Imaging Africa: a strategic approach to optical microscopy training in Africa

Life scientists in Africa have had limited opportunity to participate in international advanced scientific training programs and workshops, which largely benefit researchers in North America, Europe and the Asia–Pacific region. Here, we chronicle the strategies adopted and challenges encountered in organizing Imaging Africa, an all-expenses-paid, continent-wide practical workshop in optical microscopy hosted in South Africa from 13 to 17 January 2020. Our experience can help steer other groups who similarly seek to organize impactful and sustainable training initiatives in Africa.

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Africa represents a critical front line in research against diseases that affect not only humans but also agricultural plants and livestock. The continent shoulders 23% of the global disease burden[1–5] while accounting for 17% of the global population[6]. Therefore, Africa offers the world a valuable window into the understanding of similar epidemics occurring elsewhere[7]. Likewise, as one of the few regions in the world where human populations frequently meld with diverse natural ecosystems, the continent also presents a valuable gateway to study and to preserve the delicate balance between environmental conservation and human needs[8]. Despite the many historical challenges, Africa is an essential pillar in global health, food security and environmental conservation that must be carefully developed and harnessed[9].

Consequently, investing in African research has been a continuing endeavor for a number of decades[10]. Many initiatives have sought to develop research infrastructure and capacity for the African scientific community[11–13]. These encompass a diverse range of priorities in both basic and translational research, with examples including H3Africa[14], the International Centre of Insect Physiology and Ecology[15], the South African Medical Research Council Genomics Centre[16], the West African Centre for Cell Biology of Infectious Pathogens, the Sub-Saharan African Network for TB/HIV Research Excellence, the Developing Excellence in Leadership, Training and Science (DELTAS) Africa program, the Kenya Medical Research Institute, the Forestry and Agricultural Biotechnology Institute, the Africa Health Research Institute, the Institut Pasteur International Network, the Botswana Harvard AIDS Institute Partnership and DrosAfrica[17]. Such efforts and many others[2,18,19] are helping equip scientific communities to perform cutting-edge research—particularly those in the regions targeted by these programs.

Bolstering scientific research capacity in resource-limited regions, however, requires more than adding technologies and infrastructure to be successful. It needs to be supplemented with the training of scientific talents to leverage the maximal capabilities of these technologies. The popularity of technique-specific workshops or boot camps, offered worldwide to train the next generation of scientists, is a testament to this necessity. Of equal importance, capacity building needs to embrace an approach that ensures equitable and widespread access to resources and training for African scientists from both resource-rich and resource-limited settings. Unfortunately, African scientists are often sidelined by workshops conducted in other continents due to prohibitive travel costs and the challenge of navigating the labyrinth of travel restrictions imposed on many African nationals[20]. Likewise, there have been precious few training opportunities on the continent, despite efforts such as IBRO-Simons Computational Neuroscience Imbizo (ISi-CNI)[21] and Deep Learning Indaba[22]. With limited opportunities for this type of skill development, African life scientists, if given a chance to attend an international workshop, tend to gravitate toward techniques most commonly used in their research. Unfortunately, this limits the opportunities for researchers in Africa to complement existing expertise with newer and potentially powerful methodologies that could benefit life science research on the continent. Here, we focused on microscopy for two reasons. First, microscopy is broadly used in life science research and is applicable across a large range of biological size scales, making it an ideal technique to engage scientists from a diverse cross-section of research disciplines. Second, microscopy workshops are generally resource intensive. An instrument collection that is representative of contemporary imaging methodologies can be cost-prohibitive for many African institutions, resulting in a dearth of comprehensive microscopy exposure and training opportunities. Therefore, a proactive solution is to bring the microscopy training opportunities directly to Africa—a process that could itself be confronted with various challenges.

In this Comment, we outline the hurdles of offering a continent-wide, all-expenses-paid microscopy boot camp course in Africa, the steps needed to overcome such difficulties and the ways that we implemented them in the Imaging Africa workshop. More importantly, we discuss how initiatives such as Imaging Africa might be received by the local scientific community, and how we maximized the local impact through creative, extracurricular community outreach activities. The insights gained from our experience could provide a blueprint for creating similar training programs in Africa and other developing regions of the world.

Challenges

A continent-level microscopy workshop will inevitably face a combination of challenges. Such an educational initiative requires advanced instruments, a well-equipped computer lab, long-distance travel and local housing. Furthermore, the success of such undertakings hinges on location, financial cost and equitable accessibility, as well as long-term sustainability of impact. It is

important that practical considerations be taken into account during initial planning. Logistical issues that must be considered during venue selection include ease of travel, research infrastructure accessibility and relative cost of workshop expenses, along with local institutional support and commitment for future offerings of the workshop. A challenge specific to a continent-wide workshop in Africa is the financial barriers that could exclude the majority of the target audience from attending. Travel costs in Africa are prohibitive for at least two reasons: the geographical isolation of many research institutes, which necessitates international air travel to attend workshops, and the lack of cost-effective long-haul transportation more commonly found in Europe, Asia and North America.

In addition, because of uneven research investment, not every African university has a sufficient instrument portfolio to complement the diverse practical aspects of a workshop. Therefore, to ensure that participants have the opportunity to gain valuable hands-on experience, organizers are heavily dependent on commercial partners. Although it is commonplace to invite industry participation in most imaging workshops, there is a considerable lack of commercial footprint in Africa. This precludes most microscope manufacturers from readily mobilizing their inventory to provide essential support for such workshops.

Africa is far from being a monolithic continent: the socioeconomic and technological differences among African countries are vast. Without careful forethought to take such factors into consideration, the participants in a continent-wide workshop will be heavily skewed toward those from countries that are more populous or that have significantly more established research infrastructure. This makes equitable skill development a key aspect to consider early on during planning. In addition, numerous past scientific undertakings driven by external investments that aimed to address this discrepancy have not always achieved their full potential[10–12,23] because of a lack of continued investment beyond initial efforts. It can represent a loss of opportunity and, worse yet, a waste of time and resources for all parties if the initial success of a workshop is not followed by longer-term engagement. Furthermore, without continued interest and engagement, there is less incentive and opportunity for skill-sharing between researchers and the spread of knowledge beyond the initial workshop participants. A failure to leverage the expertise of those who have benefitted from the workshop to disseminate knowledge would be a missed opportunity to create an amplification effect. Organizing a successful continent-level microscopy workshop therefore requires creative solutions.

Solutions and approaches

As an educational initiative aimed at addressing the problems outlined in the previous section, Imaging Africa offered a continent-wide, fully funded microscopy boot camp that combined (i) theory-based lectures, (ii) practical learning on a range of microscopes, (iii) hands-on, quantitative digital image processing and analysis and (iv) a symposium on emerging imaging technologies. One comparable opportunity is the ISi-CNI[21], which is conducted annually in Cape Town, South Africa, and is focused on, but not restricted to, students from Africa. Its curriculum centers around cutting-edge computational and theoretical neuroscience and is focused on training neuroscientists with complex data in realizing the full potential of their biological queries through advanced computational methods. In contrast, Imaging Africa aims to provide broader training of African life scientists regardless of their specific field of research. The goal here was to propel the all-African participants to a level at which hypothesis-driven experiments can be performed through advanced microscopy and meaningful biological information can be extracted with quantitative investigation.

Venue. The combination of reliable infrastructure and relative ease of travel pointed to Cape Town as a suitable location for the inaugural Imaging Africa workshop. The well-equipped Confocal and Light Microscope Imaging Facility at the University of Cape Town (UCT) also made the institution an ideal workshop venue. Furthermore, the success of such an undertaking hinges heavily on host institutional commitment. In this regard, the UCT Institute of Infectious Disease and Molecular Medicine (IDM) provided significant local support that included computer rooms, laboratory space, lecture venues and administrative assistance. An added advantage that a South African city offers is the established commercial footprint that would allow our industry partners to better support the week-long Imaging Africa course.

Financial support. The choice of Cape Town was not without its disadvantages, however. In addition to being one of the more expensive cities in Africa, it is also one of the farthest-removed locations on the continent. This exacerbated the cost of travel for attendees and posed a challenge in making the workshop freely accessible to all participants. To that end, the diversified support and funding sources from multiple philanthropic and commercial stakeholders (Howard Hughes Medical Institute, the Gordon & Betty Moore Foundation, the Chan-Zuckerberg Initiative, Zeiss Research Microscopy Solutions, and Oxford Nanoimaging) allowed us to cover all international and local travel, lodging, food, registration and other workshop-related costs for all attendees.

Equitable inclusion. Financial barriers are not the only obstacles that must be overcome to ensure diverse and inclusive participation. One responsibility that we recognized during planning was to make this training opportunity equitably accessible on a continent with a mixed record in addressing biased exclusion[24]. Imaging Africa strived to make participation in the workshop realistically attainable to any life scientist on the continent, regardless of background. However, we fully anticipated that applicants from highly populous or higher-income countries would dominate the applicant pool. Another well-established complication is that female participation in science is disproportionately low in Africa[24]. To address these challenges, we developed a selection process that adopted Diversity, Equitability and Inclusion (DEI) best practices[25]. Such consideration is essential in preventing the perpetual marginalization of scientists who otherwise would not have the opportunity to participate in training courses of this kind.

Advertisement. Having an equitable training opportunity does not necessarily translate into general awareness if the opportunity is unevenly communicated. Because our ambition was to make Imaging Africa as inclusive as possible, it was important to ensure that the workshop announcement was distributed to as wide an audience as possible. The greatest challenge we faced in this regard was finding methods to contact researchers from the many and distributed research communities throughout Africa, in part due to the paucity of centralized, continent-wide, community-based resources that would facilitate the announcement of our workshop. Therefore, our advertisement strategy was dependent on directed e-mail distributions as well as website and e-mail announcements by groups such as the Microscopy Society of Southern Africa and the Alliance for Accelerating Excellence in Science in Africa[26]. It is important to note that this was our first attempt to engage

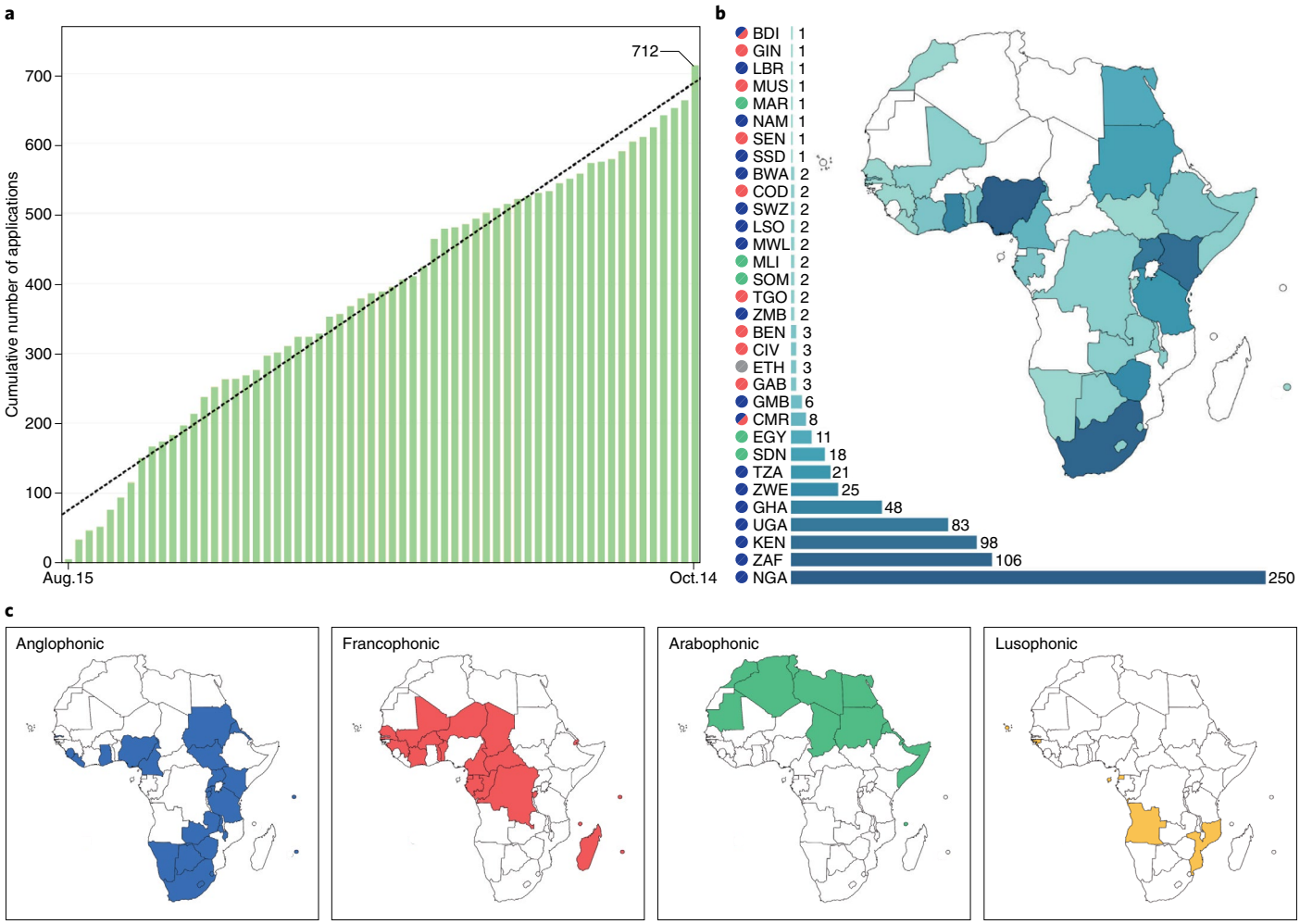

Fig. 1 | Distribution of applicants for Imaging Africa 2020. a, The cumulative total number of applications received during the 60-day enrollment period. Applications opened on 15 August 2019 and closed on 14 October 2019, during which time 712 eligible applications were received. **b**, Distribution of applications for Imaging Africa 2020 by nationality. The bar graph indicates the number of applications received from the corresponding, blue-highlighted countries in the map. The colored circles adjacent to applicant nations indicate the representative language(s) of that nation as per **c**. **c**, Overview of African nations with English (blue), French (red), Arabic (green) or Portuguese (yellow) listed as official languages[48] (linguae francae not included). BEN, Bénin; BDI, Burundi; BWA, Botswana; CIV, Côte d'Ivoire; CMR, Cameroon; COD, Democratic Republic of Congo; EGY, Egypt; ETH, Ethiopia; GAB, Gabon; GHA, Ghana; GIN, Guinea; GMB, The Gambia; KEN, Kenya; LBR, Liberia; LSO, Lesotho; MAR, Morocco; MLI, Mali; MUS, Mauritius; MWI, Malawi; NAM, Namibia; NGA, Nigeria; SDN, Sudan; SEN, Senegal; SOM, Somalia; SSD, South Sudan; SWZ, Eswatini; TGO, Togo; TZA, Tanzania; UGA, Uganda; ZAF, South Africa; ZMB, Zambia; ZWE, Zimbabwe. Maps of Africa were created using mapchart.net.

with the large and diverse African scientific community. Our strategy, which relied heavily on e-mail advertisement, can be improved upon in the future, as discussed below.

Applications and selection

Reception. The daily cumulative total number of applications received for Imaging Africa 2020 showed a consistent rate of enrollment during the two-month period, averaging 11.8 applicants per day (Fig. 1a). This resulted in a total of 712 applicants from 32 African countries (Fig. 1b), which was equivalent to a 30-fold over-subscription of the workshop. There were, indeed, a greater number of nationalities represented in the applicant pool than the number of open slots, 24, offered in the workshop. As was anticipated, Nigeria, the most populous African nation, fielded the most applications, with 250. Similarly, South Africa, which has the largest science expenditure per capita on the continent[23,27], produced the second most applicants, with 106. Together, these two countries—which represented one-sixteenth of the applicant nations—generated half of all applications received for Imaging Africa 2020. Though encouraging, the combination of a large applicant pool and a considerably skewed distribution of applicant nationalities posed a challenge in selecting participants. Furthermore, a considerable overlap between applicant nationalities and English-speaking countries was evident (Fig. 1b,c). This notable bias in applicant nationality toward English-speaking countries suggests that our message did not reach the non-Anglophonic scientific communities as effectively. Although the discrepancy cannot be explained by language alone, organizers of future initiatives should strive to correct this oversight.

Selection. The workshop attendees were selected based on their responses to the

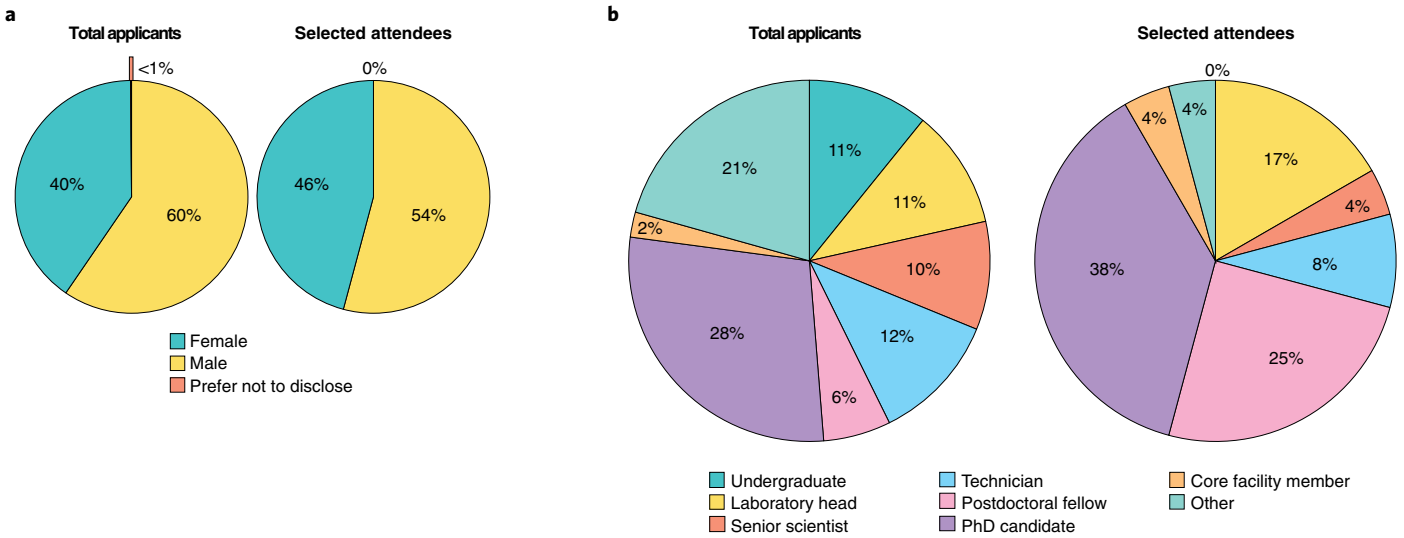

Fig. 2 | Maintaining a diverse and representative composition of workshop attendees. a, Comparison of the gender representation in Imaging Africa applicants ($n = 712$) and attendees ($n = 24$). One applicant preferred not to disclose gender. **b**, Proportional representation of different career stages among applicants and workshop attendees.

application form. The application form was carefully designed with the intent to allow prospective attendees to gauge their own knowledge of and experience with a wide range of microscopy techniques. It asked the applicants to state, in their own words, their specific expectations and the desired personal outcomes should they attend the workshop. Furthermore, the applicants were tasked with explaining how they would transfer the knowledge they acquired at the workshop to their colleagues. Additionally, all applicants were required to summarize their current research and how it could be facilitated by microscopy.

The overwhelming number of applicants necessitated a streamlined and partially automated review process. However, we feared that this might sideline applicants from under-represented nations. Therefore, we employed a two-tier approach that acted to preserve as much national diversity as reasonable. In the first-tier selection step, a stricter exclusion criterion was used to specifically reduce the number of applicants from the five most highly represented countries (Fig. 1b). Applications from Nigeria, South Africa, Kenya, Uganda, and Ghana were more heavily scrutinized during the review process based on the applicants' self-reported microscopy expertise. Thereafter, applications from the remaining 26 nations (Fig. 1b) were assessed based on the applicants' prior exposure to any modality of microscopy. Together, the remaining 68 applications were reviewed and independently scored by all teaching faculty members. This second-tier evaluation was blinded to nationality and gender. The applicants were scored based on a holistic evaluation of each applicant's justification for training, opportunity for skill dissemination, prior microscopy experience and future microscopy needs. The 24 applications with the highest cumulative scores were selected.

Attendee representation. This selection process successfully maintained a high degree of diversity across numerous factors. Of the 24 successful applicants, 14 and 10 were ultimately chosen from the pools of highly represented and less represented countries, respectively, with a total of 14 nationalities being represented. After our blind selection process, 46% of successful applicants were female (Fig. 2a). In regard to career stage, PhD students, laboratory technicians, core facility personnel and lab heads were fairly represented, while senior scientists and postdoctoral fellows were not (Fig. 2b). Although we were largely successful in maintaining diversity, in future we plan to increase our efforts to improve representation to include people from more countries and career stages as well as with a more diverse range of imaging experience. It should be noted that for a continent-wide workshop, maintaining attendee diversity is heavily dependent on context-specific factors such as the course content and the composition of the initial applicant pool. As such, organizers of other workshops are advised to filter applicant pools based on these factors while at the same time adhering to fair inclusion and equity practices.

Course design

Many aspects of Imaging Africa followed a standard curriculum seen in microscopy workshops conducted elsewhere. Lectures were given on a variety of topics, and the curriculum included (i) the fundamentals of optics, (ii) basic contrast methods in microscopy, (iii) fluorophores and fluorescence microscopy, (iv) advanced microscopy modalities, (v) image processing and analysis and (vi) the use of microscopy in research areas relevant to Africa. Our lectures were further enhanced by corresponding hands-on exposure to various microscope systems (Fig. 3). The topics and the depth at which they were covered were tailored in response to the information provided by attendees in their applications. We also supplemented fundamental topics with advanced techniques to highlight how complex biological questions can be further investigated. By covering both basic and advanced methods, we aimed to broaden the attendees' horizons and encourage further interest in applying different microscopy techniques to their research.

Aside from the curriculum, effective delivery of the content to a range of learning styles[28,29] was an equally important element for the workshop. In general, we have found that it is highly effective to teach microscopy-related content to life scientists in a manner that makes biological query the central component. Corresponding to the research interests of the attendees (Supplementary Table 1), discussions during the workshop focused on how microscopy can be used to address a wide

Fig. 3 | Immersive learning and hands-on experience with a broad range of microscopy tools. Left, Imaging Africa attendees and teaching faculty working with field-ready, low-cost mobile phone microscopes. Right, for the group project, participants used and compared samples between various imaging techniques, such as structured illumination microscopy (SIM). Photo credit: M. Reiche.

variety of topics, such as infectious disease research and plant biology. This approach was especially beneficial to this audience and helped the attendees contextualize the microscopy applications within their own knowledge of the biological topics important to them. This general strategy was also effective given that for many, the full breadth of microscopy may have been viewed in an unfamiliar light. To make the microscopy topics more accessible, the course material was delivered in a hypothesis-driven, quantitative experimental design format[30]. Furthermore, this approach dovetailed effectively with our intention of creating an immersive learning experience that emphasized class discussion, hands-on practical exposure, opportunities for informal interaction and team projects. This interactive teaching method is also accommodating given the diverse set of culturally rooted learning styles typical to the continent[29,31]. As an example of such an approach, the attendees were provided suitable background information about a biological process and then formulated hypotheses about the observed phenomena. They then discussed and designed microscopy-based experiments in small working groups to test these hypotheses using their newly acquired knowledge. This allowed us to minimize top-down didactic teaching and empower the students to synthesize the solutions to research problems and devise their own microscopy-based experiments. Furthermore, we included a full section of the workshop dedicated to hands-on exploration of mobile-phone-based microscopes[32] (Fig. 3), a tool that has been shown to have unique relevancy to many parts of Africa[33,34]. Overall, wherever possible we purposely steered away from passive learning and toward interactive and learner-centric approaches, with the hope that this would lead to a better understanding of the content and increased microscopy utilization in the future.

Course outcomes

Figure 4 highlights the attendees' responses to a few notable questions in the anonymous post-workshop survey. The most favored components of the workshop were (i) the focus on how microscope choice should fit into the larger scheme of experimental design and (ii) image data processing and analysis. The unanimously positive response to learning how different microscope modalities are specifically and effectively used to investigate different types of biological questions lent credence to this teaching approach. In the experimental design process, microscope choice is intimately linked to image processing and analysis[30]. The Imaging Africa attendees found the latter topic to be most beneficial for their immediate experimental needs. The considerable interest in image analysis further highlights the need to develop these skills among scientists in Africa. Importantly, by focusing on the open-source Fiji software package[35] as the main image analysis tool, we ensured that all techniques presented at the Imaging Africa workshop were freely accessible.

Overall, all of the participants shared a strong desire to gain more hands-on exposure to both the preparation of samples and the use of microscopes. However, most attendees initially approached the workshop with a desire to "learn how to operate the microscope" rather than to understand its fundamentals. Although direct, practical training is undoubtedly beneficial in developing microscopy skills, learning how to operate an instrument without adequate underlying microscopy knowledge can result in an incomplete understanding of the application of microscopy, inadvertently denying the learner access to the full utility of available technologies or leading them to erroneous results[30]. We therefore made it clear early in the course that our focus would be on helping to equip the attendees with the knowledge and confidence to apply microscopy in their research, and not to provide an 'operator's manual' for a given microscope. This realignment of expectations was remarkably well received at the conclusion of the workshop (Fig. 4). The participants ultimately recognized and appreciated how optimal microscope selection and proper utilization was critical within the grander scheme of experimental set-up. This, in turn, reinforced the understanding of how proper experimental design facilitates subsequent quantitative analyses and can ultimately reveal meaningful biological insights.

The workshop, however, was not without its pitfalls. We learned that the intensive nature of our workshop, in which participants were expected to work on their projects late into the evening, was counterproductive, resulting in rapidly diminishing learning efficiency. Owing to their relative lack of exposure to the fundamentals of microscopy, the attendees required more time to absorb the course material and to rationalize the approaches necessary for the class projects. We were also constrained by the number of microscopes available to the attendees. Even though several high-end instruments were made available to us by our industry partners and the host institution, the attendees craved the opportunity to gain more hands-on experience with the microscopes (Fig. 4). The feedback received underscores the

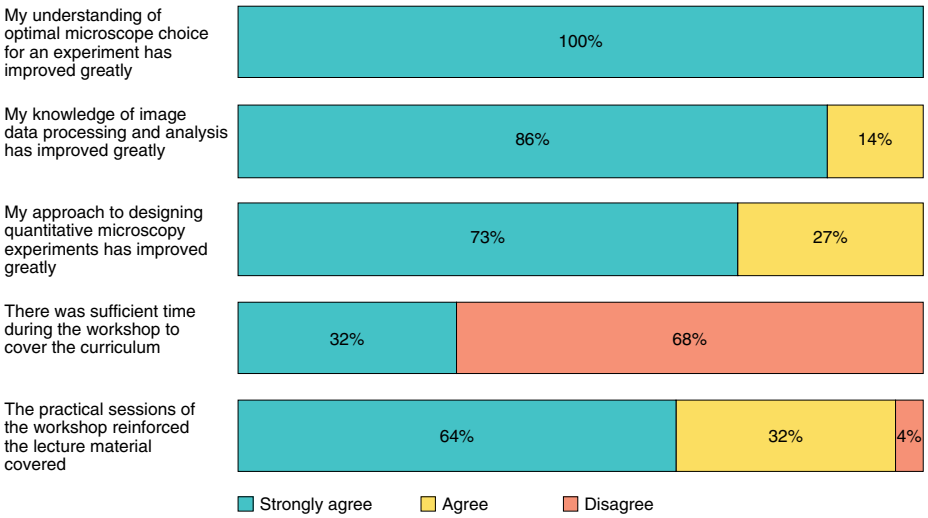

Fig. 4 | Responses to selected survey questions. The tallied anonymous responses of attendees assessing various outcomes of the workshop. Specifically, attendees were asked to rate their knowledge improvement following the workshop and to provide an indication of whether they felt the workshop content was well balanced between theoretical lectures and hands-on exposure. Total responses = 22.

importance of extending the duration of future workshops or distributing pre-workshop learning material.

Of notable interest was feedback regarding how attendees learned of Imaging Africa. Awareness of the workshop was predominantly propagated through personal communications from colleagues or friends through platforms such as e-mail and messaging apps. This observation is indeed extremely important to share, as future workshop organizers should bear this in mind when designing an advertising strategy. This also highlights the importance of developing a connected imaging community of African researchers to disseminate learning opportunities more effectively in the future.

Expanding the impact of Imaging Africa

Organizing a training course in South Africa also presented us with several extracurricular opportunities to further multiply the immediate impact of the workshop. In this manner, we were able to extend the outreach of the program to both the local community and the wider scientific audience in South Africa.

Eh!woza. South Africa transitioned from an oppressive, racially segregated past only 27 years ago. The structural legacy of apartheid persists most visibly in the existence of 'townships'—peri-urban areas which historically served to keep non-white individuals outside economic centers. Rates of infectious diseases, such as tuberculosis and HIV infection, remain high in these areas. By engaging with young people in townships, Eh!woza[36], a public outreach organization, aims to empower students through a better understanding of infectious disease research as well as to enable them to tell their own stories about the impact of these diseases. With a congregation of young African scientists who have successfully made their way through post-graduate studies, Imaging Africa provided an ideal opportunity to inspire youth from the largest township in Cape Town, Khayelitsha. In collaboration with Eh!woza, 20 high-school students (15–18 years old) joined the workshop delegates one afternoon for lunch and discussed perspectives on tertiary education. Thereafter, the Eh!woza group attended short talks given by the international faculty members. To create an immersive and engaging experience, the youth group tested mobile phone microscopes[32] and were given an origami-based 'Foldscope'[37] that they assembled and used to visualize a selection of microscopy slides. The combination of interaction with the Imaging Africa attendees and hands-on experience with the Foldscope not only exposed the members of the youth group to science, but also provided them a tool that could be used to propagate the excitement of exploring the microscopic world with their peers.

Symposium. The Imaging Africa workshop brought together a unique group of attendees, faculty members and commercial partners, which provided an ideal opportunity to include a larger audience through a research symposium. Furthermore, the entire international faculty team shared many common research priorities pertinent to Africa, including infectious disease research, the development of inexpensive tools for use in resource-constrained settings, and making microscopy and imaging probes widely and freely available. For the symposium, we ensured that everything presented was either directly applicable or readily available to the African audience. Further, the symposium was held in conjunction with a poster session featuring the research of the workshop attendees as well as some of the South African scientific audience. The event, titled "Advancing Microscopy Frontiers in Africa," established a platform on which the international team as well as South African scientists jointly presented their research and provided a strong conclusion to the week-long Imaging Africa program. We hope that this community-wide microscopy exposure will serve as a catalyst for future microscopy interest and excitement.

Discussion

We believe that Imaging Africa can serve as an example of how to approach an endeavor of this nature (see Supplementary Fig. 1 for a plan overview). Overall, the approach must be formulated in a way that is capable of encompassing and balancing the vast socioeconomic and geographical differences within Africa. Equitable admission processes must adhere to the best practices of DEI[25,38–40], particularly at this continental scale. One of the key principles discussed here is the importance of tailoring the curriculum to local research priorities and ensuring that it puts biological inquiry first and technologies second. It is interesting to note that many students enrolled in the microscopy workshop expecting to learn how to 'operate' the microscopes. Such an expectation is understandable, given their limited prior microscopy experience in many cases. Yet, the attendees subsequently approved, with unanimity (Fig. 4), of our emphasis on how to 'utilize' microscopy through hypothesis-driven, quantitative experimental design[30]. Although our post-workshop evaluation was designed to capture performance indicators of the training program that will help us improve future iterations of the workshop, we also measured the overall success of Imaging Africa in several other key aspects. These included (i) the workshop's effectiveness in conveying to the attendees the importance of designing biological experiments that rationally utilize microscopy approaches, (ii) the longer-term impact on the attendees and the successful application of their

Box 1 | The intangible elements of Imaging Africa

The Advanced Imaging Center (AIC) at the Howard Hughes Medical Institute's Janelia Research Campus has received hundreds of applications from researchers around the globe seeking to take advantage of the unique pre-commercial imaging technologies and expertise it offers[49]. However, to date we have received only a single proposal from the entire continent of Africa—a glaring problem that prompted us to examine the underlying causes. To a large extent, this under-representation is the direct result of our own neglect in promoting this unique accessibility program to African scientists. Further examination revealed that our oversight was emblematic of a more systemic problem. Not only is there a scarcity of training programs in Africa, but those that are available tend to be localized to a specific region or country.

The idea of organizing the Imaging Africa workshop was initially seeded by Michael Reiche, a molecular microbiologist from South Africa, who joined the AIC as an Advanced Imaging Fellow[50]. Having a first-hand, local perspective helped raise our awareness of how to navigate some of the challenges of hosting a continent-wide workshop in Africa. By listening to and incorporating this invaluable perspective, we were able to maximize the impact of this major undertaking.

The most long-lasting impression for the teaching faculty was of the students—a remarkable array of talented scientists whose commitment to their research was palpable and whose desire to learn was contagious. It was inspiring to discuss with, and learn from, the attendees about their research priorities during many informal conversations. What made the experience even more gratifying was learning that their research was largely initiated and propelled by real and immediate needs affecting their communities.

Very important, too, was the collapsing of hierarchies—any notions of a faculty–student distinction dissipated almost immediately at the onset of the course. It was precisely this informal camaraderie between the faculty and the attendees that made the experience special. We were further uplifted by the strong sense of pride among the attendees, many of whom considered themselves to be representatives of their respective scientific communities. Moreover, each attendee recognized their responsibility to share the experience they gained with others at their home institutions. We have been encouraged to learn that many of the attendees continue to sustain their new-found friendships after the workshop, which will hopefully pave the way for future collaborative partnerships.

An intangible but powerful result of the Imaging Africa workshop was its impact on everyone who was involved with it. This included University of Cape Town staff and students, who volunteered their time simply to be able to say they had taken part, as well as commercial vendors who reiterated how encouraging it was to have an event on their calendar that had Africa-wide involvement as its ethos. Engaging with the grass-root initiative of Eh!woza left a long-lasting emotional imprint on everyone involved. The ambition, curiosity and dedication of the youth in this program struck a personal chord with the teaching faculty, who took it as a compelling and hopeful sign for future scientific talent in Africa. Ultimately, this experience has not only reinforced our concerted desire for further partnership in Africa, but has also shown that bold, long-lasting, continent-level engagement is possible.

new microscopy knowledge in their own research and (iii) the galvanizing effect of the workshop in bringing the African microscopy community together. The latter is exemplified by the recently established African BioImaging Consortium (ABIC, http://www.africanbioimaging.org/), which aims to develop and connect microscopists and biologists throughout Africa. This community-driven endeavor was seeded as a direct outcome of the Imaging Africa workshop and seeks to expand the role microscopy plays in biomedical research on the continent by making microscopy expertise, resources and opportunities more accessible. With current membership representing 51 African institutions, ABIC will serve as an effective conduit for future communication of Imaging Africa. This centralized community hub will help in overcoming the information silos illustrated in Fig. 1c and allow microscopy training opportunities to reach more researchers throughout Africa.

Reciprocally, this workshop offered tremendous learning opportunities for the teaching team and stakeholders alike (Box 1). It is likely that the obstacles we faced in organizing Imaging Africa are fundamentally similar in nature, if not in extent, to the challenges one would face in other resource-constrained regions of the world. We found that informal conversation with local scientists and the workshop participants proved immensely informative in guiding us to formulate a roadmap for future expansion of our endeavor. The issues and barriers expressed by members of the African scientific community include (i) uneven and inequitable access to research infrastructure, (ii) a paucity of exposure to many advanced techniques, (iii) a lack of intra-continental collaboration[41,42] and (iv) frustration over the marginalization of African scientists with respect to global research resources[43]. The next phase of our engagement must be a mandate that will more universally address the hurdles in instrument accessibility, training, expertise availability and global partnership for African life scientists.

The overwhelming number of applicants to the workshop, at nearly 30-fold the available workshop capacity, signals an indisputable message: there is a pressing need for microscopy training initiatives that are reserved specifically for the diverse African scientific community. This should assuage any doubt about whether such educational outreach programs will be well received. In fact, it has created a momentum that must be collectively harnessed by funding agencies, multinational organizations such as Global BioImaging[44] and any scientist enthusiastic about sharing their expertise with a talent pool of great potential. However, the empowerment of African scientific talent cannot be achieved through uncoordinated, one-off undertakings. It will require steadfast commitment and planning to effectively broaden scientific participation in Africa. Otherwise, the impact of any single, well-intentioned effort diminishes rapidly with time: the initial enthusiasm will quickly be overshadowed by other local and pressing challenges[45], and the propagation of the skills and knowledge attained at the training courses will be halted. The foundational knowledge learned during training programs must be continually reinforced and, more importantly, amplified through peer-to-peer exchange. It therefore necessitates a sustained, multipronged effort to ensure continued dissemination of knowledge and adoption of microscopy.

To maintain the momentum of Imaging Africa, we developed the Imaging Africa Microscopy Club: an online journal club focused on the application of microscopy in research topics central to the African community. The Imaging Africa workshop, together with the Microscopy Club, were therefore our initial one-two punch to

launch the initiative. Building on this, we aim to improve future iterations of our workshop based on feedback from the attendees. First, we will rotate the Imaging Africa workshop through a number of host institutions and nations. Second, it is equally important to supplement the current workshop with additional, science-focused training programs. Examples of this complementary approach include smaller, 'satellite' workshops that focus on sample preparation, microscopy techniques and related data analyses specific to targeted research topics. Workshops at different levels serve distinct roles. On one hand, smaller, science-focused workshops can dive deeper into the application of microscopy in specific topic areas. On the other hand, a microscopy workshop such as Imaging Africa raises the general awareness of what microscopy can do as it provides a more comprehensive survey of the available techniques. Furthermore, large, continent-wide workshops can be more inclusive of researchers from a variety of scientific backgrounds.

Indeed, the week-long Imaging Africa workshop brought together scientists from diverse scientific, geographical and cultural backgrounds to partake in various class projects as teams. It strengthened collaborative spirit among the attendees[23], and it kindled close friendships that would not have developed otherwise. However, it is important to note that mere attendance at a workshop does not necessarily translate into long-term participation and engagement. We need to devise creative approaches to incentivize the workshop attendees to continue their exploration in imaging science and, even more importantly, to pass along the knowledge learned from these workshops to their peers. To this end, the use of low-cost, open-source tools—such as Fiji[35], CellProfiler[46] and Octopi[47]—in the future will allow subsequent workshop attendees to venture into their own explorations at the conclusion of the training course. Likewise, it is important to encourage African scientists to take the lead in advocating microscopy education and implementation throughout the continent. As such, we plan to facilitate an online microscopy webinar series that can achieve a twofold effect. First, it will establish an opportunity to introduce basic course concepts to incoming Imaging Africa students. Second and more importantly, it will also provide a platform for African microscopists and Imaging Africa alumni to share their knowledge with their peers. Ultimately, this will help sustain the momentum generated by the Imaging Africa workshop and provides strong role models for young scientists to follow. It also engenders a strong message that this is science for Africa, by Africans.

The Imaging Africa initiative aims to inspire other future workshops as much as it seeks to facilitate the current training program. It offers a vignette of the many promising approaches to empower the African research community. In parallel, it highlights the necessity of enlisting commercial partners for the success of such undertakings. It also underscores the need for funding agencies to be receptive and nimbly responsive to bold and pioneering educational ventures. We are hopeful that the demonstrated success of Imaging Africa will incentivize funding agencies and industry partners to support future open-access training programs. Similarly, we eagerly look forward to future initiatives spearheaded by experts in other technical fields. Any successful effort should have at its core a sincere desire to work hand-in-hand with our African colleagues as part of the global scientific community. Ultimately, the African scientific community and the local governments should be supported in their own research agendas and priorities[10,43]. African scientists should be welcomed as integral members of the global scientific discourse, decision-making and research endeavors[24]. The experience of African scientists in the innovative use of limited resources, coupled with their strong intellectual and cultural contributions, can only strengthen the development of solutions to the many great challenges facing this increasingly connected world. ❐

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Competing interests

The authors declare no competing interests.

Additional information

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