds.), *Engineering practice in a global context: Understanding the technical and the social* (pp. 223–244). CRC Press/Balkema. http://dx.doi.org/10.1201/b15792-11

Trevelyan, J. P. (2014). *The making of an expert engineer*. CRC Press/Balkema/Taylor & Francis.

Trevelyan, J. P. (2016). Extending engineering practice research with shared qualitative data. *Advances in Engineering Education*, *5*(2), 1–31. http://advances.asee.org/publication/extending-engineering-practice-research-with-shared-qualitative-data/

Trevelyan, J. P. (2020). *Learning engineering practice*. Taylor & Francis. https://doi.org/https://doi.org/10.1201/b22622

Trevelyan, J. P. (2022). A Social science research agenda for engineering practice. In S. H. Christensen, A. Buch, E. Conlon, C. Didier, C. Mitcham, & M. Murphy (Eds.), *Engineering, social sciences, and the humanities: Have their conversations come of age?* Springer, Cham. https://doi.org/10.1007/978-3-031-11601-8_13

Trevelyan, J. P., & Tilli, S. (2007). Published research on engineering work. *Journal of Professional Issues in Engineering Education and Practice*, *133*(4), 300-307. https://doi.org/10.1061/(ASCE)1052-3928(2007)133:4(300)

Trevelyan, J. P., & Tilli, S. (2008, June 20–22). *Longitudinal study of Australian engineering graduates: Perceptions of working time* [Conference presentation]. American Society for Engineering Education Annual Conference, Pittsburgh.

Trevelyan, J. P., & Tilli, S. (2010, December). *Labour Force Outcomes for Engineering Graduates in Australia*. http://www.tandfonline.com/doi/abs/10.1080/22054952.2010.11464047

Trevelyan, J. P., & Williams, B. (2018). Value creation in the engineering enterprise: An educational perspective. *European Journal of Engineering Education*, *44*(4), 461–483. https://doi.org/10.1080/03043797.2017.1421905

Trompenaars, F., & Hampden-Turner, C. (2021). *Riding the waves of culture: Understanding diversity in global business* (4th ed.). Nicholas Brealey Publishing.

Vinck, D. (Ed.). (2003). *Everyday engineering: An ethnography of design and innovation*. MIT Press.

Vinck, D. (2019). Maintenance and repair work. *Engineering Studies*, *11*(2), 153–167. https://doi.org/10.1080/19378629.2019.1655566

Ward, P. R., Mamerow, L., & Meyer, S. B. (2014). Interpersonal trust across six Asia-Pacific countries: Testing and extending the 'high trust society' and 'low trust society' theory. *PLOS One*, *9*(4). https://doi.org/10.1371/journal.pone.0095555

Waris, M., & Kokab, R. U. (2017). Baradarism and politics of the Sarghoda District. *Pakistan Journal of History and Culture*, *38*(1), 59-81. http://www.nihcr.edu.pk/Latest_English_Journal/pjhc%2038-1,2017/4.%20Baradarism%20and%20Politics,%20Waris%20awan,%20Rizwan.pdf

Williams, B., & Figueiredo, J. (2010, April 14–16). *Engineers and their practice: A case study* [Conference presentation]. IEEE Conference on Education Engineering (EDUCON), Madrid.

Zhu, J., Hu, Y., Li, Y., Zhang, Z., & Li, W. (2021). Perceptions towards prior learning experiences: Lessons learned from early and mid-career professional engineers in a Chinese context. *European Journal of Engineering Education*, *47*(1), 193–209. https://doi.org/10.1080/03043797.2021.1954602

Zhu, J., Hu, Y., Zheng, T., & Li, Y. (2021). Engineering leadership in a Chinese industrial context: An exploration using the four capabilities model. *Journal of Engineering Education*, *110*(3), 765-790. https://doi.org/10.1002/jee.20404

Zhu, J., Wang, S., Zhang, B., & Wang, D. (2021). Adapting to changing labor productivity as a result of intensified heat stress in a changing climate *GeoHealth*, *5*(4), e2020GH000313. https://doi.org/10.1029/2020GH000313

Zussman, R. (1985). *Mechanics of the middle class: Work and politics among American engineers*. University of California Press.

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Employers' perspectives on employability skills and attributes of mining engineering undergraduates in South Africa

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There is an increasing demand for universities to produce work-ready graduates in the mining sector. Universities and industry therefore acknowledge the need to support graduate employability through various strategies that focus on theory-practice integration. Mining engineering undergraduate programmes offered in South Africa furnish students with knowledge and skills that enable them to effectively transition to the workplace. This signifies the valuable employability skills and attributes which are highly sought after in the workplace. This article presents data based on interviews with employers in the mining industry. The paper draws from Kolb's experiential learning theory which provided an analytical lens for the study. The article presents findings on the following themes: development of reflective learning experiences; enhancing workplace experience through work-integrated learning (WIL); development of employability skills; and university and mining company partnerships. In conclusion, this qualitative study on employers' perceptions regarding the attributes of mining engineering undergraduates may play a significant role in understanding the mining sector's contribution to fostering employability among students.

Keywords: competencies; employability skills; attributes; mining engineering; work-integrated learning

Introduction

Education providers, industry and governments have embraced the concept of employability as a solution to labour market changes. Employability is considered a crucial aspect that enables graduates to transition into the workplace. As Clarke (2018) highlights, universities are pressured to equip graduates sufficiently with employability skills to enable them to be marketable. The competitive labour market values graduates possessing relevant work experience. Employability skills and competencies form capital that is necessary for employment prospects (Fajaryati & Akhyar, 2020). Tomlinson and Anderson (2021) assert that human and social capital are significant in understanding and explaining employability outcomes.

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Employers constantly demand skilled graduates capable of meeting the needs of the competitive labour market. Universities are challenged in the sense that employers often require graduates with a comprehensive set of soft skills and attributes (Wald & Harland, 2019). Personal competencies are key to expanding the capabilities of graduates to adapt to workplace complexities. There have been persistent concerns from employers regarding the employability of graduates exiting universities (Fajaryati & Akhyar, 2020; Matsouka & Mihail, 2016). In response, universities continue to engage in initiatives that improve graduate attributes and employability skills and that address policy and market pressures (Healy, 2023), thus becoming responsive to the needs of the employment system (Cai, 2013). Due to the heightened focus on employability and the successful transition of graduates to the labour market, universities play a crucial role in developing work-ready graduates (Orr et al., 2023). Work-ready students possess knowledge, skills and abilities that enable them to transition from university into professional practice or employment (Smith & Worsfold, 2015).

Academics in universities interpret employability skills from a theoretical knowledge perspective while employers are concerned with practical knowledge. Academics at universities of technology are more likely to focus on applied/practical skills, whereas at traditional research universities, they may focus more on theoretical knowledge. Typically, universities of technology focus on vocationally oriented programmes while universities focus on foundational degrees (Griesel & Parker, 2009). Nonetheless, there has been a shift concerning the development of graduate employability, which entails the integration of theory and practice into learning. However, employers in the mining field often provide limited workplace learning opportunities to nurture students' employability while they are still at university.

The paper analyses an empirical case study in a South African context, investigating the perspectives of employers regarding the employability skills of mining engineering undergraduates. The paper first provides an overview of the literature, followed by the theoretical framework, and then the methodological approach adopted for data collection and analysis. An analytical tool to understand and interpret employability skills and graduate attributes in workplace settings is drawn from experiential learning theory (Kolb, 1984). Further, the article presents the findings and subsequently a detailed discussion. The implications of the results on graduate employability and employability policies in the industry are also discussed. Finally, conclusions are drawn from the discussion and areas for further research are suggested.

Context of the research

The South African economy is linked to mining and mineral resources owing to an abundance of mineral wealth (Cameron & Drennan, 2017). Despite recent systemic challenges, the mining sector seems to be robust and remains a leader in wealth and employment creation (Minerals Council South Africa, 2019). Crucially, a free-market economic paradigm influences the expansion of the mining industry. According to Van Der Merwe (2011), the mining sector has contributed immensely to the country's economic and political development.

The mining sector supports the training of students and lecturers in academic and technical institutions. The South African mining industry remains vulnerable to a skills shortage (Musingwini et al., 2013). Consequently, universities continue to produce a skilled workforce for the mining sector, thus contributing to the expansion of the sector. The linkages between mining companies and universities set the ground for the acquisition of knowledge and transferable skills. The curricular focus on mining engineering tends to introduce students to and offers them a firm foundation in key theoretical and practical mining concepts.

Professional bodies contribute significantly to the engineering profession in South Africa (Kloot & Rouvrais, 2017). In this manner, for university qualifications to be recognised, accreditation must be obtained from the Engineering Council of South Africa (ECSA). In addition, practising engineers with relevant qualifications are expected to register as professional engineers and receive a certificate of competency. Van der Merwe (2011) asserts that compulsory professional registration of mining engineers would enforce professional development.

It is worth highlighting that the mining industry essentially supports the development of student employability through work-integrated learning (WIL). Undergraduate students complete a period of vacation work in mining companies doing individual projects as negotiated by students and workplace supervisors. Placement in mining companies enables students to navigate the dynamics associated with theory-practice integration. This link demonstrates that university–industry partnerships contribute to nurturing skills and competencies. Maseko (2018) argues that WIL in mining engineering shapes professional skills for mining engineering undergraduates.

Reviewed literature on approaches to developing student employability

Employability is considered a critical aspect of university teaching and the quality of learning outcomes. Developing employable graduates is viewed as a means whereby universities produce graduates who can navigate the complexities of the contemporary labour market through WIL (Björck, 2021). It is an increasing trend that employers demand graduates possessing skill sets and attitudes relevant to the workplace (Clarke, 2008). As such, the relevance of graduate attributes has been prioritised within employability discourses. Wald and Harland (2019) emphasise that graduate attributes are a dominant feature of university missions and objectives as articulated to various stakeholders.

The current mining workplace demands for work ready graduates

The disruptive impact of technology has adverse implications for the labour market. In light of this, the current labour market constantly requires employable graduates with relevant skills that could enable them to perform jobs effectively. Clarke (2008) argues that it is crucial to align higher education with the necessary work skills required by employers by including graduate attributes in the curriculum. The focus is on developing knowledge, skills and attitudes that contribute to effective performance in the labour market (Römgens et al., 2021). Job-related competencies include a set of personal resources that allow individuals to perform a job while generic competencies extend to transferable job-related competencies required for making job transitions, thus being valuable to employability in terms of obtaining new employment (Peeters et al., 2019). Competence-based approaches to employability involve learning in the workplace (Clarke, 2008).

Graduating with undeveloped employability skills subjects graduates to criticism from potential employers (Cavanagh et al., 2015). Employers often bemoan the graduates' lack of relevant skills required in professional contexts (Sarkar et al., 2021). In light of this, Thebuwana et al. (2016) assert that there is an existing disconnection between university education and its application in the workplace. This could be attributed to the lack of relevant practical experience required by potential employers. Despite the outcry by employers, Clarke (2008) observed that many employers seem reluctant to offer generic skills development.

The significance of WIL in mining engineering programmes

WIL focuses on the integration of practical and theoretical activities aligned with the workplace to enhance graduate employability (Dimenas, 2010). Smith and Worsfold (2015) emphasise that a dialectic involving theory and practice serves as a pedagogical process that facilitates theory-practice integration. The importance of WIL in nurturing employability for the future of work has been demonstrated by various studies (see Jackson & Bridgstock, 2021; Jackson et al., 2022; Palmer et al., 2018; Ramnund-Mansingh & Reddy (2021). These studies reveal that the WIL approach strengthens the development of generic and technical skills required from graduates to enter the labour market (Clarke, 2008; Jackson & Dean, 2022).

A learning environment prioritising graduate employability allows students to develop work-readiness skills from experiential learning activities (Orr et al., 2023). WIL potentially improves employability, thus leading to the development of employable graduates (Palmer et al., 2018). The forms of knowledge to be acquired in learning contexts should be clearly articulated to students as they develop employability skills. Students often learn in contexts that are not related to practice, which ultimately influences how they develop conceptual and practical knowledge. Panther and Montfort (2017) argue that understanding how students categorise knowledge seems to provide insights into their ability to apply it in different contexts, thereby preparing them for engineering practice. Students obtain knowledge from academic subjects and often experience challenges in understanding the relevance of disciplinary knowledge, especially transferring it to the workplace (Winberg et al., 2011).

To date, a commonly explored indicator of employability is discipline-based and professional skill development (Jackson & Bridgstock, 2021). In their study, Sarkar et al. (2020) emphasise the importance of inquiry-based and problem-based learning which allows students to engage in challenging problems that enhance knowledge, skills and competencies desired for the workplace. As such, embedding learning activities is useful for skills development and gaining work experience (Jackson & Bridgstock, 2021). Similarly, Beagon et al. (2019) argue that embedding professional skills into engineering programmes could potentially improve students' technical and non-technical skills. Exposure to authentic work environments to develop knowledge and skills seems to support students' perceived employability (Jackson & Dean, 2022). However, potential host organisations often indicate that workload leads to a shortage of staff to oversee students during work placement. It is also worth noting that the lack of student placement in the industry manifests as a problem for mining engineering (Maseko, 2018).

University industry partnerships in mining engineering

University–industry partnerships form part of the engineering ecosystem in South Africa. Establishing these partnerships significantly contributes to raising awareness and developing employability. The university–industry partnerships create a conducive environment for WIL, which supports reflective learning. Maseko (2018) asserts that effective partnerships are necessary for improving WIL.

Mining engineering programmes have increasingly included courses that support the development of graduate attributes and employability. This approach is central to the practice-based application of knowledge in real work contexts. The emphasis here is on the ability to adapt to complex labour market changes. Wald and Harland (2019) argue that it is essential to prioritise powerful knowledge in the curriculum which adequately structures the knowledge, attributes and skills desired by employers. A study conducted by Ishengoma and Vaaland (2016) shows that effective university–industry linkages involve activities that enhance employability, such as joint student–industry projects, internships, and an active role of industry in curriculum development.

Accreditation of mining engineering programmes by ECSA

The ECSA exit-level outcomes provide standards for shaping graduate attributes and employability. Mining schools across universities have mapped the ECSA exit-level outcomes into the mining engineering curricula to facilitate the acquisition of knowledge and skills (ECSA, 2018). These standards are essential for guiding the assessment process to foster and ensure the acquisition of knowledge and skills. Accreditation legitimises university-housed programmes since it carries the judgement of the external professional body (Klassen & Sá, 2019). The core idea is based on facilitating an effective evaluation and measurement of student learning to improve learning outcomes and enhance graduate employability. ECSA accreditation requirements do not focus only on the curriculum structure, but rather extend to the quality of teaching and learning, and the programme aims and outcomes (Oladirana et al., 2012).

Accreditation enables universities to translate the exit learning outcomes by aligning them with specific modules in a degree programme. The challenge is that ECSA originally required knowledge-based outcomes, and then shifted to graduate attributes as outcomes. However, lecturers are trained to work on theoretical knowledge, but they have limited capacity to develop students with learning experiences required in practical contexts. Above all, accreditation helps to determine the expected levels of proficiency and standards of achievement for each learning outcome (Crawley et al., 2014).

Drawing from the existing literature, evidence confirms the importance of developing skills and attributes for mining engineering undergraduates. WIL enhances employability skills required for the mining field. Wald and Harland (2019) argue that instead of frequently changing education to address contemporary demands, universities should focus on strengthening the quality of foundational knowledge and skills. This article examined the perspectives of employers concerning the desired employability skills and graduate attributes required for mining engineering practice. Employer perceptions are crucial in understanding the transitions from university to the workplace (Cai, 2013).

Theoretical framework

Experiential learning theory, coined by David Kolb, provided an analytical lens for this study. The endorsement of the theory stems from studies that used experiential learning to demonstrate the development of employability in the workplace (Jackson & Dean, 2022; Reid et al., 2021; Villarroel et al., 2020). Experiential learning theory is based on the assumption that the learning that students such as mining engineering undergraduates acquire emerges from directly engaging with the realities of what is being studied (Kolb, 2015). The theory describes learning in a cycle characterised by the following stages: concrete experiences, observation and reflection, formation of abstract concepts and generalisations, and testing the implications of concepts in new situations (Kolb, 1984). Using the cycle to examine ways in which learning emerges from experience reveals that a mining engineering learner engages with an experience, observes and reflects from the experience, utilises analytical skills to integrate concepts and ideas from observations, and then applies the new concepts in practice (Reid et al., 2021).

Kolb's analytic frame identified reflection and experience as key elements of experiential learning theory which provide an account of how students transform experiences to construct new knowledge. The learning cycle is underpinned by an integration of action and reflection as well as experience and concept, suggesting that the reflective process enhances the development of employability skills (Kolb & Kolb, 2017). Within experiential learning theory, attention is given to the logical sequence that experience occurs first, then knowledge is the latter product of experience acted upon by the process of reasoning (Michelson, 1996). Concrete experience enables learners to utilise their experiences by being involved in specific situations, while abstract conceptualisation involves giving meaning to the experience encountered by students.

Transformation of experience occurs through experience involving the practical application of knowledge in the real world, as in mining (Kolb, 1984). Reflective observation entails reflecting on previous stages to consolidate the integration of lessons acquired from all the experiences (Kolb, 2015). These principles are relevant to demonstrate how mining engineering undergraduates learn from their experiences to enhance employability skills. This draws attention to what the employers' perceptions reveal about how the learning process allows students to improve employability skills required by the labour market.

The relevance of experiential learning theory to employability is that it recognises students' reflections on the work experience gained during work placement in mining companies. This theory defines learning as a process of human adaptation involving the whole person in the formal classroom and the workplace (Kolb & Kolb, 2017). In essence, the workplace significantly enables employers to observe learners' acquired knowledge and employability skills developed. Specifically, in this study employers revealed how mining engineering learners reflect on acquired experiences to develop the desired employability skills and attributes relevant to mining engineering. Fenwick (2006) asserts that power relations structure hierarchies of knowledge and skills, thus determining who gets to judge skills such as in the mining workplaces.

This article therefore used experiential learning theory to explain employers' interpretations of how mining engineering learners cultivated their employability skills in the workplace. Specifically, the theory emphasises the transformation of knowledge to form employability skills. Importantly, this signals that employers could interpret the desirable skills possessed by mining undergraduates upon completing work placement. However, an observed limitation of the learning cycle lies in the assumption that it does not depict the socio-emotional aspects that influence student learning in the workplace. Highlighting another limitation of the theory is that in some instances learners would not directly learn from direct experience but rather from the experience of other people within their context (Vince, 1998).

Methods

This article explored employers' perceptions regarding key factors that are necessary for preparing aspiring mining engineers to be prepared for the workplace. It sought to understand the level of competencies of mining engineering undergraduates by reflecting on the perspectives of mining engineers and workplace supervisors. Fundamental questions guiding the study were: (1) what are the perceptions/perspectives of employers regarding the employability skills of mining engineering undergraduates? (2) To what extent do mining engineering undergraduates develop employability skills in the workplace?

The article reports on empirical research conducted from June 2018 – April 2019 as part of a PhD project. This research employed a qualitative case study which included semi-structured interviews. Approval to conduct the study was gained from the University of the Western Cape Humanities and Social Science Research Ethics Committee (Ethics Reference Number: HS18/2/7) before commencing with data collection. Data was generated through semi-structured interviews conducted in three selected mining companies located in the Gauteng Province in South Africa. The selected five mining engineers and five workplace supervisors from the respective mining companies participated in this study. Purposive sampling aided in selecting the participants. The article draws on the responses from the ten participants who consented to participate in the study. The participants were selected based on their position and substantive responsibility of supporting students during work placement. In addition, the mining engineers were ECSA-registered. In mining companies, students are governed by workplace learning policies developed by the human resource office.

The interviews were considered appropriate for this study since they allowed the participants to voice in-depth insights concerning the employability of mining engineering undergraduates. The interview questions were developed using insights drawn from the literature. The interviews generated rich insights and allowed the interviewer to probe and seek clarity whenever ambiguities emerged. Although there were variations noted across the mining companies, enough uniformity allowed data coding and analysis. The data were transcribed, anonymised, coded and analysed using ATLAS.ti data analysis software. The thematic categories captured the meaning from interviews and supported data to be presented according to the emerging themes and patterns (Braun & Clarke, 2006). The empirical data aided in understanding and interpreting the perceptions of employers regarding the employability skills of mining engineering undergraduates.

Analysing the results based on Kolb's Model

The qualitative data obtained from the interviews was coded and the analysis revealed the following themes: enhancing workplace experience through WIL, development of reflective learning experiences, development of employability skills, and university and mining company partnerships. Through the cycle of Kolb's model, employers revealed their perceptions and how the workplace fosters employability learning. The results are therefore presented in the light of how they relate to the four-stage cycle of experiential learning.

Concrete experience

Enhanced workplace skills and applied knowledge is used as an indicator of analysed concrete experience. Kolb indicates that knowledge develops from testing out the experiences of learners. The participants' perceptions are anchored on the basis that WIL is essential for developing work experience through work placement which is concrete. They hold the view that an institutionally endorsed WIL programme is ideally tailored to strengthen direct practical experience through engaging in new tasks. The participants emphasised the need to engage students in a process that best enhanced their acquisition of practical experience. The findings suggest that continuity of experiences occurs across different learning contexts whereby students actively experiment with concepts. On this basis, mining engineers and workplace supervisors appear to link theoretical knowledge to its application in practical settings. A key aspect of practical experience lies in fostering the process of reflective observation. This signals a commitment to problem-solving in mining companies, thus effectively transforming the acquired experience. Essentially, students reflect on the hands-on activities undertaken during placement in mining companies. Participant ZK3 expressed the following: 'Practical experience gives the student's knowledge of how the work environment functions so that they can know what to expect in mining contexts.'

The mining engineers reported that WIL focuses on developing competence, employability, and knowledge acquisition, thus fostering experience. The participants revealed that the work environment is a learning space that allows students to develop a clearer picture of mining operations in mining contexts. A common view amongst the participants was that placement of students in mines strengthens their ability to understand how to apply theory in the work environment. As one interviewee (participant LKC 9) said: 'Students come to the mine to learn about the sections in the mine and they understand what they have learnt from school. They are oriented by the shift sections and shift miners who supervise them.'

Abstract conceptualisation

The development of an employability skill set is used as an indicator for analysing abstract conceptualisation. Abstract conceptualisation is concerned with thinking, reflecting and acting on intellectual knowledge derived from concepts and theories. The participants echoed that through ECSA exit learning outcomes, the abstract concepts are embedded into the curriculum to strengthen the relevant standards that address the educational requirements of a mining engineering role. ECSA learning outcomes emphasise the abstract conception of subject matter content. It is worth noting that interviewees stated that the development of an employability skill set and competencies for mining engineering undergraduates is necessary for improving employability as per the curricula outcomes. Generic and technical skills are regarded as crucial in the learning process of mining engineering students, as well as a means of promoting the real-world connection between learning and the application of content. In this case, generic skills refer to skills that have potentially broad applications to a range of disciplines and situations (Freudenberg et al., 2011). Job-specific skills were referred to as technical skills. Both the mining engineers and workplace supervisors reported that learners develop employability skills through forming and re-forming experience. The table below shows the employability skills that were identified by employers in this study.

Table 1: *Employability skills identified by employers*

Response theme for sub-categories	Skills coded from the employers' responses
Generic skills	People skills & communication Leadership & teamwork Problem solving & adaptability Accountability Honesty and integrity Emotional intelligence & resilient thinking
Technical skills	Project management & financial planning Mine planning & production

Table 1 (Cont.): *Employability skills identified by employers*

	Engineering management & business acumen
	Surveying & geotechnical skills
	Computer literacy
	Compliance with regulations/legislation

It is worth noting that the identified employability skills were evident in the responses given by both mining engineers and workplace supervisors. This implies that employers regard them as the most desirable competencies required for the mining engineering profession.

Reflective observation

The reflective observation stage was analysed using an indicator focusing on developing a reflective learning experience. This stage involves observing and reflecting on experiences in contextualised settings, thus allowing deep learning and retention of information. The participants noted that students developed their competencies through developing a firm understanding of practical strategies that enabled them to navigate the work environment which ultimately resulted in the acquisition of experience. Mining engineers and workplace supervisors reported that involving students in mining systems and structures contributed to developing their organisational acumen, based on their learning to adapt to the workplace. In this case, students reflected on their acquired knowledge from various perspectives, thus forming new experiences. All the employers mentioned that within the mining companies, students developed work competence, thus improving skills that enabled them to remain productive when performing mining engineering-related tasks. For instance, Participant ZK4 explained that: ‘Work competence allows students to demonstrate the application of basic knowledge in the workspace.’

The participants mentioned that reflective activities enabled students to understand social and human dynamics leading to new learning experiences in workplace settings. This indicates that social and emotional intelligence is a necessity in mining contexts, given the frequent student–employer interactions designed to foster a higher level of reflection. Some participants argued that academic and workplace contexts constitute distinctive activities and this often poses adaptation challenges to students during their transition to the workplace.

Active experimentation

Mining sites provide a context for constructing new knowledge through experimentation, thus contributing to improving competencies for mining engineering learners. The findings revealed an agreement between mining engineers and workplace supervisors concerning the significance of university–industry partnerships. The participants reported that the university and mining partnerships focused on providing workplace learning and experiential learning opportunities.

The participants echoed that the collaboration between mining schools and companies provided formalised internships, an environment which is necessary for nurturing employability. It was reported that during the work placement period that occurs in the third year, students are assigned an engineering project. This form of the student–industry project facilitates experiential learning, thus leading to knowledge retention in the workplace.

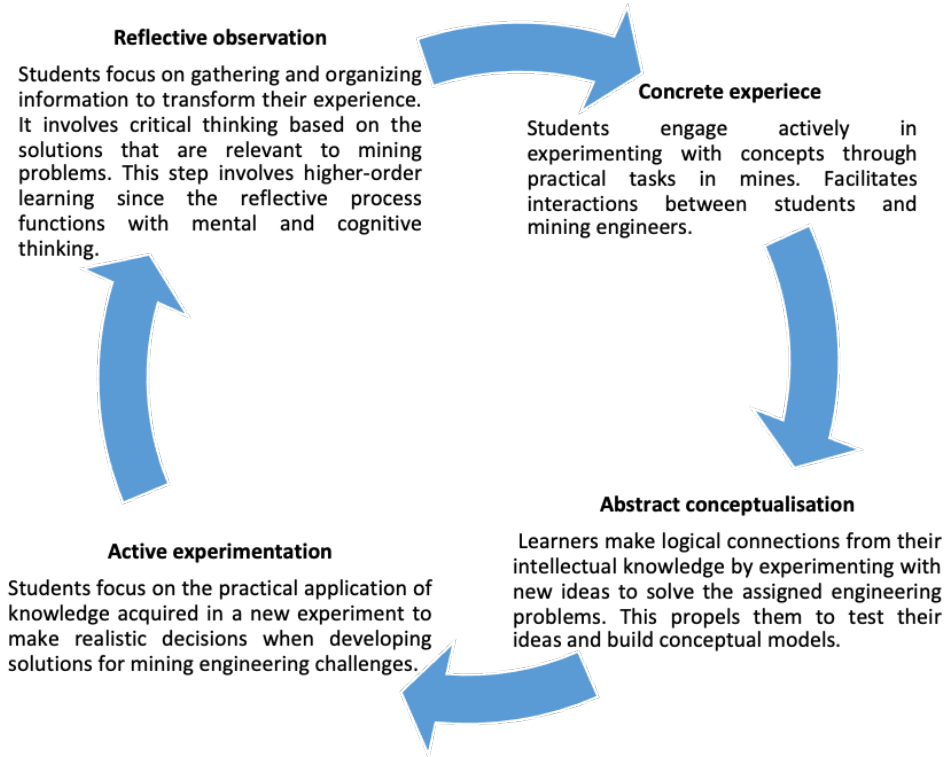

Figure 1: *Experiential learning cycle demonstrating formation of experience*

The phases of the experiential learning theory described above suggest that new knowledge and skills emerge from grasping and transforming experience. The figure above demonstrates how mining engineering undergraduates develop knowledge and experience during the workplace learning period. Each step is not a discrete event leading to the other; rather a student might move through and between the stages.

Returning to the theme of active experimentation, the participants stated that mining engineering professionals are often invited to offer guest lectures to contribute to sustaining these collaborations. The participants reported that these partnerships are essential for influencing knowledge incorporated into the mining engineering curriculum. The findings reflect a mutual understanding between universities and mining companies, regardless of their differences in organisational mandates as well as approaches to learning. This suggests that engaging in a variety of activities would be useful for developing graduate attributes required in mining engineering.

Discussion

The findings indicated that the ECSA exit level outcomes play a pivotal role in the development of student employability as well as graduate attributes. The standardised exit-level outcomes essentially guide universities to develop courses incorporating knowledge required in the mining field. Translating knowledge and skills into learning outcomes and facilitating the attainment of expected proficiencies require customisation at the curriculum design phase (Crawley et al., 2014). The employers were inclined to perceive the ECSA guidelines (ECSA, 2014) as useful in providing a substantive role in developing the employability skills of future mining engineers. To this end, the findings show that the inclusion of the ECSA exit-level outcomes strengthens the development of employability skills and subject-related competencies.

The findings illustrate that the mining engineers and workplace supervisors regard WIL as crucial in developing the employability of mining engineering students. The analysis demonstrates that employers recognise the importance of work exposure offered to mine engineering students. Through the lens of experiential learning theory, mining engineering undergraduates learn from active engagements and practical activities which facilitate the application of theoretical knowledge and reflection on experiences to inform future learning (Kolb, 1984). The findings suggest that mining engineering learners who undergo WIL placement are highly likely to improve their employability skills by being at the centre of the experiential context. This suggests the perspectives of mining engineers and workplace supervisors strongly endorse the value placed on practical knowledge in strengthening mining-related skills for learners.

Experiential learning manifests itself in the aspects of WIL. One is the focus on reflection which is perceived to be paramount in assisting students to develop relevant experiences. Aligned with the reflective practice of experiential learning, students develop abstract concepts while in the classroom; upon reaching the mining field they observe and reflect in order to cultivate concrete experiences from specific mining engineering situations. Kolb (1984) argues that knowledge is tested on the experiences of the learner by transforming experiences into action. This approach promotes student-centred learning, thus empowering students to think critically while engaged practically by solving mining engineering problems. This finding supports a previous study by Garwe (2020) which established that performance character leverages job knowledge, hands-on skills, practical orientation and work-related competencies.

Another aspect of experiential learning is work experience. Work experience encompasses essential skills such as creativity, problem-solving, decision making and flexibility. The data illustrates that adaptation to the workplace allows mining engineering students to accumulate work experience by thinking about it as well as acting and reflecting (Kolb, 1984). The reflective exercise between students and their workplace supervisors, emerging from debriefing sessions, allows them to be mindful of their improvement. Purposeful reflection processes support students in learning from experiences that facilitate employability development in varied workplace contexts (Reid et al., 2021). Predominantly, learning occurs from directly applying knowledge to solve complex engineering problems. Experiential learning empowers learners to adapt to the physical environment (Kolb, 1984). In this case, mining engineering learners adapt to functioning in a practical mining context. Consequently, these processes shape their professional expertise due to interaction with mining specialists. The capacity of students to acquire relevant work experience therefore rests on their ability to develop employability skills and strengthen their desirability in the mining engineering field.

The findings suggest that through collaboration, experienced mining engineers mentor and guide students during work placement as well as encourage reflection. This process exposes students to industry-focused learning which enhances their employability skills, since they learn by doing. The findings are consistent with Martin et al. (2019), who found that supervising can take the form of mentoring. In this case, the students are allocated mentors to support them in learning how to navigate the mining field; however in contexts where engineers have extreme workloads, dedicating time to advise students remains a challenge. This obstacle deters mining engineering learners from securing an opportunity to learn from experts on how to contextualise engineering knowledge in the workplace. Leveraging university–industry partnerships, however, reflects the strategic intent to enhance employability skills.

The employers reported that students possessed the necessary employability skills but still need to strengthen their practical skills as expected in their respective workplaces. The identified generic and technical skills are developed from the critically reflective process of experiential learning. The nature of these employability skills suggests that experiential learning is a valuable tool that allows mining engineering students to contextualise their knowledge in practical settings, signalling reflective observation. The employer's perceptions indicate that generic skills are integral to disciplinary knowledge infusing and enabling academic knowledge and learning (Crawley et al., 2014). The findings are consistent with those of Fajaryati and Akhyar (2020), who assert that according to the employers' demands, communication, teamwork, problem-solving and technical skills are required to enhance employee productivity in the workplace.

The results show that employers value and acknowledge that transferable skills are necessary for facilitating a seamless transition into the workplace. The emphasis is placed on the ability to develop concrete experiences to enhance work readiness. Mining engineering learners need a diverse set of knowledge and skills that enables them to process information which is necessary for solving complex problems that they will encounter in the workplace (Haupt & Webber-Youngman, 2018). These results matched those observed by Jackson et al. (2022), which affirm that critical thinking, fostering innovative behaviour, building confidence, and communication skills are necessary for preparing learners for future work. In this manner, students interact with disciplinary knowledge through the application, changing and translating knowledge and in turn shaping their experiences (Crawley et al., 2014). These findings are consistent with Behle's (2021) argument that subject-related skills and competencies are an important outcome and require clear pathways for transferability to the labour market. The findings reveal that industry-wide skills and professional skills are developed through engaging in both theoretical and practical knowledge, which signals the application of concrete experiences as noted by Kolb.

Drawing from the analysis above, employers acknowledge that fostering collaborations with mining companies contributes to the co-development of employability skills both in the classroom and the workplace. Course advisory panels allow mining industry representatives to contribute to programme development, thus legitimising the activities undertaken in a mining engineering programme (Kullberg & Paulin, 2019). These results match those observed in a study by Kvilhaugsvik (2022) which confirms that advisory board panels can be understood as layers of established cooperation with the world of work. These findings agree with the results of Sambell et al. (2020), Ramnund-Mansingh and Reddy (2021) and Cai (2013), who found that purposeful industry engagement builds impactful partnerships that cement the design of consistent graduate attributes and relevant employability skills. A study by Ishengoma and Vaaland (2016) on activities within university–industry linkages concluded that internships and joint student industry projects enhance students' employability. Universities should form close interactions with employers and participate in diverse employer networks (Cai, 2013).

Experiential learning has been shown as a powerful activity that influences the development of employability skills for mining engineering undergraduates. The employers view WIL as an effective strategy to enhance employability skills for mining engineering undergraduates. Evidence suggests that forming stronger relationships between mining companies, universities and professional associations could potentially nurture students' competencies. Ultimately the acquired knowledge and skills are translated into employability, thus fitting the needs of employers in mining engineering. The employers' perceptions noted in this study shed light on understanding how mining engineering could be supported to develop employability skills in the workplace. Clarke (2008) argues that promoting individual employability proves to be a powerful tool for creating sustainable competitive advantage in the labour market.

Practical implications of the study

The engineering field is constantly in need of contemporary skills, thus understanding employers' perceptions seems to be useful both at a theoretical and practical level. This study has significant implications for mining schools to strengthen the initiatives that support the enhancement of employability skills and graduate attributes. The study highlights employers' views that the employability skills of mining engineering undergraduates are linked to skills development in engineering. This finding raises awareness of the importance of creating a conducive environment that promotes university–mining industry collaboration. Focusing on university–industry linkages would contribute to building knowledge on how the mining schools can align their programmes with the labour market needs. Employers' critical perspectives contribute to curriculum review and course redesign, which links to the development of employable graduates. This could be achieved by integrating employability skills into the curriculum. Hence, this reflects the notion of undergraduate teaching as a component of the engineering ecosystem.

Limitations and suggestions for future research

The limitations of this study are evident in the limited sample size, given that only ten employers were interviewed. The extent to which these participants represent mining employers might be limited. Further studies could increase interview participants across the mining industry. Employers are often not trained in how to assist students to translate knowledge to the workplace, and this challenges skills transfer. A further study with a focus on empowering employers to facilitate skills transfer for learners is suggested. It would also be useful for future research to examine the perspectives of mining engineering learners and investigate how they maximise their learning experiences to strengthen their competencies during work placement.

Conclusion

The findings showed that the competitive labour market requires mining engineers to possess relevant employability skills. The employers emphasised the value of skills, abilities, intellectual and practical knowledge. The core argument highlights that mining engineering learners are likely to improve their employability by directly engaging in mining-related activities that allow reflection and acquisition of work experience. The study concludes that it is essential for universities to strengthen employability initiatives such as WIL to enhance the employability skills and attributes of mining engineering learners. This study argues that to enhance students' skills transfer in the workplace, mining engineers and workplace supervisors should receive adequate training on assessment and supervision. In essence, this would provide clarity regarding the transfer of knowledge and skills in the workplace.

The employers recognised that the ECSA exit level outcomes play a pivotal role in framing the development of employability skills for mining engineering undergraduates, which concurs with global competency needs. Given that employers observed a deficiency in some of the necessary skills in mining engineering undergraduates, it would be beneficial for them to rethink how to design and implement initiatives that foster graduate employability in the workplace. The implication is that policymakers should acknowledge that developing graduate attributes should be a collaborative effort between the industry and universities. Overall, the study outcomes highlight the interconnectedness of the mining industry, ECSA, and mining schools, and their joint contributions to developing employability skills and graduate attributes for mining engineering undergraduates.

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References

Beagon, Ú., Niall, D., & Ní Fhloinn, E. (2019). Problem-based learning: Student perceptions of its value in developing professional skills for engineering practice. *European Journal of Engineering Education*, *44*(6), 850–865. https://doi.org/10.1080/03043797.2018.1536114

Behle, H. (2021). Taking stock: Employability as an outcome of higher education. Evaluating developments in the German higher education system. *Higher Education Quarterly, 75*(4), 562–574. https://doi.org/10.1111/hequ.12318

Björck, V. (2021). Taking issue with how the work-integrated learning discourse ascribes a dualistic meaning to graduate employability. *Higher Education*, *82*, 307–322. https://doi.org/10.1007/s10734-020-00650-y

Braun, V. & Clarke, V. (2006) Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2) 77–101. https://doi.org/10.1191/1478088706qp063oa

Cai, Y. (2013). Graduate employability: A conceptual framework for understanding employers' perceptions. *Higher Education, 65*, 457–469. https://doi.org/10.1007/s10734-012-9556-x

Cameron, A., & Drennan, G. (2017). The geoscience education pipeline in South Africa: Issues of skills development, equity and gender. *Journal of the Southern African Institute of Mining and Metallurgy*, *117*(6), 567–576. http://dx.doi.org/10.17159/2411-9717/2017/v117n6a7

Cavanagh, J., Burston, M., Southcombe, A., Bartram, T. (2015). Contributing to a graduate-centred understanding of work-readiness: An exploratory study of Australian undergraduate students' perceptions of their employability. *The International Journal of Management Education,* 13(3), 278–288. https://doi.org/10.1016/j.ijme.2015.07.002

Clarke, M. (2008). Understanding and managing employability in changing career contexts. *Journal of European Industrial Training*, *32*(4), 258–284. https://doi.org/10.1108/03090590810871379

Clarke, M. (2018). Rethinking graduate employability: The role of capital, individual attributes and context. *Studies in Higher Education*, *43*(11), 1923–1937. https://doi.org/10.1080/03075079.2017.1294152

Crawley, E. F., Malmqvist, J., Ostlund, S., Brodeur, D., & Edstom, K. (2014). *Rethinking engineering education: The CDIO approach.* Springer International Publishing.

Dimenäs, J. (2010). Beyond dichotomization: A different way of understanding work integrated learning. *Journal of Cooperative Education & Internships*, *44*(2), 44–49.

Engineering Council of South Africa. (2014). *Whole qualification standard for Bachelor of Science in Dngineering (BSc (Eng))/ Bachelors of Engineering (BEng): NQF Level 7*. http://www.ecsa.co.za

Engineering Council of South Africa. (2018). *Ensuring the expertise to grow South Africa: Criteria for accreditation of engineering programmes meeting stage requirements*. https://www.ecsa.co.za

Fajaryati, N., & Akhyar, M. (2020). The employability skills needed to face the demands of work in the future: Systematic literature reviews. *Open Engineering*, *10*(1), 595–603. https://doi.org/10.1515/eng-2020-0072

Fenwick, T. (2006). Learning as grounding and flying: Knowledge, skill and transformation in changing work contexts. *Journal of Industrial Relations, 48*(5), 691–706. https://doi.org/10.1177/0022185606070112

Freudenberg, B., Brimble, M., & Cameron, C. (2011). WIL and generic skill development: The development of business students' generic skills through work-integrated learning. *Asia Pacific Journal of Cooperative Education*, *12*(2), 79–93.

Garwe, E. C. (2020). Does the timing of work integrated learning affect graduate employability outcomes? *South African Journal of Higher Education, 34*(5), 192–209. https://hdl.handle.net/10520/ejc-high-v34-n5-a15

Griesel, H., & Parker, B. (2009). *Graduate Attributes: A baseline study on South African graduates from the perspective of employers*. Higher Education South Africa; South African Qualifications Authority. http://hdl.voced.edu.au/10707/40519

Haupt, G., & Webber-Youngman, R. C. W. (2018). Engineering education: an integrated problem-solving framework for discipline-specific professional development in mining engineering. *Journal of the Southern African Institute of Mining and Metallurgy*, *118*(1), 27–37. http://dx.doi.org/10.17159/2411-9717/2018/v118n1a4

Healy, M. (2023). Careers and employability learning: Pedagogical principles for higher education, *Studies in Higher Education*, *48*(8), 1304–1314. https://doi.org/10.1080/03075079.2023.2196997

Ishengoma, E., & Vaaland, T. I. (2016). Can university–industry linkages stimulate student employability? *Education + Training*, *58*(1), 18–44. https://doi.org/10.1108/ET-11-2014–0137

Jackson, D., & Bridgstock, R. (2021). What actually works to enhance graduate employability? The relative value of curricular, co-curricular, and extra-curricular learning and paid work. *Higher Education*, *81*, 723–739. https://doi.org/10.1007/s10734-020-00570-x

Jackson, D., Shan, H., & Meek, S. (2022). Enhancing graduates' enterprise capabilities through work-integrated learning in co-working spaces. *Higher Education*, *84*, 101–120. https://doi.org/10.1007/s10734-020-00570-x

Jackson, D., & Dean, B. A. (2022): The contribution of different types of work-integrated learning to graduate employability, *Higher Education Research & Development*, *42*(1), 93–110. https://doi.org/10.1080/07294360.2022.2048638

Klassen, M., & Sá, C. (2020). Do global norms matter ? The new logics of engineering accreditation in Canadian universities. *Higher Education*, *79*, 159–174. https://doi.org/10.1007/s10734-019-00403-6

Kloot, B., & Rouvrais, S. (2017). The South African engineering education model with a European perspective: History, analogies, transformations and challenges. *European Journal of Engineering Education*, *42*(2), 18–202. https://doi.org/10.1080/03043797.2016.1263278

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall, Inc.

Kolb, D. A. (2015). *Experiential learning: Experience as the source of learning and development* (2nd ed.). Pearson Education.

Kolb, A. Y., & Kolb, D. A. (2017). Experiential learning theory as a guide for experiential educators in higher education. *Experiential Learning and Teaching in Higher Education, 1*(1), 7–45. https://nsuworks.nova.edu/elthe/vol1/iss1/7

Kullberg, S., & Paulin, D. (2019). Program advisory boards in engineering education-industry representatives and their contributions to program development [Conference presentation]. 11th International Conference on Education and New Learning Technologies, Palma de Mallorca, Spain. https://doi.org/10.21125/edulearn.2019.0693

Kvilhaugsvik, H. (2022). Bridging higher education and the world of work? Employer panels in Nordic university governance. *European Journal of Higher Education, 12*(2), 117–133. https://doi.org/10.1080/21568235.2021.1886138

Martin, A., Rees, M., Fleming, J., Zegwaard, K. E., & Vaughan, K. (2019). Work-integrated learning gone full circle: How prior work placement experiences influenced workplace supervisors. *International Journal of Work-Integrated Learning, 20*(3), 229–242. https://hdl.handle.net/10289/13044

Maseko, L. A. (2018). A review of work-integrated learning in South African mining engineering universities. *Journal of the Southern African Institute of Mining and Metallurgy*, *118*(12), 1315–1323. http://dx.doi.org/10.17159/2411-9717/2018/v118n12a10

Matsouka, K., & Mihail, D. M. (2016). Graduates' employability: What do graduates and employers think? *Industry and Higher Education*, *30*(5), 321–326. https://doi.org/10.1177/0950422216663719

Michelson, E. (1996). Beyond Galileo's telescope: Situated knowledge and the assessment of experiential learning. *Adult Education Quarterly, 46*(4), 185–196. https://doi.org/10.1177/074171369604600401

Minerals Council of South Africa. (2019). *Integrated Annual Review 2019. #Making Mining Matter*. https://www.mineralscouncil.org.za/downloads/send/14-current/1050-integrated-annual-review-2019

Musingwini, C., Cruise, J. A., & Phillips, H. R. (2013). A perspective on the supply and utilization of mining graduates in the South African context. *Journal of the Southern African Institute of Mining and Metallurgy*, *113*(3), 235–241.

Oladirana, M.T., Pezzotab, G., Uziaka, J., Gizejowskic, M. (2012). Re-engineering an Engineering Education Programme: Example of the University of Botswana [Conference presentation]. AAEE Conference, Melbourne, Australia.

Palmer, S., Young, K., & Campbell, M. (2018). Developing an institutional evaluation of the impact of work-integrated learning on employability and employment. *International Journal of Work-Integrated Learning*, *19*(4), 371–383.

Panther, G., & Montfort, D. (2017). Comparing students and practicing engineers in terms of how they bound their knowledge [Conference presentation]. AAEE2017 Conference, Manly, Sydney, Australia. https://par.nsf.gov/servlets/purl/10051200

Peeters, E., Nelissen, J., De Cuyper, N., Forrier, A., Verbruggen, M., & De Witte, H. (2019). Employability capital: A conceptual framework tested through expert analysis. *Journal of Career Development*, *46*(2), 79–93. https://doi.org/10.1177/0894845317731865

Orr, P., Forsyth, L., Caballero, C., Rosenberg, C., & Arlene Walker, A. (2023). A systematic review of Australian higher education students' and graduates' work readiness. *Higher Education Research & Development*, *42*(7), 1714–1731. https://doi.org/10.1080/07294360.2023.2192465

Ramnund-Mansingh, A., & Reddy, N. (2021). South African specific complexities in aligning graduate attributes to employability. *Journal of Teaching and Learning for Graduate Employability*, *12*(2), 206–221.

Reid, A., Richards, A., & Willox, D. (2021). Connecting experiences to employability through a meaning-making approach to learning. *Journal of Teaching and Learning for Graduate Employability*, *12*(2), 99–113.

Römgens, I., Scoupe, R., & Beausaert, S. (2020). Unraveling the concept of employability, bringing together research on employability in higher education and the workplace. *Studies in Higher Education*, *45*(12), 2588–2603. https://doi.org/10.1080/03075079.2019.1623770

Sarkar, M., Overton, T., Thompson, C. D., & Rayner, G. (2020). Academics' perspectives of the teaching and development of generic employability skills in science curricula. *Higher Education Research and Development*, *39*(2), 346–361. https://doi.org/10.1080/07294360.2019.1664998

Sambell, R., Devine, A., Lo, J., & Lawlis, T. (2020). Work-integrated learning builds student identification of employability skills: Utilizing a food literacy education strategy. *International Journal of Work-Integrated Learning*, *21*(1), 63–87.

Smith, C & Worsfold, K. (2015). Unpacking the learning–work nexus: 'priming' as lever for high-quality learning outcomes in work-integrated learning curricula. *Studies in Higher Education*, *4*(1), 22–42. https://doi.org/10.1080/03075079.2013.806456

Thebuwana, H., Hadgraft, R., & Alama, F. (2016). Transitioning into professional practice: The employer perspective [Conference presentation]. AAEE2016 Conference, Coffs Harbour, Australia.

Tomlinson, M., & Anderson, V. (2021). Employers and graduates: The mediating role of signals and capitals. *Journal of Higher Education Policy and Management*, *43*(4), 384–399. https://doi.org/10.1080/1360080X.2020.1833126

Van der Merwe, J. N. (2011). Future of the South African mining industry and the roles of the SAIMM and the universities. *Journal of the Southern African Institute of Mining and Metallurgy*, *111*(9), 581–592.

Villarroel, V., Benavente, M., Chuecas, M. J., & Bruna, D. (2020). Experiential learning in higher education. A student-centered teaching method that improves perceived learning. *Journal of University Teaching & Learning Practice, 17*(5). https://doi.org/10.53761/1.17.5.8

Vince, R. (1998). Behind and beyond Kolb's learning cycle. *Journal of Management Education*, *22*(3), 304–319. https://doi.org/10.1177/105256299802200304

Wald, N., & Harland, T. (2019). Graduate attributes frameworks or powerful knowledge? *Journal of Higher Education Policy and Management*, *41*(4), 361–374. https://doi.org/10.1080/1360080X.2019.1613310

Winberg, C., Engel-Hills, P., Garraway, J., & Jacobs, C. (2011). *Work-integrated learning: Good practice guide*. *HE Monitor No. 12 August 2011*. Council on Higher Education. https://www.che.ac.za/sites/default/files/publications/Higher_Education_Monitor_12.pdf

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Learning to build institutional capacity through knowledge-based partnerships between universities and industry: lessons for engineering ecosystems from computing in Kenya

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Two of the main challenges facing engineering ecosystems in Africa are 1) enabling universities to produce more high-quality research, and 2) creating more linkages between universities and industry to ensure that research is used, and that highly skilled workers have appropriate knowledge and training. But how can we understand knowledge-focused linkages between universities and industry in relation to other capacities and capacity building efforts within engineering systems? What are the challenges and benefits of building these linkages, and what processes and practices lead to lasting partnerships? We address these questions for the case of computing and information technology in Kenya. Our analysis comes from a three-year project which created and evaluated industrial studentship and fellowship programmes that involved partnerships with companies. University–industry linkages can be understood as an aspect of institutional capacity: a concept that refers to a range of capabilities – important across engineering ecosystems, but especially for universities – that enables production of high-quality and locally relevant research and contributes to the professional development of graduates. Other interrelated aspects of institutional capacity include mechanisms to support acquisition of funding; norms of mentorship, peer support, and scholarly communication; and structures that enable researchers to balance research and teaching. Our data reveal that while some of these capabilities are weak or missing in the Kenyan computing ecosystem, intermediary organisations can act as knowledge brokers to build linkages and facilitate learning between universities and industry. However, these linkages must be built alongside other dimensions of institutional capacity, especially social components like mentorship and peer-to-peer learning.

Keywords: research capacity; institutional capacity; university–industry linkages; knowledge exchanges; Kenya; computing

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Introduction

Many of the challenges facing engineering ecosystems in Africa are fundamentally about knowledge, namely concerns about its production, quality, and function within those systems. Scholars of innovation, engineering education and policy articulate these challenges in two main ways. Firstly, there are calls to create more research activity in the applied sciences and engineering in Africa as a means to boost economies and solve social problems (Molla & Cuthbert, 2018; Atuahene, 2011; Sawyerr, 2004). Factors that hinder research production are many, such as heavy teaching loads at universities due to increasing enrolments, cumbersome administrative responsibilities, and diminishing government funding for research (Mohamedbhai, 2008). A second main challenge for African countries is that weak linkages between industry and universities inhibit adoption, uptake, and utilisation of research produced at universities. Common constraints and causes seen to hamper linkages include a lack of academic staff with industrial experience and/or doctoral degrees, a shortage of opportunities for internships or industrial placements for students, a lack of industry input to support curriculum development and research design, and insufficient or absent institutional support to engage with industry (Kruss & Visser, 2017; World Bank, 2014; Royal Academy of Engineering, 2012; Ssebuwufu et al., 2012; UNESCO, 2010).

As we think about engineering as an ecosystem that stresses interactions and interdependencies between actors that span multiple hierarchies and types of relationships (Klassen & Wallace, 2019), it seems like a key moment to interrogate these challenges related to knowledge generation and mobilisation within engineering systems, what we refer to as knowledge-based linkages or partnerships between actors. These challenges have persisted despite a history of science and technology capacity building initiatives in Africa. In this paper, we make two specific contributions: a conceptual contribution to understanding institutional capacity, and an empirical contribution to building knowledge-based partnerships based on stakeholder analysis. The following research questions guide our work: how can we understand research and knowledge-based linkages between universities and industry in relation to other capacities and capacity building efforts within engineering systems? How do different stakeholders describe their experiences of a knowledge-based partnership between industry and university? What are the challenges and benefits of building these linkages and what processes and practices are key to creating lasting partnerships, especially in sub-Saharan African contexts where the mechanisms of university–industry linkages are underexplored?

We address these questions for the case of computing and information technology in Kenya – a disciplinary and national context that epitomises the challenges articulated above, and one that is relatively unexamined in the literature. Computer science is not a dominant research area in Africa (Pouris & Ho, 2014). Kenya spends only 13.3% of its gross domestic expenditure on research and development (R&D) on engineering fields; computer science and engineering account for only 97 publications in the Web of Science from 2008 to 2014 (UNESCO, 2015; World Bank, 2014). Only 9.6% of innovation-active firms in Kenya considered universities or technical colleges as an important external source of information for innovation, while 44% relied on their own internal sources of information to innovate (NPCA, 2019). Our own previous work on computing in Kenya identified weak linkages between researchers and firms; large teaching and administrative loads for researchers; and a lack of institutional support for early-career researchers to access research funding, conduct research, and establish research programmes (Harsh, Bal, Wetmore, Zachary, & Holden, 2018; Harsh, Holden, Wetmore, Zachary & Bal, 2019). Based on these findings, we co-designed a pilot project to address institutional barriers to building research capacity by creating and evaluating industrial studentship and fellowship programmes. Project funding was awarded to California Polytechnic State University (Cal Poly) and African Centre for Technology Studies (ACTS) for a three-year period by the International Development Research Centre of Canada (IDRC) under the project stream, 'Strengthening engineering research and training in Africa'. This paper presents the findings from analysis of project implementation and evaluation data and makes recommendations on how institutional capacity can be strengthened.

We argue that university–industry linkages can be understood as an aspect of institutional capacity: a concept that refers to a range of capabilities – important across engineering ecosystems, but especially for universities – that enable production of high-quality and locally relevant research and contribute to the professional development of graduate and early career researchers. Other interrelated aspects of institutional capacity include mechanisms and policies to support acquisition of funding; norms of mentorship, peer support, and scholarly communication; and strategies and structures that enable researchers to balance research and teaching. Our data reveal that while some of these capabilities are weak or missing in the Kenyan computing ecosystem, intermediary organisations can act as knowledge brokers to build linkages and facilitate learning between universities and industry. However, these linkages must be built alongside other dimensions of intuitional capacity, especially social components like mentorship and peer to peer learning.

To address our purpose of understanding the conceptual and pragmatic aspects of knowledge-based linkages between universities and firms, and provide lessons for engineering ecosystems in Africa, the paper is structured as follows. We first give an overview of the landscape of research capacity and university–industry collaborations in Kenya and then present our conceptual framework which focuses on institutional capacity. Next, we describe our project and the logics of the programme design, and the data and methods used in this paper. In the subsequent section, we present our analysis of the challenges in forming collaborative research and knowledge exchanges and then the enabling factors that largely allowed us to overcome these challenges. We conclude with some general reflections on the implication of the study for policy and scholarship on engineering ecosystems in Africa.

Research capacity and university–industry linkages in Kenya

Universities are a main driver of research in Kenya, so discussions of research capacity must be understood in the context of the higher education system. Over the past decades, the higher education sector in Kenya has expanded rapidly. Starting with only one public university and one private university in 1970, there were 78 accredited universities in Kenya in 2022, including 42 chartered public universities and 20 private chartered universities (CUE, 2019). While new colleges and universities have been established, programmes of study and course offerings have expanded, student enrolments have increased, but the number of PhD students has remained relatively low. In 2015, there was a total of 7 146 enrolled PhD students, constituting only 1.3% of the total higher education intake across all institutions. Doctoral students were present in higher numbers in business and administration programmes. There were fewer PhD students in engineering programmes as compared with the agricultural sciences. In 2016, the computer science/computing programmes had a total enrolment of 201 PhD students who made up only 2.89% of the total number of doctoral students (Barasa & Omulando, 2018).

The effects of low levels of student enrolment in doctoral programmes are compounded by low graduation rates and extended period of completion of the programmes (Matheka et al., 2020). Graduation rates for PhD students are low due to the dynamic interplay of several structural factors in the higher education sector. At the institutional level, inadequate supervision and a paucity of support programmes, funding, and resources contribute to low graduation rates and a prolonged period of study. There is an insufficient number of qualified PhD holders among the academic staff who can supervise doctoral students (see for instance Itegi & Michubu, 2020; Barasa & Omulando, 2018). Existing supervisors, already burdened with heavy teaching loads and administrative duties, often supervise multiple students beyond the recommended numbers. In addition, most doctoral students are enrolled part-time and balance family life, full time employment, and the demands of their programme of study (Mukhwana et al., 2016).

The production of high quality and useful research requires qualified researchers with the requisite training and skills and well-resourced universities that can support researchers. Strengthening research capacity is ‘a process of individual and institutional development which leads to higher levels of skills and greater ability to perform useful research’ (Trostle, 1992, p. 1321). The reforms in the higher education sector over the past few decades have had unintended consequences that have adversely impacted the research capacity of universities. Johnson and Hirt (2011) argue that the marketisation and privatisation of higher education has played out differently in sub-Saharan Africa than in the Global North. Academic capitalism, or the adoption of a market rationale due to external pressures, drives universities to devise revenue generation strategies from their core educational, research and service missions (Slaughter & Rhoades, 2004) and has had negative consequences on research activity and capacity in Kenya. Academic capitalism in the form of new programmes and fee-paying students, while contributing to university revenues, has been detrimental to research. Teaching loads became heavy and cumbersome, leaving faculty with little time to devote to research (Wangenge-Ouma, 2012). Universities have had to look for external sources of funding as government subsidies and funding for higher education decreased. In the absence of research funding from firms and industry, funding from international development organisations and private foundations have filled the gap. However, this source of research funding is often short-term and unpredictable (Arvanitis et al., 2022). Each funder has its own strategic priorities and motivations that can influence research agendas. Consequently, research is often oriented to development priorities rather than industry needs (Harsh et al., 2018, 2019; Johnson & Hirst, 2011).

The alignment of research and knowledge production with industry needs is further hampered by the lack of links between Kenyan universities and the private sector. There is bidirectional lack of awareness of shared value contributions between local industry and universities, resulting in limited collaboration and insignificant knowledge exchanges between Kenyan universities and industry (Jowi & Obamba, 2013; Ogada, 2000). The collaboration between industry and universities in Kenya is often limited to internships and industrial attachments of students, some of which are motivated by corporate social responsibility mandates in industry (Case et al., 2016; Tumuti et al., 2013). Despite these internships and attachments, most of the links between universities with industry are not well structured (Nyerere, 2012). University training has also yet to address the needs and requirements of industry; there is a mismatch of skills of university graduates and the skills that are attractive to industry. This mismatch is more evident in new fields related to computing such as machine learning and data science, and for rapidly evolving sectors such as information communication technology (ICT) (African Development Bank, 2013). Several national reports and policies recognise this gap and have recommended strategies to strengthen linkages and partnerships between these actors. For instance, a specific goal of the National Education Sector Strategic Plan for the period of 2018-2022 is to use Kenya's curriculum competence-based reforms to ensure that the skills taught in educational institutions match the requirements of the industry, and to emphasise national values, integration of science and innovation, and adoption of ICT technologies (Republic of Kenya, 2018).

Conceptual framework: institutional capacity

Our project design was guided by an innovation systems approach which emphasises interactions among actors and institutions, learning, and institutional capabilities as critical for impactful innovation and enhanced economic growth (Johannessen, 2009; Lundvall, 1992). Work within innovation systems reveals that university–industry (U–I) linkages are highly heterogeneous, based on the characteristics of firms and universities; incentives and behaviours of individual researchers and companies; incentives to cooperation and collaboration; organisational barriers and bottlenecks; and channels of knowledge transfer (Filippetti & Savona, 2017; Agrawal, 2001).

Three main types of U–I linkages based on the channels of interactions are research collaborations, educational collaborations, and academic entrepreneurship. Research collaborations include joint R&D projects; educational collaborations based on learning processes and interactions such as industry participation in student projects, jointly organised courses, student internships, and staff training; and academic entrepreneurship characterised by a focus on commercialisation and the creation of spin-offs and start-ups. Existing research on U–I linkages has largely focused on the latter type of linkage, academic entrepreneurship (Nsanzumuhire & Groot, 2020). In contrast to academic entrepreneurship activities, which tend to create one-way knowledge transfer from universities to industry through licensing and patenting, academic engagement or 'knowledge-related collaboration by academic researchers with non-academic organisations' includes both formal activities like research collaborations and consulting and informal activities like advising and networking with practitioners (Perkmann et al., 2013, p. 424). Knowledge exchange in academic engagement is not straightforward and is facilitated by trust; communication practices such as boundary spanners or the exchange of personnel during the collaboration, training, and workshops; the use of intermediaries; and prior experience in academic engagement (de Wit-de Vries et al., 2019).

While there is an abundance of scholarly work that has examined U–I collaborations within innovation studies, very few of these are specific to the African context (Kruss et al., 2015). In their review of the literature on U–I collaborations in sub-Saharan Africa, Zavale and Langa (2018) point out that most of this literature has focused on the determinants of these collaborations, ignoring the mechanisms through which universities and industry collaborate. As in other parts of the world, university–industry interactions in the sub-Saharan region are highly heterogeneous, but they are often not knowledge-intensive (Kruss et al., 2012). Kruss and Visser (2017), in an analysis of the innovation system in South Africa, found that university differences in terms of reputation, role in national development, and resources are important in shaping academic engagement with industry.

Our project focused on establishing knowledge-oriented linkages – those linkages that involve creating and utilising research – between universities and industry as a mechanism for building institutional capacity to conduct high-quality and locally relevant research and to strengthen research cultures. We use the term 'institutional capacity' to refer to a range of enabling capabilities that are essential to providing a conducive research environment, including linkages and networks with industry and other universities; mechanisms and policies to support acquisition of research funding; norms of mentorship, peer support, and scholarly communication; and strategies and structures that create space to balance research and teaching. There is a long history of donor-funded science and technology capacity building initiatives that focus on human capacity (programmes to create more PhD graduates), infrastructure (providing buildings, laboratory hardware and software) and more recently, on national funding streams by strengthening science granting councils. Institutional capacities can act to connect these other capacities and create a research culture which values and supports research across sectors and organisations (Marjanovic et al., 2012; Jones et al., 2008; Whitworth, et al., 2008; Nchinda, 2002). This in turn helps couple supply and demand for knowledge, leading to research that has intellectual merit and local relevance (Figure 1).

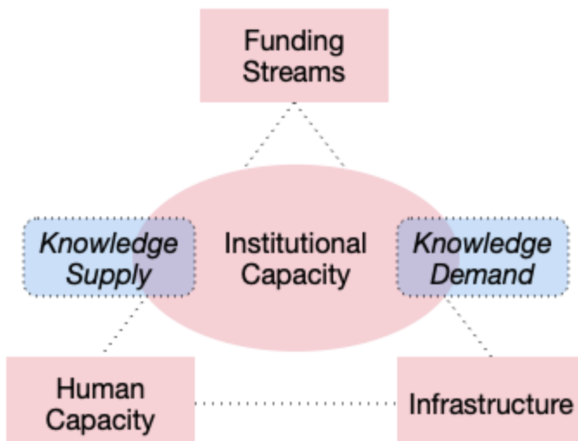

Figure 1: *Institutional capacity connecting other capacities and coupling knowledge supply and demand*

In the case of Kenya, the wider institutional ecosystem plays an important role in supporting the accumulation of capabilities for innovation across sectors. Kingiri (2022) shows this specifically in the case of biotechnology. Our research on capacity building in computer science in Kenya and Uganda also demonstrated that institutional and structural factors, including university and departmental structures and strategies, and the relationship between university and industry, strongly influence researcher productivity and the impact of research (Harsh et al., 2018, 2019). A successful strategy to strengthen research capabilities must take these various institutional factors into account. But building and strengthening research capacity is a 'fragile' goal (Trostle 1992, p. 1322). It requires striking a fine balance between the various supporting factors; the disappearance of any of these supports can restrict opportunities to build capabilities and can hamper existing capacity. This is the balance we aimed to strike as we designed and carried out a pilot programme to build institutional capacity for the computing research ecosystem in Kenya to which we now turn.

Programme design

At the onset of the project, an advisory board was constituted with members from industry, administrators from universities and other relevant stakeholders working in the computing and information and communication technology sectors to provide overall guidance throughout the project. Programme design was an iterative process which was collaboratively undertaken by the project team and revised based on consultations with the advisory board and additional key stakeholders, including faculty members at partner universities.

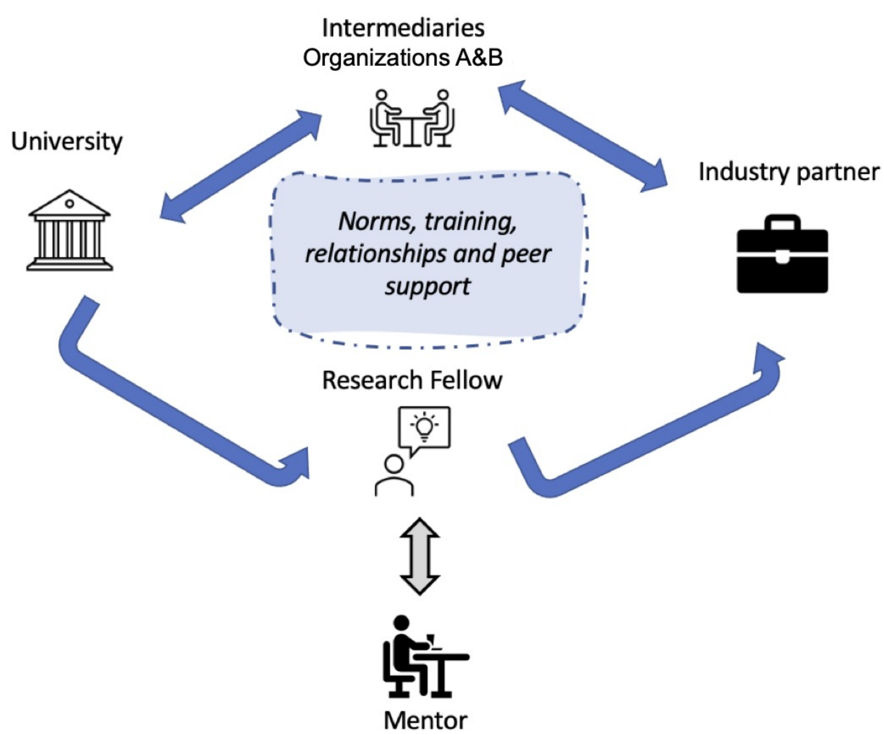

Figure 2: *Programme design. From Klassen et al. (2022)*

The main elements of the programme design are depicted in Figure 2. The interactions between the main actors (universities, industry partners, research fellows, and intermediary organisations) were designed specifically to create capabilities necessary to build institutional capacity discussed above, including research norms, training, relationships, and peer support. Mentors were added to the programme design early in the implementation phase, as discussed below.

The project developed pilot versions of three programmes that addressed structural and institutional capabilities to enable knowledge-based linkages between universities and companies:

1. Industrial fellowships consisting of computing faculty members spending 3 to 6 months in a firm conducting a collaborative research project.
2. Industrial studentships that enabled students to collaborate with industry partners to work on industry-relevant research projects.
3. Postdoctoral fellowships awarded to recently graduated PhDs to strengthen the research functions of a university.

The project commenced on 1 February 2019 and ended on 31 January 2022 after an extension due to the Covid-19 pandemic. Participants in the fellowship and studentship programmes were recruited from three participating universities, namely the University of Nairobi, Jomo Kenyatta University of Agriculture and Technology, and Strathmore University. The selection criteria included academic performance and evaluation of a detailed research proposal. All submitted applications were shortlisted by the host university and the final selection was made by an expert committee composed of members of the advisory board. We received 22 applications for the postdoctoral fellowships and studentships, of which the committee selected nine candidates (two postdoctoral fellows, six PhD students and one master’s student). Table 1 provides details of the fellows and students who completed the programme. The industry partners were a heterogeneous group and included a global technology company (IBM Research – Africa), local information technology firms, a university medical center, and a non-profit organisation working on agricultural and environmental issues.[1]

Table 1: *Fellowships and studentships*

Programme type	**University**	**Industrial partner**	**Mentor affiliation**
Industrial studentship	University of Nairobi	Internet Solutions	University of Nairobi
Industrial studentship	Strathmore University	Communications Authority of Kenya	Strathmore University
		Mewing Networks	
Industrial studentship	Jomo Kenyatta University of Agriculture and Technology	Centre for Agriculture and Bioscience International	Jomo Kenyatta University of Agriculture and Technology
Industrial studentship	Jomo Kenyatta University of Agriculture and Technology	IBM Research – Africa	Jomo Kenyatta University of Agriculture and Technology
Industrial studentship	Strathmore University	IBM Research – Africa	African Centre for Technology Studies (ACTS)
Industrial studentship	Strathmore University	Strathmore Medical Centre	Strathmore University
Industrial studentship	University of Nairobi	Seven Seas Technologies	Strathmore University
Postdoctoral fellowship	University of Nairobi	Kenya Climate Innovation Centre	African Centre for Technology Studies (ACTS)

The project was designed in two phases. Phase 1 provided one year of support to develop a research proposal with an embedded industrial component that addressed the needs of the industrial partner and then jointly executed that research. Phase 2 facilitated deeper engagement between fellows and their industrial partner by co-developing a grant proposal that met industrial needs and provided broader societal benefits. The transition of the fellows to Phase 2 of the programme was dependent on successful performance in Phase 1, based on specific deliverables

[1] Some of the students and fellows were not able to find a partner that was a private company. This is evidence of the difficulty of creating linkages between universities and industry in Kenya. However, the non-private partners chosen still had specific remits to use and mobilise research.

and requirements (including policy briefs and participation in programme workshops and seminars), and feedback from the industrial partners gathered during meetings that included the industrial partners and project team members. All the students except one successfully completed Phase 1 of the programme. In terms of outputs, the students submitted four policy briefs and three blog posts documenting the work done in collaboration with their industry partners at the end of Phase 1. At the end of Phase 2, all participants had completed their fellowships in collaboration with their industry partner.

The creation and implementation of the three programmes was closely interlinked with social science research to advance knowledge about institutional capacity building and to better understand how the pilot programmes and strategy might be scaled. Our approach was one of co-creation and action research which enabled real-time social learning between actors (Dick et al., 2015; Greenwood & Levin, 2006). In our case, this was the research team (social scientists based at Cal Poly and ACTS), computer science researchers and administrators, and industrial managers. To help enable more real-time learning, project reflection was explicitly built into the project design. The project team from Cal Poly and ACTS met regularly throughout the project and documented reflections through meeting minutes and annual reports to the project funder, IDRC.

Data and methods

Monitoring and evaluation were integrated into the programme design as key social science components to track progress, identify bottlenecks, and ensure results. Surveys were administered to participants online using Google Forms at different stages of the project: at regular three-month intervals, and a longer survey at the start and the end of the project. The survey questionnaires were developed by the project team with the specific objectives to assess the implementation of the project, monitor the progress of the programme fellows, identify potential problems, and gather feedback from the programme participants, mentors, and faculty. The surveys administered to the programme fellows were a combination of close-ended and open-ended questions. We asked respondents about the availability of opportunities to engage in research activities and collaborations and to learn and develop professional skills as a programme participant, the quality of mentorship, and the relationship with their industrial partner. The third monitoring survey that covered the period from April to June 2020 included additional questions about the impact of the pandemic on their work and interactions with other fellows, mentors, and industrial partners. The surveys administered to the mentors were also a mix of close-ended and open-ended questions to gather information on their mentorship experience, including frequency of interactions, benefits of mentoring, effective mentorship skills, and suggestions for improving the mentorship component of the programme. While all 9 programme fellows were regular in responding to the surveys, the response rate of the faculty mentors varied from two to seven.

A survey was also administered to the 35 participants of an introductory programme workshop which was held on 27 June 2019 and was attended by faculty and researchers from our partner universities, industry partners, representatives of non-profit organisations with an interest in university–industry linkages (including Linking Industry with Academia and Kenya Education Network Trust), and computing professionals. We received 19 completed questionnaires from across all of these stakeholder groups which presented valuable insights on the current state of university–industry linkages, ways to strengthen collaborations, mentoring, training research skills, past experience with U–I collaborations, professional and soft skills in demand by industry, and motivating factors to apply to the programme.

The introductory programme workshop, and presentations during a visit to the IBM Research office, were video recorded, adding an additional and richer data point for our social science research. The main goals of the introductory workshop were to share programme expectations and procedures, discuss best practices for supervision, mentorship, and proposal writing, and build relationships between programme participants and with industrial partners. The day-long workshop was a combination of presentations and panel discussions. A panel discussion on the institutional barriers to the production of usable research provided insights into the varying challenges faced by industry and universities in forging strong linkages. The programme fellows presented an overview of their proposed research and received feedback from workshop participants. The visit to IBM Research included a tour of the facilities, presentations from IBM researchers, and a further discussion of the challenges of forming collaborations between universities and industry in Kenya.

Round-table discussions were conducted and recorded via Zoom video conferencing with programme mentors and industrial partners at the end of Phase 1 to gather a more nuanced perspective on the programme, as well as provide an opportunity for stakeholders to reflect on the issues connected to the development of institutional capacity. The round-table discussions were designed as a dialogue between the programme mentors, industrial partners, and the project team to assess implementation, reflect on the different perspectives, and explore future scaling of the project. A separate video conference meeting was organised by IBM where the two programme fellows presented their research and received feedback on their presentations, followed by a more unstructured discussion between the project team and IBM partners on the programme conducted in the absence of the programme fellows. Audio transcripts were automatically generated for Zoom meetings. The transcript files were manually edited to correct inaccuracies and errors by checking against audio recordings. In addition, designated project team members took detailed meeting notes.

We also conducted 20 semi-structured, in-depth interviews with computing researchers and professionals, and programme fellows. Our previous research on the computing landscape in Kenya has revealed the existence of multiple knowledge settings beyond the university where students interact with computing and data science professionals to network, collaborate, and learn. These professionals are important actors shaping the training of students and, as prospective employers, have a stake in the professional development of computing students. The interview protocols were developed by the project team and included questions on individuals' education, training, and career background; perspectives of current computer science research in Kenya; motivations for participating in the programme; modes of collaboration with partners; challenges and definitions of success for their work; and overall perspective of the programme structure and activities. The interviews thus provided data on the opportunities and challenges of computing research to address local needs and to investigate the role local universities and industry can play in the evolving landscape of computing research and data on industry perceptions and requirements, barriers to establishing university industry linkages, and existing opportunities for professional development. Interviews in 2019 were conducted face-to-face in Nairobi. Interviews in 2020 and 2021 were conducted over Zoom due to the Covid-19 pandemic.

The survey responses were analysed by a descriptive analysis of sample averages and basic trends to monitor the programme. The survey analysis was triangulated with qualitative data from interviews, round tables, and meeting discussions. We conducted a content analysis of the interview transcripts, Zoom meeting transcripts and notes, and open-ended survey questions to discern the patterns in the data that formed the themes for our analysis. Codes or 'tags or labels for assigning units of meaning' to the descriptive data were developed iteratively using a combination of deductive and inductive approaches (Miles & Huberman 1994, p. 56). The initial development of codes was based on research literature and theory. This inductive approach was combined with a more deductive approach to code development that was driven by the data. Several iterations of analysis and discussions refined our content analysis.

In the next sections we discuss our findings based on our analysis of the survey data, interview and round-table data, as well as our reflections on the project process.

Findings and analysis

Our empirical contribution examines how different stakeholders describe their experiences of a knowledge-based partnership between industry and university to understand how these linkages can be strengthened to build institutional capacity. In the analysis, we expose the challenges and benefits of building these linkages, and describe the practices that are key to creating lasting university–industry partnerships.

We first discuss some of the major challenges that arose during programme implementation as well as those identified through our analysis of the evaluation data. We then present our findings regarding the enabling factors that facilitate the development of research linkages between universities and industry, and the key social and cultural processes and practices that create lasting institutional capacity in academic computing departments.

Faculty participation

We encountered a roadblock early in the project when the faculty industrial fellowships did not take off as envisioned. The industrial fellowships were designed to provide faculty with an opportunity to spend 3 to 6 months in a firm, learn about the skills and knowledge requirements of the firm, and collaborate to produce research that is industry relevant and usable in the local context.

Getting buy-in from the universities, particularly public universities, to support the development of faculty industrial fellowships proved to be problematic. The universities did not have any policies or precedent to support the arrangement. Faculty members were also reluctant to commit because their teaching load and administrative duties did not leave room for any additional demands on their time. While redesigning the faculty industrial fellowships to overcome this bottleneck, we found that providing financial resources in the form of a stipend was critical for getting buy-in from faculty members and ensuring their participation. This resulted in a re-definition of terms and conditions for the faculty members' contracts and a reformulation of the role that faculty would play in the project.

The reformulated version introduced flexibility in the role that faculty would play in the programme. We defined the parameters of their role very broadly. Faculty fellows would co-supervise the students and postdoctoral fellows, guide their research, facilitate access to industrial partners, and help find industry relevant projects for the students to work on. They could also avail the opportunity to undertake joint research and write research grants with other project fellows if inclined. The faculty fellows could define their own role within the programme by choosing the set of activities they would focus on. In addition, a certain amount of flexibility was also built in how they allocated their time to the project. Based on their schedules, faculty could decide when to spend the time required by the programme (four months during Phase 1). The revised industrial fellowship was successfully completed by four faculty members at the end of Phase 1.

On realising that the support from faculty members was not easily forthcoming, we also introduced an additional mentorship component, enlisting mentors drawn mainly from the programme's advisory board as well as from members of the AfricaLics[2] network to support the students and fellows. Mentors were allocated to all the industrial students and postdoctoral fellows in accordance with their area of expertise. The mentors did not replace industry partners; instead, their knowledge and expertise were an added resource for the fellows. As explained below, this component of the programme serendipitously proved to be highly successful.

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[2]The AfricaLics network connects scholars working within the areas of innovation and development with specific focus on African countries – https://www.africalics.org/

The participation of faculty members in the programme did not meet all the goals, even after reformulating the faculty industrial fellowships. None of the faculty fellows availed the opportunity to co-develop research proposals with the project fellows. While the faculty members did not collaborate with the fellows on writing research grants, they did guide their research and provide feedback. Their role in the programme remained a supervisory one and they did not form more collaborative relationships with the students and postdoctoral fellows by participating in joint research activities or writing any collaborative outputs. This was mainly due to their existing time commitments, but also due to the incentive structures for academic research which often does not attach value to industrial partnerships. The expectations about receiving a stipend remained an issue as was evident in the final survey response by a faculty fellow to an open-ended question about the least satisfying aspect of their experience: 'the students were given a better stipend regime than the faculty members.'

Industry participation

The panel discussion at the introductory workshop highlighted the lack of trust, shared vision, and leadership as impediments in forging long-term partnerships between universities and industry. It was difficult for both parties to engage with each other in meaningful ways, given mismatches in the reward systems, incommensurability of partner expectations, and unclear institutional policies and guidelines to support learning-based collaboration. The survey data corroborates these views. The three main factors that inhibited the development of strong university linkages with industry identified in the surveys were lack of financial support, lack of established networks with industry, and industry secrecy stipulations. Responses to the open-ended question about ways to strengthen university–industry linkages highlighted the critical role of trust and included suggestions for building relationships and networks and establishing student internships and dialogue forums. Other suggestions included establishing deliberate structures and policies to support linkages, such as policies to enforce linkages by identifying them as a requirement for accreditation, including an industrial collaboration component in the final thesis, strengthening university placement offices, and including university–industry linkages as a strategic priority of the university management boards.

There was a wide variance in the institutional capacity of industrial partners to forge these partnerships and avail the expertise prevalent in the local universities. The industrial partners fell into two broad categories: those who had existing internship programmes and those who did not. Prior experience with interns contributed to a successful structuring of the collaboration. A partner like IBM Research – Africa had the resources, established internship programmes, and experience of successful university–industry partnerships for a smooth integration of the industrial fellows, while many of the other industrial partners had to start from scratch and establish new systems for the students to undertake their industrial fellowships. During the round-table discussion with IBM Research – Africa, IBM staff reported that while they had had experience with PhD students, this was the first time that they worked with a doctoral student studying at a Kenyan university. Three other industrial partners had never worked with graduate students on a collaborative project.

Industrial partners provided different resources to fellows. These included office space, access to wi-fi networks, transportation to a fieldwork site, data, staff time, access to technical expertise, and access to existing stakeholder networks. IBM Research – Africa also provided laptops and access to their training modules. One programme fellow based at IBM commented on the importance of this training: 'ICT is dynamic in nature and therefore I had to learn new skills through training to work on my research activities while engaging with IBM in the programme.' This statement is a clear indication of the opportunities for capacity building provided by the project, as well as of the failure of universities to equip students with relevant research skills. Universities and a traditional classroom setting may not be sufficient to provide the skill-building programmes in a rapidly evolving discipline required for graduates to remain relevant in a changing labour market. Learning collaborations and knowledge-based U–I linkages can help produce graduates with the appropriate knowledge and training.

A common challenge expressed by all the industrial partners during round-table discussions was a lack of involvement during the early stages of formulation of the students' projects. Several students had their own research for their university degrees underway, and they used the opportunity offered by this programme to add on the industrial component to their research in progress rather than integrate their research interest with industrial needs into a new project. Being on board in the early stages of these research projects would have also helped speed up required approvals, prevented delays in information sharing, and resulted in better management of time and resources. Co-developing the work plans and research with the students would have identified specific needs, incorporated the industrial partners' goals, and made it easier to get buy-in from the organisation. For IBM Research, a key challenge was being unable to assess the skills of the fellows in advance of the programme, which would have helped to place them with the appropriate research team. The industrial partners were of the view that developing a shared understanding of the programme expectations and ways to enforce those expectations would have resulted in more efficient programme management by the industrial partners: 'It took us some time before we aligned ourselves internally and realised the scope of his work … But I guess in the beginning, that's where we needed to understand the scope and the amount of resources that we needed to put in, especially on the field.'

The statement indicates the need to clearly articulate details of the overall project design and the skills and experience of the specific postgraduate students, so firms can determine how they can benefit from the partnership and navigate their internal management processes. The stage at which the students were recruited into the project was also raised as a point of consideration. Industry partners preferred students who had recently commenced their programme of study so that they had ample time to properly engage with the research and guide the student accordingly.

The mismatch in terms of reward structures and organisational norms also became a concern as demonstrated in the case of one of the students working on a project on network security issues.

> Maybe if you have to do it again, the thing I would really recommend is probably getting the whole scope of what the project entails … For me, I think I needed to know that the project could also be helpful for our organisation, so we just have this some sort of, let me say, bureaucracy and stuff like that, when it comes to involving external parties or third parties in helping us achieve certain objectives.

At times, the industrial partner was reticent in providing additional information and data due to privacy concerns. Similarly, the research outputs were required to undergo a screening by the legal team to ensure trade secrets were not disclosed. However, during the round-table discussion, this partnership was characterised as very successful, both in terms of the outputs produced and in meeting the expectations of both partners, due to the buy-in and support provided by the industrial partner. The importance of buy-in from the industrial partner was emphasised by a programme fellow while reflecting on their experience at the end of Phase 1 of the project.

> I believe, since this is a learning process, a little boost towards smoothening the networking aspect and encouraging industrial partners to work with the participants would be great. For example, having a workshop where potential industrial partners are brought together with the mentor, participants, and organisers can help create a buy-in for the industrial player.

Buy-in should be an explicit goal and an explicit term used in the early formation of partnerships. The notion of buy-in is an idea that resonates with a business mindset of transactional value and helps to optimise engagement.

Diverse structures of learning

During our research, we found that the computer science/computing educational landscape in Nairobi reveals diverse structures of learning. These include traditional university learning, self-studying via the internet, learning communities, and communities of practice at the workplaces. Learning communities arose as an innovative practice in higher education to enhance student learning and involvement; however, in Nairobi these communities had been formed outside of the post-secondary context by graduate students eager to utilise computer science to address local needs by learning the latest techniques, enhancing their skills, and keeping their knowledge current. These learning communities were characterised by peer-to-peer learning and were mentorship-based. One interview participant described his experience with learning communities:

> I did a lot of online courses. In my [university] course many did not know where we would use maths and did not pay attention. Courses are outdated, Fortran was used, and applications didn't exist. I learned by thinking outside: online courses such as edX, MOOCs [massive open online courses] like introduction to Python, introduction to ML [machine learning] using Spark, introduction to OS [operating systems], using Python. That is how my journey to AI [artificial intelligence] came about with the question of what more can I do?

The participant saw university education as too theoretical and thus sought out multiple learning communities through online courses to learn the latest applied computing skills.

To a large extent, these communities formed because universities are unable to provide training in the skills that are in demand by industry. Computer science is a rapidly changing field, and the university curriculum is unable to keep up with the new developments.

> Learning has to be hybrid: the fundamentals and formal problem-solving techniques taught in university and then self-taught communities that dip into data and new techniques … Online resources are freely available. The biggest challenge with self-learning is consistency. This is brought in by the community. It means opportunities are also shared and there is a sense of community. Not just learning is shared but also opportunities. So, I'm seeing a lot of that informal organisation that's also propelling a lot more people into the distance.

As this participant explains, the process of knowledge exchange is dynamic and fluid with linkages shaped by the context, discipline, and the nature of the participants. In the case of computer science, the diversifying educational opportunities and formats are challenges that both universities and industry must adapt to and leverage to develop sustainable modes of interactions based on trust. The up-to-date skills and expertise of the members of these communities align with industry needs. But these are shifting and organic communities, unlike the stable structure of universities, making it difficult for industry to establish formal partnerships and tap into this pool of expertise. Mugabo et al. (2015) came to a similar conclusion in their review of trainings to strengthen research capacity outside of academic settings in sub-Saharan Africa, where they found that structured programmes could prove to be successful in developing capable researchers, but such programmes were often hampered by a lack of institutional support.

We now turn to the key enabling factors that helped build more robust linkages with industry and overcome some of the challenges discussed above.

Intermediary organisations

A key enabling factor for building institutional capacity was the active role played by ACTS as an intermediary organisation. As discussed above, a lack of communication and a shared understanding of the value of U–I linkages impeded the development of collaborations between universities and industry. This was further compounded by mismatches in the reward systems and absent or unclear institutional policies and guidelines to support learning-based U–I collaborations. Within innovations systems research, intermediary organisations are described as brokers or nodes that connect actors and support the innovation process by performing a multitude of roles. Intermediary organisations can facilitate communication, build trust, and use feedback to improve and strengthen the relationships (Howells, 2006).

ACTS has credibility with universities based on its highly qualified research staff, quality of research outputs, and expansive research networks that includes the AfricaLics network. Its credibility with industry is also based on its role in evidence-based policymaking and a long history of networking between government agencies such as Kenya's research granting council and science advisory body (the National Council of Science Technology and Innovation) and the private sector. This experience was vital to connect fellows with industry partners and to orient their research to meet industry needs. As one fellow put it:

> My research objectives were the most [significant] barriers, they were just academic. But after reviewing my research objectives based on the lessons and conferences at ACTS [on] inclusion of industrial partner[s] taught by [Co-Principal Investigator (Co-PI)] my research could now attract some industrial partners, and through ACTS's support I got IBM.

The roles that ACTS performed included establishing memorandums of understanding (MoUs) with universities; assisting each individual student and fellow in finding an industrial partner; establishing MoUs with industrial partners; and then actively managing relationships.

Intermediary organisations can help to negotiate the misalignment of incentives, goals, and behaviours of researchers and companies that acts as a barrier to U–I linkages. The management of these conflicting motivations and goals is an ongoing process rather than an act (Parker & Crona, 2012). ACTS, as a research and policy organisation, has partnered with the private sector and universities on many projects and could act as a mediator and translator of the needs and requirements of these actors. It has worked in areas such as agriculture, energy, and climate change that are the research focus of many of the programme fellows and could assist in aligning their goals and objectives with those of the industrial partner. In addition, the authors have collaborated with many of the computer scientists and faculty members on earlier research projects. The project thus started with an existing history of social relationships with individuals, which helped build trust, essential for forging new partnerships.

Knowledge brokers

There were several individuals within the computing learning communities in Nairobi with the necessary expertise and credibility to act as knowledge brokers, who played a similar role as that played by intermediary organisations in building partnerships. Acting as entrepreneurs, these individuals knitted together an informal network of ties that connected actors in industry and academia and promoted mutual understanding, fostered relationships, and facilitated interactions and the exchange of knowledge across the organisational and epistemic boundaries that separated these groups. As one interviewee who founded a prominent learning community explained: ‘I noticed a skill and knowledge gap and so we started … a WhatsApp group for sharing information and resources and organise[d] questions and answers with experts’. This is a clear indication of the crucial role of peer-to-peer learning as a complementary element of capacity building/training received from experts in specific fields.

Mentorship

The mentoring relationship was found to be mutually beneficial by both mentors and mentees. Consistently, across all surveys, over 85% of the respondents found the relationship to be mutually beneficial. The mentor-mentee relationship requires a significant level of commitment by both parties. Formal institutional mentoring programmes are rare in universities in the Global South. When they exist, the lack of protected time allocated to mentorship is an impediment to successful mentoring, as faculty are stretched thin between their teaching, administrative and research workloads (Nakanjako et al., 2011).

The responses to the open-ended questions about the mentor-mentee relationship identified a few challenges in establishing a meaningful mentoring relationship. These included a misalignment of the research interests of faculty members who served as mentors and those of the students; a lack of initiative by students in asking for feedback on their work; and at times, the busy schedule of the mentors and faculty members. Overall, the students found their interactions with mentors and faculty members to be very beneficial as they shared their research experiences and knowledge, critiqued their work, and guided them in refining research questions and defining the scope of their research project.

The responses in the final survey administered to the mentors included their perception of their role within the broader framework of knowledge-oriented linkages between academia and industry. The responses indicate that mentors who had experience working with industry or strong connections with industry could play a more active role in brokering the relationship between their mentees and industry partners.

> I believe the model should support a tripartite approach: where the student-mentor-industrial partner work together going forward on the final outputs of the research. Mentor working together with industry will grow the relationship between the mentor and industry and help him/her to help future students to identify research areas that are relevant to industry and the community.

Mentoring programmes must be tailored to the local context to result in mutually beneficial relationships between junior researchers and experienced faculty (Ssemata, 2017). The programme structure could be strengthened by ensuring that all the linkages between the actors are multidirectional and collaborative. Mentors only interacted with the programme fellows. The mentorship component can be enriched by identifying mentors with industry experience who can work with the industrial partners to support the students and postdoctoral fellows.

Interactions and peer-to-peer learning

Our project was designed so that the students and postdoctoral fellows would form a cohort characterised by peer-to-peer learning, shared experiences, and sustained interactions beyond the life of the project. Regular in-person meetings were held during Phase 1 of the project which subsequently were held via videoconferencing during the pandemic. The programme participants shared updates and presented their research findings during these meetings. Fellows ran their ideas past others in the cohort and were engaging in peer critique. By the end of phase 2, two-thirds of the fellows responded in surveys that they had been asked at least frequently by a fellow student to critique their work. One participant further explained: 'My interaction with other fellows in the programme was positive and enabled me to engage in peer-to-peer learning … peer-to-peer learning with fellow researchers assisted me [to address] the challenges I encountered during my research activities.

It is difficult to predict if these interactions would persist over time, but the open-ended responses and interview data revealed other benefits that resulted from interactions with fellow participants. For instance, many participants described how peer-to-peer interaction extended their professional networks: 'Networks that came from interaction amongst ourselves (the fellows) were very effective in that you linked to other professionals through fellows or colleagues'.

Development of research skills

In general, the quality of the research proposals submitted by the students as part of their application to the programme was not high. This represents a clear issue with their training because grant writing and scientific publications are important for the career success of researchers. Research skills and professional development skills are often neglected in university learning and training. In such a context, non-academic trainings can help researchers develop essential research skills such as formulating research questions, developing manuscripts for publication, and integrating findings into policy and practice (Mugabo et al., 2015). To strengthen research skills, workshops on grant writing and proposal development and seminars (webinars during Phase 2) were organised where the students interacted with the supervisors, mentors, and industrial partners. The seminar series for the students was led by the project Co–PI from ACTS. One participant describes the importance of these meetings: 'Monthly talks by [Co–PI from ACTS] really helped us and grant proposal writing by Prof [Executive Director of ACTS] opened our grant writing skills a lot.' Monthly meetings with the students also incorporated specific capacity building elements. ACTS team members engaged with the students in proposal development activities, provided linkages with ACTS staff responsible for resource mobilisation to train and assist the students on grant proposal writing, and provided a working experience with ACTS staff. As a student participant put it: 'The university was focused on helping students graduate. I learned skills through training while working with industry and the programme.'

Conclusions and implications

The idea of engineering ecosystems is still early in its conceptualisation, but its usefulness comes from the ability to model and understand complexities, hierarchies, and dynamic interactions (Klassen & Wallace, 2019). In this paper we show how another systemic approach, namely innovation systems, provides a useful way of thinking about knowledge-based linkages inside an engineering ecosystem, and how they relate to other processes of engineering systems. In particular, we understand university–industry linkages as an aspect of the concept of institutional capacity: enabling capabilities needed to create and mobilise useful knowledge that is structural, social, and cultural. Linkages are supported by relationships and trust between individuals in different organisations and sectors; manifested in strategies of faculty members and industry managers to provide mentorship for junior colleagues; strengthened by communities of peer interaction for criticism and support; and built on a foundation of norms that promotes publishing, grant-writing and sharing knowledge. These kinds of capabilities are harder to see than the results of other capacity-building efforts which create new buildings and laboratories, individuals with diplomas, or new money streams coming from national grants councils. However, we argue that institutional capacity can connect and amplify these other capacities, a key part of creating a 'selection environment' in an ecosystem where knowledge can flow between actors, individuals can find skilled employment for which they are trained, and organisations can grow and have impact.

Our pilot project created industrial fellowships and studentships that formed partnerships between universities and firms working in computing and information technology in Kenya. The path to form these partnerships had many challenges. Enlisting faculty participation was difficult because of demands on their time due to high teaching loads that resulted from the commercialisation of higher education in Kenya. This is an irony here: making higher education more commercial had the side effect of making it harder for universities to partner with commercial firms. Finding industrial partners which saw the value of research for their organisation, and which had capacity to work with fellows was also difficult. Making the situation more complex was the diverse educational landscape of computing in Nairobi, where learning happens in universities, but also in learning communities that leverage free online resources, and on the job.

However, our project was mostly able to overcome these challenges and build robust partnerships with industrial partners. A main enabling factor was the key role of ACTS as an intermediary organisation. Having been present and working in science, technology engineering and innovation systems in Kenya, ACTS and the project leaders had strong relationships with universities and firms, and specific individuals within these organisations, and already had the roots of trust. With a spirit of flexibility and willingness to rethink the project, for instance by adding compensation for faculty and rethinking their role and adding a mentorship component – these roots of trust were able to grow into social, cultural processes that formed the key parts of institutional capacity. With help from knowledge brokers, the project built mentorship structures, a strong and supportive peer community, and processes to research skills development. All of these enabling capabilities are aspects of institutional capacities, without which it would not be possible to create knowledge-based partnerships with industry.

The project has several clear implications for funders, university administrators, corporate managers, policymakers, and others working to build engineering ecosystems in Kenya and elsewhere in similar African contexts. Firstly, international funders need to support institutional capacity building explicitly. Other types of capacity-building initiatives related to science and technology that focus on human capacity, infrastructure and research funding are by far more common than programmes that focus on building linkages with industry and supporting research cultures at universities. Funders should also design funding that includes and sustainably supports intermediary actors which play key roles in building trust, managing relationships, and facilitating partnerships between actors in the engineering ecosystem.

Secondly, university administrators and managers can work to reform hiring and promotion criteria for their faculty members so that those criteria give real value to linkages with industry. For instance, a research paper co-authored with an industrial partner, or a successful grant which includes an industrial partner, could be given extra positive weight in faculty evaluation processes. Universities must rethink their role in economic development, focusing on training and research activities that respond to the demands of local industries and wider society towards networking and interactive mechanisms that foster innovation (Arocena et al., 2015). Adwera et al. (2013) have argued that African training systems should follow a 'developmental education system' in pursuing their educational and training activities by adopting a multi-sector, multi-organisational interactive approach.

Similarly, managers at firms can encourage their employees to interact with universities. Low-effort types of interactions could be encouraged first, such as allowing employees the flexibility or paid time to attend seminar talks or lectures at local universities and counting these interactions as professional development activities. Then, those employees who show more interest and learn about the expertise at local universities could engage in more involved interactions like jointly conducted research and co-supervision of students.

Finally, there are several roles for government bodies to help build institutional capacity and linkages between universities and companies. The national science granting councils, like the

Kenya National Research Fund, or bodies like the Kenya National Innovation Agency, can design funding programmes to support industrial studentships or industrial postdoctoral fellows. Adding industry-focused fellowships should be part of ongoing efforts by donors to build capacity of African science granting councils. Furthermore, granting councils and agencies could partner with other government bodies, like the Ministry of Trade, Investments and Industry in Kenya and other agencies concerned with strengthening industry-academic relationship, to find additional resources to fund these programmes. There are a number of public-private initiatives to strengthen institutional capacity at different scales, but more needs to be done. For instance, another means to bolster university–industry linkages is to explicitly integrate postgraduate students, postdoctoral fellows, and faculty members into plans to create innovation parks, like the Konza Technopolis project currently underway in greater Nairobi.

These multiple recommendations need to be considered together and efforts must be coordinated to the extent that is possible. Indeed, the meta-lesson from both engineering ecosystems and systems of innovation is that impactful, sustainable, and equitable change comes when systems allow actors to learn from processes and compare across contexts.

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References

Adwera, A., Hanlin, R., & Johnson, H. (2013). Developmental education for innovation: Lessons from an experience in Kenya. *International Journal of Technological Learning, Innovation and Development*, *6*(3), 244261.

Agrawal, A. (2001). University-to-industry knowledge transfer: Literature review and unanswered questions. *International Journal of Management Reviews*, *3*(4), 285–302. https://doi.org/10.1111/1468-2370.00069

African Development Bank. (2013). *The state of Kenya's private sector*. https://www.afdb.org/en/documents/document/the-state-of-kenyas-private-sector-34093

Arvanitis, R., Mouton, J., & Néron, A. (2022). Funding research in Africa: Landscapes of reinstitutionalisation. *Science, Technology and Society, 27*(3), 351–367. https://doi.org/10.1177/09717218221078235

Arocena, R., Göransson, B., & Sutz, J. (2015). Knowledge policies and universities in developing countries: Inclusive development and the 'developmental university'. *Technology in Society, 41*, 10–20. https://doi.org/10.1016/j.techsoc.2014.10.004

Atuahene, F. (2011). Re-thinking the missing mission of higher education: An anatomy of the research challenge of African universities. *Journal of Asian and African Studies, 46*(4), 321–341. https://doi.org/10.1177/0021909611400017

Barasa, P.L., & Omulando, C. (2018). *Research and PhD Capacities in Sub-Saharan Africa: Kenya Report*. British Council and the German Academic Exchange Service (DAAD). https://www2.daad.de/medien/der-daad/analysen-studien/research_and_phd_capacities_in_sub-saharan_africa_-_kenya_report.pdf

Case, J. M., Fraser, D. M., Kumar, A., & Itika, A. (2016). The significance of context for curriculum development in engineering education: A case study across three African countries. *European Journal of Engineering Education, 41*(3), 279–292. https://doi.org/10.1080/ 03043797.2015.1056103

Commission for University Education (CUE) (2019). *University Statistics Report 2017-2018*. https://www.cue.or.ke/

Dick, B., Sankaran, S., Shaw, K., Kelly, J., Soar, J., Davies, A. and Banbury, A. (2015). Value co-creation with stakeholders using action research as a meta-methodology in a funded research project. *Project Management Journal, 46(2)*, 36-46. https://doi.org/10.1002/pmj.21483

de Wit-de Vries, E., Dolfsma, W.A., van der Windt, H.J., & Gerkema, M.P. (2019). Knowledge transfer in university–industry research partnerships: A review. *Journal of Technology Transfer*, *44*, 1236–1255. https://doi.org/10.1007/s10961-018-9660-x

Filippetti, A. & Savona, M. (2017). University–industry linkages and academic engagements: Individual behaviours and firms' barriers. Introduction to the special section. *The Journal of Technology Transfer*, *2*(4), 719–729. https://doi.org/10.1007/s10961-017-9576-x

Greenwood, D. J., & Levin, M. (2006). *Introduction to action research: Social research for social change*. 2nd ed. Sage Publications.

Harsh, M., Bal, R., Wetmore, J., Zachary, G. P., & Holden, K. (2018). The rise of computing research in East Africa: The relationship between funding, capacity and research community in a nascent field. *Minerva, 56*(1), 35–58. https://doi.org/10.1007/s11024-017-9341-1

Harsh, M., Holden, K., Wetmore, J., Zachary, G. P., & Bal, R. (2019). Situating science in Africa: The dynamics of computing research in Nairobi and Kampala. *Social Studies of Science, 49*(1), 52–76. https://doi.org/10.1177/0306312719829595

Howells, J. (2006). Intermediation and the role of intermediaries in innovation. Research Policy, *35*(5), 715–728. https://doi.org/10.1016/j.respol.2006.03.005

Itegi, F. M. & Michubu, M.W. (2020). Navigating through postgraduate research: Experiences of doctoral studies students in Kenyan universities. *International Journal of Innovative Research and Knowledge*, *5*(7). https://www.researchgate.net/publication/344070122_Navigating_Through_Postgraduate_Research_Experiences_of_Doctoral_Studies_Students_in_Kenyan_Universities

Jones, N., Bailey, M. & Lyytikäinen, M. (2008). *Research capacity strengthening in Africa: Trends, gaps and opportunities*. Overseas Development Institute: London. https://cdn.odi.org/media/documents/2774.pdf

Johannessen, J-A. (2009). A systemic approach to innovation: The interactive innovation model. *Kybernetes*, *38*(/2), 158–176. https://doi.org/10.1108/03684920910930330

Johnson, A.T., & Hirt, J.B. (2011). Reshaping academic capitalism to meet development priorities: The case of public universities in Kenya. *Higher Education*, 61, 483–499. https://doi.org/10.1007/s10734-010-9342-6

Jowi, J.O., & Obamba, M. (2013). Research and innovation management: Comparative analysis of Ghana, Kenya, Uganda. Background document. Programme on Innovation, Higher Education and Research for Development (IHERD), OECD and SIDA. https://www.oecd.org/sti/

Kingiri, A. N. (2022) Exploring innovation capabilities build up in the deployment of crop biotechnology innovation in Kenya. *Innovation and Development, 12*(2), 305-324, https://doi.org/10.1080/2157930X.2021.1884934

Klassen, M., Matemba, E., Harsh, M., Kingiri, A., & Bal, R. (2022). *Building research cultures in Kenya through postgraduate fellowships with industrial partners* [Unpublished paper]. IDRC, Canada.

Klassen, M., & Wallace, M. (2019). *Engineering ecosystems: A conceptual framework for research and training in Sub-Saharan Africa* [Conference presentation]. 7th African Engineering Education Association International Conference, Lagos Nigeria.

Kruss, G., and Visser, M. (2017). Putting university–industry interaction into perspective: A differentiated view from inside South African universities. *Journal of Technology Transf*er, *42*, 884–908. https://doi.org/10.1007/s10961-016-9548-6

Kruss, G., Adeoti, J.O., & Nabudere, D. (2015). Bracing for change: Making universities and firms partners for innovation in sub-Saharan Africa. In E. Albuquerque, K. Lee,

Lundvall, B.-A. (1992). *National systems of innovation: Toward a theory of innovation and interactive learning*. Pinter.

Matheka, H.M., Jansen, E.P. & Hofman, W.A. (2020). PhD students' background and program characteristics as related to success in Kenyan universities. *International Journal for Doctoral Studies*, *15*, 57–74. https://doi.org/10.28945/4467

Marjanovic, M., Hanlin, R., Diepeveen, S. & Chataway, J. (2013). Research capacity-building in Africa: Networks, institutions, and local ownership. *Journal of International Development, 25(7)*, 936–946. https://doi.org/10.1002/jid.2870

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage Publications.

Mohamedbhai, G. (2008). The role of higher education for human and social development in Sub-Saharan Africa. In G. Haddad, H. van Ginkel & J. Salmi et al. (Eds.), *Higher education in the world 3. Higher education: New challenges and emerging roles for human and social development* (pp. 191–210). Global University Network for Innovation.

Molla, T. & Cuthbert, D. (2018). Re-imagining Africa as a knowledge economy: Premises and promises of recent higher education development initiatives. *Journal of Asian and African Studies, 53*(2), 250–267. https://doi.org/10.1177/0021909616677370

Mugabo, L., Rouleau, D., Odhiambo, J., Nisingizwe, M.P., Amoroso, C., Barebwanuwe, P., Warugaba, C., Habumugisha L., & Hedt-Gauthier, B.L. (2015). Approaches and impact of non-academic research capacity strengthening training models in sub-Saharan Africa: A systematic review. *Health Research Policy and Systems, 13*, article 30. https://doi.org/10.1186/s12961-015-0017-8

Mukhwana, E., Oure, S., Too, J., & Some, D.K. (2016). *State of postgraduate research and training in Kenya*. Commission for University Education (CUE). Discussion Paper 02. Nairobi, Kenya. https://www.researchgate.net/publication/307906274_State_of_Post_Graduate_Research_and_Training_in_kenya

Nakanjako, D., Byakika-Kibwika, P., Kintu, K. , Aizire, J., Nakwagala, F., Luzige, S., Namisi, C., Mayanja-Kizza, H., & Kamya, M.R. (2011). Mentorship needs at academic institutions in resource-limited settings: A survey at Makerere University College of Health Sciences. *BMC Medical Education, 11* (53). https://doi.org/10.1186/1472-6920-11-53

Nchinda, T.C. (2002). Research capacity strengthening in the South. *Social Science & Medicine 54*(11), 1699–1711. https://doi.org/10.1016/S0277-9536(01)00338-0

NEPAD Planning and Coordinating Agency (NPCA) (2019). *African Innovation Outlook III 2019*, Pretoria: NPCA. https://www.nepad.org/publication/african-innovation-outlook-iii

Nsanzumuhire, S.U., & Groot, W. (2020). Context perspective on university–industry collaboration processes: A systematic review of literature. *Journal of Cleaner Production*, *258,* article 120861. https://doi.org/10.1016/j.jclepro.2020.120861

Nyerere, J. (2012). Higher education research, science and technology transfer: A look at the policy strides made in East Africa. *SA-eDUC Journal*, *10*(1). http://education.ku.ac.ke/images/stories/research/HEduResearchSci_Technology_Transfe r.pdf

Ogada, TM (2000) Universities, research and development organizations and intellectual property. Paper presented at Regional Seminar on the benefits of the intellectual property system for universities, university researchers and research and development organization. Dar es

Salaam, Tanzania, 20–22 June 2000. https://www.wipo.int/edocs/mdocs/innovation/en/wipo_ip_dar_00/wipo_ip_dar_00_1.pdf

Parker, J., & Crona, B. (2012). On being all things to all people: Boundary organizations and the contemporary research university. *Social Studies of Science*, *42*(2), 262–289. https://doi.org/10.1177/0306312711435833

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabel, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A., & Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations, *Research Policy*, *42*(2), 423–442. https://doi.org/10.1016/j.respol.2012.09.007

Pouris, A. & Ho, Y.S. (2014). Research emphasis and collaboration in Africa. *Scientometrics, 98*, 2169–2184. https://doi.org/10.1007/s11192-013-1156-8

Republic of Kenya. (2018). *National education sector strategic plan for the period 2018 – 2022*. Ministry of Education. https://www.globalpartnership.org/node/document/download?file=document/file/kenya-nessp-2018-2002.pdf

Royal Academy of Engineering. (2012). *Engineers for Africa: identifying engineering capacity needs in sub-Saharan Africa. A summary report. https://raeng.org.uk/media/tlajtabc/raeng_africa_summary_report.pdf*

Sawyerr, A. (2004). African universities and the challenge of research capacity development. *Journal of Higher Education in Africa/Revue de l'enseignement Supérieur En Afrique, 2*(1), 213–242.

Slaughter, S. & Rhoades, G. (2004). *Academic capitalism and the new economy: Markets, state, and higher education*. The Johns Hopkins University Press.

Ssebuwufu, J., Ludwick, T., & Béland, M. (2012). *Strengthening university–industry linkages in Africa: A study on institutional capacities and gaps*. Association of African Universities. Association of Universities and Colleges of Canada. http://dx.doi.org/10.13140/RG.2.2.21422.15685

Ssemata, A.S., Gladding, S., John, C.C., & Kiguli, S. (2017). Developing mentorship in a resource-limited context: A qualitative research study of the experiences and perceptions of the Makerere university student and faculty mentorship programme. *BMC Medical Education, 17*(123), 1–9. https://doi.org/10.1186/s12909-017-0962-8

Trostle, J. (1992). Research capacity building in international health: Definitions, evaluations and strategies for success. *Social Science & Medicine, 35*(11), 1321–1324. https://doi.org/10.1016/0277-9536(92)90035-O

Tumuti, D. W., Wanderi, P.M., & Lang'at -Thoruwa, C. (2013). Benefits of university–industry partnerships: The case of Kenyatta University and Equity Bank. *International Journal of Business and Social Science*, 4(7). https://ijbssnet.com/journals/Vol_4_No_7_July_2013/4.pdf

UNESCO (2015). *UNESCO world science report: Towards 2030*. Paris: UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000235406

Wangenge-Ouma, G. (2012), Public by day, private by night: Examining the private lives of Kenya's public universities. *European Journal of Education, 47*(2), 213–227. https://doi.org/10.1111/j.1465-3435.2012.01519.x

Whitworth, J.A., Kokwaro, G., Kinyanjui, S., Snewin, V.A., Tanner, M., Walport, M., & Sewankambo, N. (2008). Strengthening capacity for health research in Africa. *The Lancet, 372*(9649), 1590–1593. https://doi.org/10.1016/S0140-6736(08)61660-8

World Bank. (2014). *A decade of development in Sub-Saharan African science, technology, engineering and mathematics research*. World Bank Group. https://doi.org/10.1596/978-1-4648-0700-8

Zavale, N.C., & Langa, P.V. (2018). University–industry linkages literature on Sub-Saharan Africa: Systematic literature review and bibliometric account. *Scientometrics*, *116*, 1–49. https://doi.org/10.1007/s11192-018-2760-4