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Dreams and dream spaces of West African molecular microbiology

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The molecular bacteriology laboratory

Introduction: laboratory dreams

Antimicrobials – strictly, antibacterials (otherwise known as antibiotics) – are the medicines we use to treat infections caused by bacteria. The World Health Organization has observed that we know very little about how much and how badly disease-causing germs can evade antimicrobial drugs in Africa because too few laboratories are measuring or studying antimicrobial resistance there (WHO 2014). In fact, isolation, identification and susceptibility testing to determine whether bacteria are resistant or sensitive to specific antimicrobials use very old methods analogous to those employed by Robert Koch and Alexander Fleming in the nineteenth and early twentieth centuries, admittedly with modern standardizations (Gradmann 2013). If the bacteriology that can fill surveillance maps for the WHO is so simple, why is it so rare on the continent most threatened by drug resistance (O'Neill 2014)?

From the laboratory perspective, there are two fundamental reasons why too little is known about drug resistance in Africa. The larger and most important one has to do with the state of diagnostic and public health laboratories on the continent, something that is not the focus of this article. The second is tied to the scarcity of hypothesis-driven research laboratories, or, in other words, spaces for scientists' dreams. Africa has the smallest number of laboratories studying antimicrobial resistance in any category and the fewest researchers that study bacterial resistance (WHO 2014; Okeke 2011). As a resistance researcher whose work on this topic is grounded on the continent, I have met most of them.

Dreams are central to discovery-based science. Discoveries themselves are dream outcomes, but not the focus of this article. Instead, my focus is on dreaming of the potential to do science: that is, to participate in discovery. Thus, the dreams discussed here relate to the tools of experimentation and their presence, or absence, in scientists' laboratories. Training and finances are strong contributors to laboratory construction but are far from the only variables because dreams precede funding applications. Even the best-resourced scientists select favoured approaches among many options, they decide which experiments must be performed in-house, which should be contracted out, and who can perform them to standard. These decisions in turn determine what pieces of equipment will

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ultimately line the benches of the scientists' laboratory space, how these will be operated, and what the equipment's tenure will be in the lab. Thus, pieces of equipment are purchased or loaned with money but the equipping of laboratories is largely based on scientists' ideas, aspirations and possibilities. And therefore, I argue, dreams can be read from laboratories.

Dreams that relate to laboratory construction are almost entirely envisioned by one or a few personnel who oversee a laboratory, conventionally referred to as 'principal investigators'. The dreams of scientists in the laboratory – managers, technicians and trainees – are more difficult to read from laboratory layouts. A new principal investigator in a first-rate US institution typically arrives to an empty or near empty laboratory with a start-up cash package to equip it.[1] In addition to specialist materials, the investigator will commonly have to purchase the equipment, glassware, Bunsen burners, waste receptacles and sometimes even laboratory furniture required to bring their dreams to life (Barker 2010). If they can finance their dreams, laboratory life will continue; if not, the laboratory will shut down when the investigator is denied tenure and his or her dreams will be replaced by those of another. By contrast, in many UK universities, laboratories for postgraduate research are concurrently and sequentially occupied by multiple principal investigators. These spaces are equipped by a conglomerate of dreamers, each a principal investigator in his or her own research programme. The laboratories chiefly reflect the dreams of the more successful scientists, and those who are less able to secure funding must make do with the dream weaving of their colleagues. As research needs and projects change, new equipment is introduced and outdated equipment is removed. While dreams may result in the entry of pieces of equipment, other pressures such as funding and longevity take them away. Benches become dotted with equipment from different ages and the laboratory is gradually modernized over time. African laboratories can and have been built on both models. Nigerian and Ghanaian university laboratories are conventionally built on the British model, but recent global health research has also spawned shiny new laboratories built from scratch in a US start-up model of sorts.

Scientific training most frequently leads to very practical occupations involving sample processing in diagnostic, industrial, biotechnology and environmental laboratories so that our science-based civilization can operate. Scientific practitioners in these labs typically clock in to nine-to-five jobs, follow strict protocols and compile reports for healthcare providers, manufacturers or regulatory agencies. Research scientists, whose laboratories are equipped in the way I have described, in contrast, may use similar technical methods but their motivations are harder to read and therefore a key interest of science ethnographers (Latour and Woolgar 1986). Why, given the long years of training and comparatively small remuneration, do talented individuals build a career in scientific research along the Euro-American model that is a cycle of hypothesis building, hypothesis testing by experiment and communication via peer-reviewed journals? And, one must also ask, why do it in an African terrain known to be difficult for this type of science? Why choose to make discoveries in a place where suitably skilled

[1]The new look of a new investigator's lab is what I view as a somewhat paltry reward for years of intensive and competitive training that today include a very lengthy post-doctoral research period in an established investigator's lab.

personnel and funds are scarce, the wherewithal to operate must be imported at great cost and 'standards' are almost entirely dictated externally? The answer to these questions is difficult to pinpoint precisely, because, I believe, it lies in dreams.

Laboratory dreams

After a century of neglect, lab building in Africa has become fashionable (Okeke 2006; 2011; Petti *et al*. 2006; Bridges *et al*. 2014). The current drive to build scientific resources that will underpin treatment and public health interventions for the priority diseases HIV, tuberculosis and malaria had only limited impact on laboratories for other bacterial pathogens and for basic science research. Even while the gorgeous new labs that have appeared in Africa in the last decade serve the purpose of conducting clinical trials for US-developed drugs, or providing disease surveillance in a project conceived in Western Europe, these labs reflect scientists' dreams. However, in those specific instances, the dreamers are often far away and sufficiently resourced to transpose their dreams onto another landscape. Many of these labs have African managers, but laboratory managers are not dreamers; they are scientific practitioners implementing the dreams of others. When imported dreams cease or are withdrawn, resources that have been much admired and much needed can crumble away (Geissler *et al*. 2016b). Thus, there is value in owned dreams – dreams that are envisioned on African pillows, set in African landscapes, enacted within African laboratories and conveyed to another generation of dreamers.[2]

This article is about my observations at three bacteriology labs in West Africa that lack the façade of shiny 'new' microbiology labs set up as part of the current global health movement (Crane 2013), but that are highly productive and built on domestic dreams. They evolve as British institutional laboratories do, but their capacities to change, as well as the selective pressures acting on them, are very different from those in the West.

A key limitation of this analysis is that there was bias in selecting the laboratories I have chosen for this close examination. These are far from being the only labs that work in this way, but because they are in my field and my area of geographic interest, I know them, their aspirations and their products quite well. I have a good understanding of which shortcuts are permissible in our field and therefore I can assess the infrastructure and limitations of these labs and the quality of work they can do. All three research resistance to antimicrobial drugs (antibiotics) by bacteria – again, my field and my bias – but they do have research interests that extend beyond the sphere of my own inquiry. My interest in them extends beyond the academic to a need to understand how laboratories can be built, grown and replicated in West Africa, as I work to build a West African lab of my own.

[2]Boundaries for 'African' dreamers and 'Western' science are admittedly fuzzy. Indigenous African science is extensive but not the subject of this article except in contexts where it informs or has been blended with Western science. I am also deliberately simplifying this analysis by not including non-Africans who dream in Africa or like Africans. Non-Africans in this context are defined not necessarily or solely by their nationality but by their mobility and their far greater access to external resources not targeted at Africans. The highlighted principal investigators of the labs in this article are West Africans according to any definition and the science they practise originated in Robert Koch's German school.

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It is common to hear a scientist refer to their or another 'lab', but the meaning of the word 'lab' varies depending on the pedigree of the scientist. In the US and many other countries in the global North, 'the lab' typically refers to the scientists who make up the research group (Latour and Woolgar 1986; Barker 2010). These are a principal investigator, staff scientists and trainees. When a principal investigator moves, the lab moves with him or her. My study focused on a part of the world where, as in the traditional UK model (now evolving towards the US model), 'the lab' is the room where scientific activities take place. Many scientists work alone and groups often comprise just the principal investigator and his or her students, but it is possible to have multiple groups in the same lab. When a scientist emigrates, the lab is left behind. Under this model, the scientist and the lab can be separated. And the scientist can enact his or her dreams within or in spite of the lab. The differences in definition of 'the lab' may not be accidental. In settings where both investigators and facilities are in shorter supply than rooms, it is easiest to define the laboratory as the room. This article focuses on laboratory spaces, but in the context of those who run them, which I believe is key to their contents, operations and products and is reflective of three scientists' dreams.

Irrespective of whether 'lab' refers to people or venue, one of the most fundamental contributions from Latour, research science's most famed ethnographer, is that the activities within a laboratory are not the whole of what makes up science (Latour and Woolgar 1986; Latour 1987). Science research is a culture within which complex actors and currencies perform. Scientific papers are outcomes – but far from the only outcomes – and even the content of those papers can be determined by factors other than experiment. Once we accept these simple tenets, we can easily agree that laboratory shortfalls in Africa amount to more than reagent shortages or equipment corrosion. The dearth of suitable, or even adaptable, laboratory facilities for Africa's many experimental biologists locks them out of the theory, discourse and shaping as well as the practice of their fields. This then means that these fields exclude a perspective that could be very different from those within it. For bacteriology, this problem has become most prominent in an era in which infectious disease research has rebounded. This rebound is justified in large part by the number of people who get sick and are killed by infectious diseases in sub-Saharan Africa, and the realization that infectious germs can travel the world without the restrictions sometimes placed on scientists. Thus, the exclusion from global decision making of a large proportion of those qualified to take scientific decisions is problematic, bordering on reprehensible. A similar paradigm has played out in biodiversity research (Osseo-Asare 2014).

At the core of debates about laboratory performance for hypothesis-driven research is a hidden debate about who can dream, and where. In the US, for example, female scientists are well represented on benches but under-represented as principal investigators, senior paper authors, major conference speakers and even scientific article reviewers (Casadevall 2015; Lerback and Hanson 2016). Ethnic and economic minorities are similarly under-represented in scientific leadership. Within Africa, females and rural indigenes are under-represented; and, critical for science globally, Africa as a whole is the most under-represented continent in biomedical science even though much of the justification for present-day science – disease, hunger, biodiversity and evolutionary history to name a few – makes Africa a logical core for inquiry (Okeke *et al*. 2016). There are

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principal investigators working on the African continent but the vast majority of African scientists who are authentic principal investigators practise their trade, and dream their dreams, on other continents.

The state of a laboratory is key to determining the validity of its output. The physical laboratory may or may not be visible to the peer reviewer of a scientific work, but the 'materials and methods' and 'results' sections of experimental scientific papers authored from the lab provide a frame for imagining it. I (and others) critiqued a paper published by Nigerian physician and immunologist Jeremiah Abalaka, who claimed to have a cure for AIDS, in part because his laboratory was reported to be underequipped for the task of antiviral vaccine development (Obadare and Okeke 2011; Lehner 2005). Real and perceived under-resourcing is also an important contributor to bias against developing country authors by reviewers and editors of Western journals (Langer *et al*. 2004). Part of the focus on African lab building for Africa is limited to portable or modular structures that can be built outside and assembled in African countries, rather than standalone, endogenous facilities (Okeke 2011; Crane 2013; Bridges *et al*. 2014). The former have the advantage of rapid, low-cost inception but do not address long-term issues for laboratories that must function with only domestic support (Bridges *et al*. 2014; Fonjungo *et al*. 2012). In some instances, the recent surge in transnational research activity has also led to certification being given precedent over capacity (Wendland 2016).

Molecularization and the updating of bacteriology research

It is possible to at least initiate basic questions, for example on the prevalence of antimicrobial resistance, with no more equipment than Alexander Fleming used to discover penicillin in the 1920s. Thus, antimicrobial resistance research can be pursued, at least to some degree, in the face of resource constraints. This topic continues to feature disproportionately in non-indexed African journals, reflecting the activities of a considerable number of Africa-based scientists working in the field who are invisible to authors of international global surveillance reports (WHO 2014). Many labs have the capacity to delineate resistant bacteria from susceptible ones but not the investigational capacity to move beyond that initial observatory step (Ntoumi *et al*. 2004; Oyebade 2010; Fullwiley 2011).

Molecular biology became a key approach for biomedical inquiry in the years following the deciphering of DNA structure and function, and, currently, all biological principles that are thoroughly understood can be worked down to the structure and function of their chemical molecules (Watson and Crick 1953; Nurse 2003). What I refer to as the *molecularization* of biology was driven in part by its ability to address mechanistic or 'How?' questions, the speed and efficiency with which this could be done, and – as science study scholars have argued – a bandwagon effect (Fujimura 1988). For all of these reasons, modern resistance research laboratories in Europe and North America gained molecular biology capabilities between the 1960s and 1990s, most of them in the 1980s. Today, while most still depend on basic bacteriological methods to identify resistance, virtually all of them do at least some work with purified DNA and/or proteins to understand the mechanisms underpinning resistance.

At the time when Western laboratories were molecularizing, almost all African laboratories had stagnated or were declining due to structural adjustment in their

countries. Tousignant (2013) and Geissler (2011) describe laboratories – in Senegal and Kenya respectively – that enjoyed early post-independence productivity but became unable to do science in the structural adjustment era. At the same time as mainstream journals were requiring biology papers to include mechanistic data in the form of molecular content, attempts to tailor molecular technologies for African laboratories were openly criticized as being a non-innovative waste of time (Barker *et al*. 1986; Pettersson *et al*. 1987; Fujimura 1988). The grimmest times are not very far behind us and created the difficult reality for the ever declining majority of African scientists who study the biology of anything but HIV (Okeke 2011; Crane 2013).[3] The mushrooming of postal research (see below) might have obscured the problem but this happened in only a few sectors. Beginning in the 1990s and escalating a decade later, there was increasing global concern about shipping infectious agents. For some diseases, notably HIV, these concerns spawned 'global health' and 'overseas' laboratories on African soil. However, many diseases and subjects, including antimicrobial resistance, were not the priorities driving these initiatives and did not find space within the resulting laboratories.

Structural adjustment programmes' (SAPs') unfortunate overlap with the molecularization of biology made it impossible for most African biologists, including those researching antibacterial resistance, to do basic and applied research to modern standards. Worldwide, the vast majority of laboratories still use now standardized methods analogous to Fleming's to detect resistance (Gradmann 2013). However, without molecular biology facilities, it is almost always impossible to tell why bacteria are resistant and, therefore, to compile a scientific report that is more than just descriptive. Descriptive science has acknowledged value but today generally receives lower priority for publication and support than hypothesis-driven science (Casadevall and Fang 2008). Laboratories in Africa that continued to research resistance during SAPs but were unable to molecularize found their work pushed out of major international journals into local, often non-indexed publications. Those outlets acknowledged the importance of documenting key preliminary findings and understood that the authors of these papers could not pursue the questions that their work had opened up but did little to raise the international profile of the authoring scientists. The best guess as to why Cameroonian scientists researching antimicrobial resistance opted to ship uninterrogated specimens to France is that a simple description of which antibiotic-resistant bacteria were in each specimen was not sufficient content for the medium- to high-impact bacteriology publication in an international journal that eventually reported the work (Djuikoue *et al*. 2016).

This article focuses on three post-SAP bacteriology laboratories researching antibacterial resistance led by English-speaking West African principal investigators trained in and after the structural adjustment era. All three of the labs I describe here perform basic microbiological tests of antibacterial susceptibility but also have some molecular biology capacity. They do not have enough to get to the very bottom of some questions, but they certainly can pursue research to

[3]Based on earlier rates, molecularization can be viewed as proceeding rapidly in the present. Considerable effort has gone into laboratory infrastructure for the first two emergencies and important changes are taking place as I write.

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an extent that allows them to publish in the mainstream journals in our field. In other words, they draw from and contribute to the circle of information that is central to their fields (Latour and Woolgar 1986). Like almost all laboratories worldwide, they all extend their own capacity through collaborations. And while they share samples with collaborating laboratories, their research can in no way be described as postal.

West African laboratories: the descriptions

I have had the unusual privilege of 'setting up' laboratories multiple times, on different continents, most recently in Nigeria, to which I returned in 2014. Prior to my return, my science and technology studies interests extended from African diagnostic laboratories, which I have observed for many years, to microbiology research laboratories of the type I run myself. This had led me to view roughly three dozen African laboratories, most in West Africa. This work describes common threads in a very small number of them that are easily visible from three modest but productive West African laboratories that not only illustrate but also enact their protagonists' dreams.

Laboratory I: MRSA at home

The first laboratory I will walk you through is that of a West African scientist who undertook undergraduate and master's level training in his own country – in fact, within the very laboratory he now heads. He became interested in staphylococcal bacteria, travelled abroad to obtain a PhD on these organisms and there was introduced to modern molecular biology methods. These methods have permitted genetic comparisons of bacterial isolates worldwide and have revealed the existence of 'pandemic lineages' of related methicillin-resistant *Staphylococcus aureus* (MRSA) that have been disseminated globally. The principal investigator (PI) of Lab I is at the forefront of understanding the epidemiology of MRSA and other staphylococci in Africa. Long before the current response to recent calls for a 'One Health' consideration of the connections between microorganisms in humans, animals and the environment (AVMA 2008), this PI was studying the genetics of staphylococci from a range of humans, domestic animals and even wildlife. He publishes at a modest rate in the best journals and is lead author on most of his publications. He is regularly invited to give 'the African perspective' at major international conferences.

His laboratory – which for the most part also doubles as his office – is extraordinarily humble. Lab I is equipped with a mix of materials he has purchased using small grants or out of pocket, long-standing equipment inherited from his (now retired) mentor's laboratory as well as donations from other laboratories around the world with whom he is well connected. There are working incubators that cannot have been purchased after the 1970s. These, like the old but comfortable laboratory stools, are robust, easily cleaned models that have served continuously for half a century and will probably continue to function for as long as the space remains a laboratory. The incubators stand along a wall interspersed with more modern, locally purchased kitchen refrigerators and a freezer. A few small items are improvised or fabricated: reagent reservoirs, loop holders and spirit

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lamps to supplement the gas Bunsen burner connected to a portable cylinder. Around the sink is a mix of reagent bottles and beakers, plastic bowls and jars, traditional and improvised scientific vessels. One entire wall of the lab is illuminated by windows overlooking a green, making for a pleasant working environment and ensuring that light floods the laboratory irrespective of whether the sporadic electricity supply is on or off.

Some of the molecular techniques required to subtype staphylococci require specialized equipment that is not present in Lab I. However, the laboratory is very tightly networked with labs so equipped – a couple on his campus, a few more elsewhere in the country and many more abroad. His research thrives because his is one of the few local laboratories that pays careful adherence to the bacteriology needed to isolate and subtype *Staphylococcus*; unlike many scientists around him (but, interestingly, like the PIs of the other two labs I will introduce), this PI elected to specialize.

Unlike the many African scientists engaged in postal research – that is, shipping specimens for analysis elsewhere (Ntoumi *et al*. 2004; Oyebade 2010; Crane 2013; Sawyerr 2004; Fullwiley 2011; Okeke 2016a) – the PI of Lab I prepares his isolates for molecular testing himself and has the wherewithal to analyse and interpret the data from that testing. His need for 'borrowed' laboratory infrastructure is actually very minimal. He understands staphylococcal genetics as well as any other leader in the field and never sends completely unprocessed specimens elsewhere. He can spend funds secured through small grants on expensive molecular biology consumables and run his experiments on equipment in other laboratories during 'downtime' when the equipment he needs is lying fallow. His modus operandi is comparable to that of small US and European laboratories that contract out some of their molecular biology experiments to automated commercial laboratories for a fee. This lab does just that, trading his expertise instead of cash. Our PI is an extraordinary resource, who contributes to training at the sites where he borrows equipment and is therefore welcome to continue to use it. He assists other local scientists in setting up equipment, trains their students and helps analyse their data. His students, who work with him in his laboratory and accompany him on tours to other local laboratories, are trained in molecular methods as well.

Julie Livingston has written poignantly about improvisation in African clinics, specifically a cancer ward where pressing life-and-death decisions must be made even though facilities are inadequate and supplies unpredictable (Livingston 2012). In comparison to a cancer care facility, a research laboratory has reduced pressure to deliver on results rapidly. Improvisation is common in African antimicrobial resistance research (Brown 1996; Okeke 2011) but is executed selectively in Lab I and the other two laboratories I studied. Tools that do not need to be standardized, such as vessels and flame sources, are freely improvised, while those for which compromise could affect the quality assurance of experiments – sterilizers, media and thermocyclers, for example – are not. Reagents are always first rate, procured from high-standard suppliers and prepared meticulously according to protocol. More is invested in procuring them than is spent to access equipment. Rather than improvise key materials and risk quality shortfalls, Lab I can wait for months or years to do something right, according to internationally accepted protocols. Conventionally, they would be overtaken by competitors or events, but no one else in the world is studying

West African staphylococci to such depth, so waiting slows things down but does not hurt. Lab I's innovative access mechanisms ensure that, in spite of resource constraints, data generated meet stringent international biomedical standards. This is an inventiveness of sorts.

Laboratory II: A physician-scientist

The US offers combined MD/PhD programmes to train physician-scientists but there are no MD/PhD programmes in West Africa. The improvisation that is common to all three profiled labs is evident in the career profile of the PI of Lab II, who constructed his own physician-scientist training programme by going to medical school, undergoing specialist training in pathology and taking a research master's degree in microbiology from a science faculty. His focus is bacterial causes of diarrhoeal disease.

Lab II's PI is a consultant pathologist, specializing in microbiology, and also has an academic appointment in the medical school. The dual appointment requires his presence at two separate, but close, campuses almost every day and makes him a mentor for medical registrars as well as biology students. At the hospital, his 'laboratory space' is the diagnostic laboratory. His request for space at the medical college met with some initial concern. Would he be able to conduct research along with the responsibilities of mentoring clinical trainees, teaching medical students and carrying an unusually large administrative burden? The space available, if he wanted it – and he did – was an old laboratory that had been shut up for many years. The PI and his first graduate student cleaned and cleared it out. They assessed the equipment and used those pieces that were useful and still working to initiate lab building. They then began to work in what evolved into the PI's research space, the hospital lab being devoted to clinical diagnostic work.

A couple of years after the lab was up and running, a nearby collaborating laboratory acquired some molecular biology equipment, which the PI and his group began to use. When access to the collaborating facility became more difficult, and staff working at that laboratory had fewer uses for the equipment, in part because of the challenges associated with acquiring consumables, the key pieces of equipment were moved to the PI's laboratory, without transfer of ownership. Their new location greatly enabled the PI's molecular work and he subsequently acquired other pieces of equipment. Lab II includes many more ancient pieces of equipment than Lab I: there are incubators, centrifuges and clamps that date back to the 1960s and 1970s. As the lab space was closed up for several years, there were periods in which old but robust equipment were unused and therefore they continue to function years after similar pieces met their demise in the continuously used Lab I. The physician-scientist research lab also houses newer pieces of molecular biology equipment on lease from the collaborating laboratory and a few other nearly new staples including a portable autoclave and the microscope. However, it is devoid of any equipment manufactured in the 1990s, other than the battered air-conditioning unit, a reflection of the laboratory's lucky survival of the evolutionary bottleneck occasioned by the SAP.[4] Indeed, one thing

[4]In evolutionary biology, a bottleneck occurs when strong selection (for example, disease or other natural disaster) eliminates almost all variants in the population. The few survivors

common to all the labs is the near absence of any SAP-era additions, strongly suggesting that this was a dreamless period.

The laboratory has large rear windows, an asset for a microbiology laboratory that must endure multiple power cuts each day. Tucked under a bench is a generator that gives power to the fridges, freezers and small equipment in use during the many power outages. At the centre of the large, Formica-covered bench is a voltage converter that allows the investigators to power a couple of donated pieces of equipment that came from the US, where the AC supply is 120 volts; the domestic supply is 240 volts.

Like the two other PIs I examine here, this physician-scientist specializes – in Gram-negative intestinal bacteria – but on occasion he will stretch or step out of his core specialty to address a problem of clinical relevance. Like Lab I, this lab purchases high-end consumables from small budgets. Being a physician-scientist, some of the quandaries that come to this PI's attention relate to patients and therefore he needs to come back with answers quickly. In those instances, it may be necessary to procure some consumable that cannot be justified for a project with limited specific aims. Medical consultants are reasonably well compensated and this PI is able to make modest laboratory purchases out of pocket, even though it is far from conventional to do so in science. Most of such purchases are used for case studies or to prime future research projects: microbiological media and consumables are too expensive to procure out of pocket for a large study. The willingness to spend his own resources on difficult cases, however, means that this lab is unusually flexible. This in turn makes the PI an ideal collaborator with other scientists as well as with clinical colleagues. His collaborative network is extraordinary and he is competent to play leading or participatory roles as the need demands.

Laboratory III: The 'why' of the diagnostic laboratory

Our third and final PI started out as a technician in a diagnostic laboratory. He performed routine bacterial cultures in a hospital and later provided services to a teaching hospital research project. He enjoyed the opportunity the research project gave him to scratch below the surface and follow up on cases and therefore elected to study for a bacteriology master's degree. Towards the end of his programme, a parasitologist returned from abroad with some molecular biology equipment. This was unpacked in the department's spacious parasitology laboratory, which had previously housed only glass bottles of preserved specimens and a couple of precious microscopes. At about the same time, our PI's supervisor's collaborator also stepped in with a small thermocycler, a centrifuge and some electrophoresis equipment. Each molecular biology set-up was paltry and only sufficient to address the limited questions associated with its source project. But together, the two sets of equipment constituted a flexible laboratory with missing pieces from one project effectively complemented by the other. Our PI was motivated to commence a PhD in molecular bacteriology that used these facilities and additionally secured a one-year studentship at a US university. Four years later, his

represent a fraction of the original population and repopulate the niche, ultimately resulting in a population that is less genetically diverse than the original one.

PhD in hand, he became co-investigator on a project funded by international grants that brought in a few more pieces of equipment. Young scientists coming after him have continued the culture of shared resources, each building their careers in a similar manner. Construction of this molecular biology lab was a collaborative process between parasitology and bacteriology and grew into a rather uncommon partnership. While each PI has pursued his own research, they have also worked together and co-authored publications. They continue to work closely with the diagnostic laboratory, which allows them to ask clinical as well as basic research questions.

Lab III is located in a city where procurement is less of a challenge than for the other two labs. Nonetheless, consumables are expensive and, like the other two laboratories, this lab gives credence to the reputation and quality of manufacturers, selecting only the best brands. This third lab uses older bacteriology equipment in the official bacteriology laboratory, which is adjacent to the molecular lab, but it began largely with new but small pieces of molecular biology equipment.

In contrast to many purpose-built labs to which access is typically restricted, the three laboratories became a magnet for close-by resources and accomplished much by pooling them. The laboratories may appear 'poor' in some respects since key pieces of equipment are old and refurbished, stretched to capacity or simply not there. Very few pieces of equipment in any of the labs were actually purchased by the PIs, and all three scientists routinely use equipment that they do not own. If one applies the broader definition of 'instrument' to include the 'organic machines' under study that measure resistance and convey resistance genes (Griesemer 1992), the richness of these laboratories cannot be contested since they contain many bacterial lineages that have not been domesticated anywhere else in the world. There are overlaps in areas of interest among the labs, in particular Labs II and III. However, this presents no problem for any of the PIs. There are too few laboratories studying what these scientists research in West Africa to meet the need for their inquiry. Thus, they are never in competition, and, like the rest of our sparse antimicrobial resistance research community in Africa, they often collaborate. As long as they can maintain functionality of and access to the electronic machines that are essential to inquiry, the principal investigators maintain global relevance in their fields.

Small bacteriology laboratories: impact and implications

Impacts of West African bacteriology laboratories

The fate of recently constructed, purpose-built laboratories in Africa is unclear if or when their typically foreign benefactors or 'partners' withdraw support (Okeke 2018). If the word 'sustainable' were applied to laboratories, the three labs I have described here could be seen in that light. However, more important than their sustainability is their evolvability in what is now a very fast-moving field. The three laboratories that are the focus of this article successfully navigated articulation challenges to resource, locate and operate their laboratories, have a modest but significant publication output and have been able to continue to advance their work and those of their mentees in the medium to long term.

These three are not laboratories that lived through SAPs. (Those bottleneck survivors perhaps deserve even closer scrutiny but are beyond the scope of this work.) Instead, they were launched after the devastating effects of SAPs had appeared, at

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a time when talented scientists either left the country or were lost to science permanently because they pursued other careers (Okeke 2000). On a continent where there was a discernible gap between precolonial and post-SAP scientific activity, the majority of African research programmes do not build on early foundations. Indeed, Geissler and Tousignant (2016) have suggested that they build on *in*capacity. These small but independent labs used pre-SAP resources, which were instrumental to the training of the PIs or were excavated when they set up their laboratories.

The overweighting of publication metrics for individual scientist assessment has been criticized in scientific circles but continues to be the most frequently used *quantitative* measure of scientific impact (Casadevall and Fang 2015). In order to compare the scientific impact of the principal investigators of the three laboratories of interest with that of others, I retrieved their publication citation details from Google Scholar. In addition, I matched each PI with another West African scientist with similar training and research focus who had emigrated to an industrialized country early in his career. Like the PIs of the three labs, all the control scientists had received their first degrees and at least some of their postgraduate training within their home countries. They have also maintained interest and connections with their home countries after emigration. Like the profiles of the three PIs that are the focus of this article, this, too, is an unusual profile. Therefore, while the number of scientists subjected to scrutiny here is small and not representative, there are few other options for unbiased matching of careers for the analysis that follows. All six scientists have a significant impact on their field, each having authored at least one publication that has been cited more than 100 times.

As shown in Table 1, overall, the emigrated scientists had higher total publication citations and higher metrics, particularly when commonly used 'impact' parameters such as total number of citations, h-index and i10 index (number of papers with at least ten cites) are compared. However, the highest-impact work of these investigators is comparable, as can be seen by the number of papers cited at least forty times. Interestingly, although the local PIs had fewer first author publications than their respective controls, a higher *proportion* of their publications were first author ones, and they all had very similar numbers (and therefore a higher proportion) of last author publications. (In the biomedical sciences, project leaders are commonly last authors on publications.) The most important distinction between the three PIs and their matched controls was the number of articles with ten cites or more that were co-authored with at least one other Africa-based author. This represented the majority of publications for the PIs and only a small minority for the emigrated scientists. Thus, the PIs are associated very strongly with high-impact science coming out of Africa, which overall is scarce.

Joan Fujimura identifies categories of a scientist's work, outside actual experimentation, that ensure that inquiry can continue. This articulation work involves acquiring resources and materials, career building, generating publications on which career advancement is assessed and commitment to those lines of research that will generate output within reasonable timelines (Fujimura 1988). Intellectual freedom notwithstanding, scientists can maintain viable enterprises only if they are successful in all those regards. Scientists who typically do not perform many of these functions, including most trainees, can focus on their experimentation

TABLE 1
Publication metrics as at the end of January 2017 for the principal investigators of the three profiled West African laboratories and three matched West African émigré controls.

Scientist	Lab I: MRSA at home	Control for Lab I	Lab II: Physician-scientist	Control for Lab II	Lab III: 'Why' of the diagnostic lab	Control for Lab III
Lab location	West Africa	Australasia	West Africa	Western Europe	West Africa	North America
Total Google Scholar citations	704	2,919	762	1,106	862	1,358
h-index[1]	14	29	14	17	10	22
i10 index[2]	16	52	18	25	10	33
i40 index[3]	3	23	6	3	6	10
First-author papers cited >10 times	7	10	3	4	4	11
Last-author papers cited >10 times	2	1	2	2	1	3
Papers with Africa-based co-authors cited >10 times	11	3	16	6	10	4

[1]A standard metric that refers to the largest number, so h publications have h citations.
[2]The number of publications cited at least ten times, which would indicate considerable impact in the microbiological sciences. A standard metric.
[3]The number of publications cited at least forty times. A non-standard metric that would indicate exceptional impact in the microbiological sciences.

only by securing a mentor who acts in these regards on their behalf. Maintaining laboratory equipment presents special challenges on the African continent that do not occur elsewhere (Fonjungo *et al*. 2012), therefore African principal investigators must maintain articulation and commitment continuously, irrespective of support for actual scientific activity. To avoid shared spaces, such as that of Lab III, becoming extinct, at least one user must remain articulate.

A principal investigator or research leader pushes his or her ideas, and those of others, through the scientific process in large part by performing the essential tasks outlined by Fujimura alongside or instead of experimentation. Principal investigators who also work at the bench will often be first or last authors on their publications. Many principal investigators cannot afford time at the bench because of the exacting requirements of these ancillary but essential functions and will more often be last authors (Weinberg 1967; see also Crane 2020). Investigators who perform little or no articulation work but generate data at the bench and/or contribute ideas will be first or middle authors on scientific papers. Each principal investigator will typically be in-house lead of a group of scientists which she or he supports with ancillary services in addition to overseeing the science. A PI-led laboratory group can consist of only one or two scientists or of several dozen. For the purpose of my analysis, which focuses on the dreams of independent scientists, if the group can perpetuate its science while staying in its space, it is successful. (Any of our PIs could perpetuate his science by emigrating to another group.)

The scarcity of true principal investigators in Africa has been lamented by science policymakers, and more recently even by funders (Oyebade 2010; *Nature* 2005; Mbaye *et al*. 2019). African ideas are insufficiently pursued because a large proportion of the continent's scientists are unable to articulate, develop scientific careers or commit to research lines, or because they do so through principal investigators elsewhere (*Nature* 2005; Ramsay 2001; Droney 2014). The shortage of domestic PIs also means that a lot of local training occurs in short-term training programmes rather than in traditional long-term apprenticeships that are the customary mode for generating new principal investigators. Like PIs everywhere, the three laboratories examined for this work have no choice but to articulate, build careers and commit to their research lines. If they ceased to perform these functions, experimentation would also cease. Because their laboratories contain fewer staff scientists and more lower-level trainees (that is, students, not post-doctoral scientists) than most PI-led laboratories in the West, forcing them to articulate not only advances domestic questions but also provides opportunities for other scientists, including a future generation of PIs.

Less than 3 per cent of 17,417 scientific papers co-authored by a West African scientist include a co-author from North, East or Southern Africa (Toivanen and Ponomariov 2011). Africans cooperate frequently with European and North American scientists but rarely with African scientists in other countries or regions (Blom *et al*. 2016; Toivanen and Ponomariov 2011). This finding is believed to be indicative of external dependence on research resources – financial and even intellectual – and therefore one of the factors diminishing regional progress. A rather unexpected finding of our three laboratories is that all of them collaborate to some degree within and beyond their countries in Africa. These specific collaborations less commonly involve one scientist

working in another's laboratory. Instead, they require each scientist to do a portion of the work in his own laboratory so that the collaborations themselves are dependent on these laboratories' survival.

'The importance of research in a university' – Mahmood Mamdani

Lack is a recurring theme in African science. Gaps produced by a lack of structure-elucidation instrumentation at the Centre for Scientific Research into Plant Medicine in Ghana, of diagnostic equipment in a Malawian medical school, or within Ugandan and Botswanan cancer treatment programmes have created a peculiar African scientist who applies other senses and acumen to his or her deductions (Droney 2014; Livingston 2012; Wendland 2010; 2016; Feierman 2011; Mika 2015). Concurrent with these and similar narratives (Tousignant 2013; Osseo-Asare 2014), our three scientists have navigated around such a lack to find routes to molecular biology capability that place them within the reach of top bacteriology journals, while still enjoying access to bacteria that few other molecular scientists can achieve. If they departed from their respective academic fields, they would leave an internationally discernible void. Their examples show that generating high-quality data from modest spaces requires training, tenacity and the more intangible capacity to dream as much as it needs funds.

Dreaming is integral to successful science. Scientific dreams in West Africa often have a different context, requiring a disavowal of 'negative interpretations' – Mbembe's term adopted in laboratory science by Droney (2014; Mbembe 2001) – and the capacity to imagine equipment on otherwise empty bench space. They also require articulation skills to wake up and find the equipment there. Through the intergenerational dreams of mentors and mentees, the actualization of dreams might be sustained. Referring specifically to the social sciences and the humanities (but illustrating one of his central points with a biomedical research example), Mahmood Mamdani recently spoke about 'the importance of research in a university', emphasizing that Africa's institutions:

> have no choice but to train the next generation of African scholars at home. This means tackling the question of institutional reform alongside that of postgraduate education. (Mamdani 2011: 1)

Mamdani proposed that African research was often driven by external, largely Western influences and by consultancy, which detract from basic research. In the biomedical sciences, these forces yield highly applied or utilitarian outcomes, such as building clinical trial capacity. That necessary expertise is in short supply, but educational policy is yet to similarly spotlight the pressing need for capacity development in the basic and early applied (that is pre-clinical) sciences, the very areas where the PIs of the laboratories I visited work. Filling that gap is essential to bringing African dreams to local and global discovery spaces and to ensure that African scientists' work is 'suitable for their own countries' (Adjanohoun 1982: x). Many newer labs in Africa arose from rapid responses to the accelerated scale-up in HIV healthcare delivery capacity over the last two decades, and, in that sense, they are 'market-driven', in Mamdani's words (2011: 3). Thus, even though they serve an important and under-resourced purpose, they can offer very little scope or space for new lines of questioning. They are utilitarian laboratories unable to accommodate domestic dreams.

Conclusion: credibility as the substance of dreams

The power that African scientists have to dream and to interpret the dreams of others is at the same time respected and suspect. Because of the difficulty in procuring needed materials and the bias against science in places where it is difficult to do, as others have outlined, credit where it is due cannot be taken for granted (Geissler and Okwaro 2014; Okwaro and Geissler 2015; Fullwiley 2011; Crane 2013; Mbaye *et al*. 2019). Emanating from the spaces described in this work is the importance of something that Latour and Woolgar (1986) refer to as 'credibility'; in their own analysis, this translates to the opportunity to do science or, in my own interpretation, the chance to dream. In addition to the more obvious rewards of science, credibility includes less visible and less tangible investments in scientists' careers that can yield even greater rewards in the future (Merton 1968; Lerback and Hanson 2016). Examples are invitations to key meetings, overt and covert 'leg ups' for support, and invitations to author review papers and opinion pieces. Most Africa-based scientists do not get these opportunities but our three PIs do and the credibility they have gained extends to their laboratories – however credibility is defined.

It is essential that African scientists get their names on co-authored project papers and have the opportunity to run the biomolecular analysis that features as the central data in a paper. But, beyond this, Africans also need to drive their own questions within and around collaborations. African dreams need to be woven through the collective fabric of microbiology's imagination. Some African scientists have doggedly pursued provocative Africa-relevant questions but have ended their inquiry part way due to lack of material resources. Unfortunately, there is every freedom to dream African dreams but, in today's science, the substance of those dreams is evidenced using equipment that is Western. By accepting to work in a limited dream space, they risk obscurity, or else, in the event of a true but unverifiable breakthrough, they risk having their dreams snatched away, exported to better-resourced climes and completed on other pillows (Osseo-Asare 2014; Droney 2014). Either way, unfulfilled dreams cannot be passed on to future generations. Trainees will leave science or leave the country if they cannot turn dreams into substance (Droney 2014). Thus, an important question for African science is not just how to dream, but how to hold on to dreams.

Dreams are intangible but they have greater permanence than mechanical and electronic equipment and are less perishable than enzymes and biomolecules. There are few long-term examples of true scientific sustainability from Africa, but a recent retrospective of the Amani Malaria Research Station in Tanzania reveals how a world-class centre of excellence can degenerate to nothingness so that the well-resourced past is marked only by deteriorating symbols reminiscent of a productivity that its caretakers do not understand (Geissler *et al*. 2016a). It is always possible that this will become the fate of laboratories that build technical expertise without teaching hypothesis building and testing: that is, those labs that perform experiments but do not dream (Okeke 2016b).

The three laboratories I have described here are smaller, less productive and less remunerated than higher-profile purpose-built laboratories in Africa or elsewhere but they are functional, adaptable, potentially sustainable and, importantly, credible in reality and in dream space. I argue that our three spotlighted laboratories

are a model for institutional reform that addresses the need to develop and drive local research questions that are potentially unconnected to extra-continentally defined emergencies. Laboratories modelled in this way could train future scientists in the milieu in which they are likely to work and dream. 'Institutional reform', as illustrated by these prototypes, is neither intentional nor administered, but this home-grown 'bottom-up' and truly visionary approach of laboratory construction is perhaps one that could serve many other African biomedical contexts.

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Abstract

By the end of the 1990s, molecular approaches predominated in biomedical science, but, for West African scientists, biology could not have 'gone molecular' at a worse time. Resource constraints led to knowledge expiry and many discovery dreams were terminated, exported or at least postponed. Pivotal transitions in methodologies, knowledge and resources temporally overlapped with an emergent imperative to address infectious disease in Africa. This prompted new initiatives from global health programmes in the North, which imported visions, disciplinary

focus and equipment for new laboratory spaces. A handful of African researchers, however, have reimagined and reconstructed existing laboratories as a means to weave their own dreams. This article examines three such laboratories. It outlines how their equipment was accumulated, the ad hoc ways in which the laboratories are supplied and maintained, their extraordinary accomplishments and their key role as domestic nodes for research. The picture that emerges is one that extends beyond technological acquisition to an enactment of the scientists' own dreams. Importantly, it is a record of outcomes from those who continued to dream while others stilled their imaginations or became canvases coloured by the dreams of other people.

Résumé

À la fin des années 1990, alors que les approches moléculaires prédominaient dans la science biomédicale, la « molécularisation » de la biologie ne pouvait pas tomber à un pire moment pour les scientifiques ouest-africains. Les contraintes de ressources entraînaient une péremption des connaissances et beaucoup de rêves de découverte étaient interrompus, exportés ou du moins différés. Des transitions charnières dans les méthodologies, les connaissances et les ressources ont coïncidé temporellement avec l'émergence d'un impératif de s'attaquer aux maladies infectieuses en Afrique. Ceci incita les programmes de santé mondiale du Nord à lancer de nouvelles initiatives qui ont importé des visions, des axes disciplinaires et des équipements pour de nouveaux espaces de laboratoires. Une poignée de chercheurs africains ont cependant réimaginé et reconstruit des laboratoires existants comme moyen de tisser leurs propres rêves. Cet article examine trois de ces laboratoires. Il décrit comment ils ont accumulé leurs équipements, la manière ponctuelle d'approvisionner et d'entretenir les laboratoires, leurs accomplissements extraordinaires et leur rôle essentiel en tant que pôles de recherche locaux. Il s'en dégage une image qui dépasse le cadre de l'acquisition technologique, jusqu'à une réalisation des rêves des scientifiques. Il importe de noter que l'article fait état de ce qui est advenu pour ceux qui ont continué à rêver, tandis que d'autres ont figé leurs imaginations ou sont devenus des toiles blanches empreintes de rêves d'autrui.