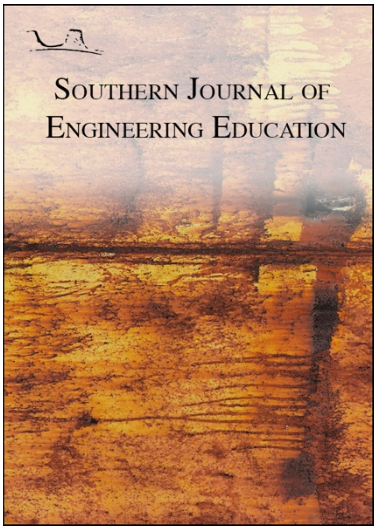


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# Learning to build institutional capacity through knowledge-based partnerships between universities and industry: lessons for engineering ecosystems from computing in Kenya

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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).

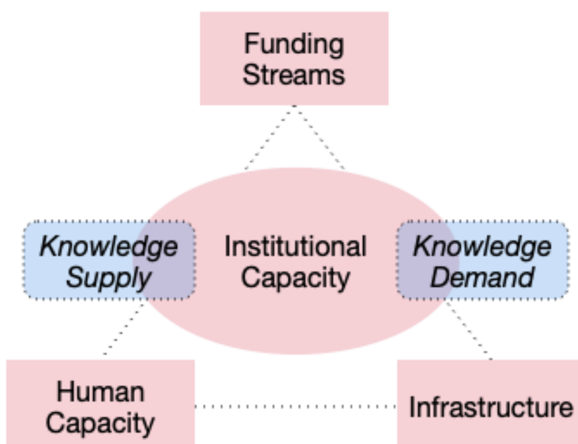


Figure 1: *Institutional capacity connecting other capacities and coupling knowledge supply and demand*

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.

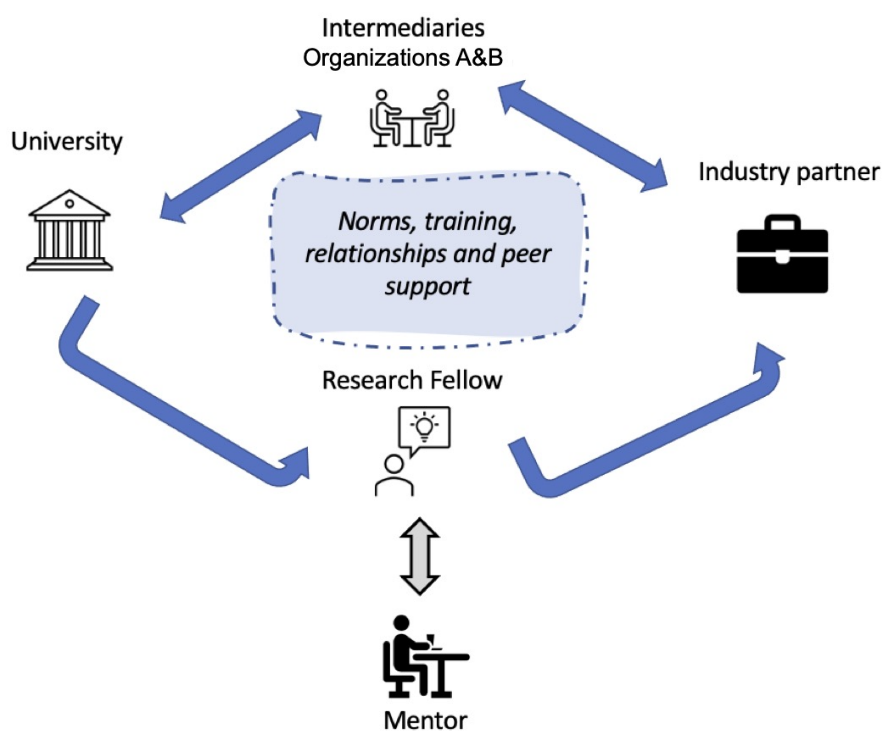


Figure 2: *Programme design. From Klassen et al. (2022)*

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<br>Mewing Networks | Strathmore University |
| 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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