

AFRI-RELAB: Africa Remote Laboratory Network

An Inclusive AI-Enabled Remote Scientific Instrumentation and Experimentation Network for Africa



Proposed pilot host: Jaramogi Oginga Odinga University of Science and Technology (JOUST),
Kenya

Initial flagship component: Physics eLabs-AI

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Executive Summary

AFRI-RELAB (Africa Remote Laboratory Network) is a proposed pan-African shared scientific infrastructure designed to democratize access to real laboratory experimentation and advanced scientific instruments. It will enable researchers, students and innovators to securely access laboratories remotely, reserve instruments, control approved experimental parameters, observe physical experiments through live video, acquire real data and retrieve reproducible experimental records without travelling to the host laboratory. The initiative addresses a major barrier to African scientific advancement: advanced laboratory equipment is expensive, unevenly distributed and often inaccessible to researchers at under-resourced and geographically isolated institutions. Rather than requiring every university to purchase every instrument, AFRI-RELAB will transform suitable existing equipment into shared, remotely accessible scientific infrastructure, increasing utilization and the return on existing research investments.

AFRI-RELAB will support **Physics, Chemistry, Biology, Engineering, Materials Science, Renewable Energy, Environmental Science and Biotechnology**. Its innovation lies in integrating real physical experimentation with secure remote instrument control, synchronized video streaming, AI-assisted laboratory support, digital twins, research-data provenance and accessible interfaces within a federated African network. Inclusion is central to the model. The platform will prioritize researchers and learners from marginalized and under-resourced communities, including persons with disabilities, women and other groups underrepresented in STEM, rural institutions, TVETs and users with limited connectivity through assistive technologies, mobile-first access, low-bandwidth modes and equitable instrument allocation.

The initiative will begin with a controlled pilot at JOOUST, Kenya, building on Physics eLabs-AI as its first flagship program, before expanding through institutional partnerships into a Kenyan, East African and ultimately pan-African network. AFRI-RELAB offers funders an opportunity to invest not simply in additional laboratory equipment, but in a scalable system that multiplies the reach, utilization and societal impact of Africa's existing and future scientific infrastructure.

1. Vision and Strategic Positioning

Vision

To create an Africa in which access to high-quality physical experimentation and scientific instrumentation is determined by scientific need, curiosity and capability and not geography, disability, gender, institutional wealth or the local availability of specialized laboratory equipment.

Mission

To establish a trusted, inclusive, secure and interoperable pan-African network through which universities, research institutions and other approved scientific facilities share controlled remote access to real scientific instruments, experimental stations, research data, technical expertise, AI-assisted laboratory services and digital-twin resources.

AFRI-RELAB will serve both research and education. Its scientific scope will progressively encompass Physics, Chemistry, Biology, Engineering, Materials Science, Environmental Science, Renewable Energy, Biotechnology and other disciplines in which physical instruments and experimental processes can be safely and meaningfully accessed remotely. The initiative is based on a shared-infrastructure

model. Rather than attempting to establish every scientific capability at a single location, participating institutions will contribute complementary experimental resources to a federated network. One institution might provide remotely accessible spectroscopy, another materials characterization, another renewable-energy testing, another biological microscopy, and another environmental monitoring. Researchers will discover and access these capabilities through a common AFRI-RELAB environment.

AFRI-RELAB is explicitly not a virtual simulation laboratory. Simulations, AI models and physics-, chemistry- or biology-informed digital twins will complement physical experimentation but will not replace it. Digital twins can allow users to prepare experiments, predict outcomes, investigate parameter spaces and compare theory with observations. The defining scientific service, however, remains interaction with real physical equipment and acquisition of real experimental measurements as shown in Figure1. This distinction is important because authentic experimentation exposes researchers and learners to effects that idealized simulations frequently suppress: measurement uncertainty, instrument resolution, noise, calibration drift, environmental variability, sample heterogeneity, systematic errors, equipment limitations and unexpected physical or biological behavior. AFRI-RELAB therefore seeks to preserve the scientific authenticity of laboratory experimentation while removing unnecessary geographical and accessibility barriers.

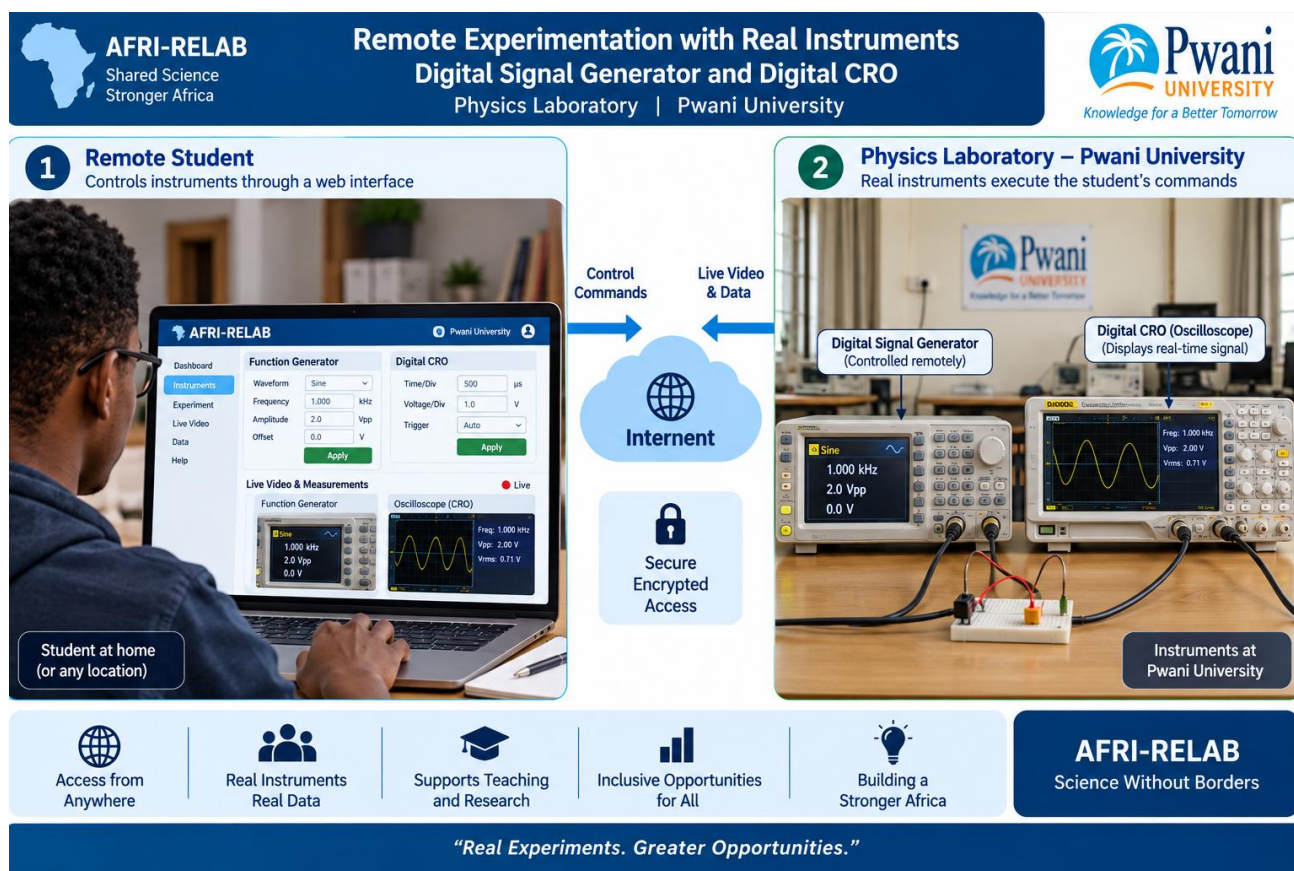


Figure 1. A remote student securely controls a digital signal generator and digital cathode-ray oscilloscope (CRO) in the Physics Laboratory at Pwani University through the AFRI-RELAB web interface. Control commands are transmitted to the physical instruments, while live video, measurements, and experimental data are streamed back to the student in real time (adapted from [1]).

2. The Problem AFRI-RELAB Addresses

Scientific progress increasingly depends on access to sophisticated experimental equipment. Yet across many African institutions, research capability is constrained not simply by a complete absence of scientific instruments, but by their **unequal geographical distribution, high acquisition and maintenance costs, limited specialist technical support, restricted access, and inefficient sharing of equipment that already exists.**

A researcher may have the expertise and a scientifically important question but lack access to a particular spectrometer, microscope, electrochemical workstation, data-acquisition system or materials-characterization instrument. This can require long-distance travel, shipment of samples to distant laboratories or overseas facilities, postponement of experiments, dependence on external collaborators, or redesign of research around whatever equipment happens to be locally available.

The resulting inequality particularly affects researchers at rural and emerging universities, TVET institutions, institutions with limited research funding, early-career researchers, persons with disabilities and other groups that face additional barriers to accessing centralized scientific infrastructure.

AFRI-RELAB addresses six interconnected barriers:

- a. **Geographical inequality.** Advanced scientific instruments and specialized laboratories are concentrated within a relatively small number of institutions and urban centers. Researchers located far from these facilities face significant logistical and financial barriers to accessing them.
- b. **Economic inequality.** Replicating expensive instrumentation across every university is financially unrealistic. At the same time, travel, accommodation, sample transportation and external laboratory charges can place existing facilities beyond the reach of researchers with limited funding.
- c. **Accessibility inequality.** Conventional laboratory environments and instrument interfaces may create substantial barriers for researchers and students with mobility, visual, hearing or other accessibility requirements. Scientific infrastructure should adapt to diverse researchers rather than requiring every researcher to interact with equipment in exactly the same way.
- d. **Digital inequality.** Remote laboratories designed around continuous high-speed broadband could simply reproduce existing inequalities in a digital form. AFRI-RELAB must therefore function across a range of connectivity conditions, including mobile devices, constrained bandwidth and intermittent connections.
- e. **Underutilization of scientific infrastructure.** Some scientific instruments have periods of unused capacity. Where technically, ethically and operationally appropriate, part of this capacity could support researchers from other institutions through controlled remote access, increasing the scientific return on existing infrastructure investments.
- f. **Fragmentation of scientific resources.** African institutions currently lack a common framework through which researchers can discover available instruments, determine their capabilities, obtain authorization, reserve experimental time, interact remotely with equipment, receive standardized experimental records and manage research data securely.

AFRI-RELAB will respond to these challenges by creating the technical, institutional and governance infrastructure necessary to transform distributed laboratory resources into a **shared African scientific capability.**

3. Core Value Proposition

AFRI RELAB reframes the research infrastructure challenge from “*Does every university need to own every scientific instrument?*” to “*Can every qualified researcher obtain equitable, safe and auditable access to the scientific instruments and experimental capabilities they need?*”

The network will treat suitable laboratory capacity as shared scientific infrastructure while preserving institutional ownership, safety, scientific quality, research confidentiality, intellectual property and local operational authority. This approach increases the value and utilization of existing facilities while extending access to institutions and researchers that lack equivalent infrastructure. Table 1 summarizes the value AFRI RELAB provides to its principal stakeholders.

Table 1. AFRI RELAB value proposition for key stakeholders

Stakeholder	AFRI-RELAB Value
Researchers	Remote access to real scientific instruments, physical experiments, raw data, specialist support and reproducible experimental records without unnecessary travel.
Postgraduate students	Access to instrumentation needed for MSc and PhD research even when the equipment is unavailable at their home institution.
Under-resourced and rural universities	Access to scientific capabilities that would otherwise require substantial capital investment, infrastructure and specialist personnel.
Students and trainees	Authentic practical experience with real instruments, real experimental uncertainty and real scientific data rather than simulation alone.
Researchers and learners with disabilities	Multimodal interfaces, voice interaction, captions, screen-reader compatibility, keyboard navigation, audio descriptions and alternative representations of experimental information.
Women and other groups underrepresented in STEM	Targeted access, mentoring, training opportunities and mechanisms designed to reduce structural barriers to experimental research participation.
Host institutions	Increased instrument utilization, institutional visibility, collaboration, research output, postgraduate training and potential cost recovery.
TVET and emerging institutions	Access to advanced experimental infrastructure and opportunities for staff and student capacity building.
Governments and research funders	Greater scientific return from existing infrastructure investments and stronger national and regional research collaboration.
Industry and start-ups	Controlled access to appropriate testing, measurement and characterization facilities subject to institutional, safety and intellectual-property policies.
African scientific community	A progressively interconnected ecosystem of laboratories, researchers, data, instruments and expertise across institutional and national boundaries.

4. Users and Inclusion Model

AFRI-RELAB will be designed as an inclusive scientific infrastructure rather than merely an online booking platform. Eligibility, prioritization, pricing and instrument-time allocation will therefore be

transparent and structured to ensure that groups already disadvantaged by geography, disability, institutional resources or connectivity are not further marginalized.

The network will support *university researchers, postgraduate students, supervised undergraduate students, TVET institutions, research institutes, educators, innovators, approved start-ups and industry researchers* where appropriate.

Particular attention will be given to researchers and learners from marginalized or underserved groups and institutions.

Key inclusion mechanisms will include:

- a. **Reserved instrument-access capacity** for qualifying researchers from institutions with limited laboratory infrastructure.
- b. **Subsidized or grant-supported experimental credits** for marginalized researchers, students and under-resourced institutions where funding permits.
- c. **Accessibility profiles** that automatically configure the laboratory interface according to individual requirements, including captions, audio descriptions, screen-reader compatibility, keyboard-only navigation, enlarged displays and voice interaction.
- d. **Mobile-first access**, enabling researchers to interact with suitable experiments using smartphones, tablets and modest computers rather than requiring high-performance workstations.
- e. **Adaptive low-bandwidth operation**, allowing users to prioritize experimental controls, numerical measurements and essential visual information when full high-definition video is impractical.
- f. **Intermittent-connectivity workflows** for experiments that can safely support them. Approved experimental parameter sets may be validated in advance, executed by the laboratory control system, and synchronized with the researcher when connectivity resumes.
- g. **Multiple video-quality levels**, ranging from synchronized high-definition multi-camera observation to low-frame-rate or periodically refreshed experimental images.
- h. **Multilingual laboratory assistance**, progressively incorporating selected African languages alongside English to reduce language barriers in scientific training and instrument operation.
- i. **Assistive AI technologies**, including speech-to-text, text-to-speech, automated captions, visual descriptions and natural-language interaction with experimental interfaces.
- j. **Gender-responsive outreach and mentorship**, including targeted onboarding and research opportunities for women and other groups underrepresented in STEM.
- k. **Transparent and equitable scheduling**, preventing institutions with greater financial resources, stronger connectivity or larger research teams from monopolizing shared instrumentation.
- l. **Local support and capacity building**, ensuring that remote access complements rather than replaces African laboratory technologists, scientists and engineers. Host-institution personnel will remain essential to instrument maintenance, calibration, sample preparation, safety and technical support.

The objective is therefore not simply to put laboratory instruments online. It is to create an **equitable scientific access system** in which a capable researcher should not be excluded from meaningful experimentation because of where they live, the institution they attend, a disability, limited financial resources or inadequate local laboratory infrastructure.

In this sense, AFRI-RELAB positions **scientific experimentation itself as a shared African resource**.

5. Scientific Scope

The network will expand progressively according to technical readiness, safety, scientific value, and the level of on site support required. Priority will be given to instruments with programmable control and data acquisition, clearly defined operating limits, and a practical separation between activities requiring physical presence, such as sample preparation, loading, calibration, and maintenance, and those that can be performed remotely.

The scientific scope will progress from high readiness pilot stations through moderately complex experimental systems to advanced analytical instrumentation and, ultimately, integrated automation and robotics. Table 2 presents the proposed phased expansion and remote readiness of the laboratory stations.

Table 2. Proposed scientific scope and phased expansion of remote laboratory stations

Phase	Remote station	Example capability	Remote readiness
Pilot	Electronics & Instrumentation	Oscilloscope, function generator, programmable power supply, DMM	High
Pilot	Sensors & DAQ	Temperature, pressure, force, acceleration, humidity and environmental sensors	High
Pilot	Renewable Energy	PV I-V characterization, battery/load measurements under safe operating limits	High
Pilot	Analytical Chemistry Measurements	pH, conductivity, temperature, colorimetry and remotely controlled sensor-based measurements	High
Pilot/Phase 2	UV-Vis Spectroscopy	Absorbance/transmittance spectra, wavelength scans, concentration studies and optical characterization after sample loading	Medium-High
Phase 2	Mechanics	Motion, vibration, oscillations and dynamics using cameras and sensors	High
Phase 2	Electrochemistry	Potentiostat-controlled cyclic voltammetry and related measurements using pre-prepared approved cells	Medium
Phase 2	Biology - Microscopy	Remote bright-field/digital microscopy, motorized stage control, focusing, image acquisition and quantitative image analysis of prepared specimens	Medium-High
Phase 2	Biology - Environmental & Plant Sciences	Remote monitoring of temperature, humidity, light, soil moisture, water quality and plant/environmental responses	High
Phase 2	Chemistry - Kinetics	Remote monitoring of reaction kinetics using spectroscopy, temperature, pH or conductivity with pre-prepared systems	Medium
Phase 2	Chemistry - Physical Chemistry	Optical, thermal, electrochemical and physicochemical characterization of approved samples	Medium-High
Phase 2	Biochemistry	Spectrophotometric enzyme/protein assays and other non-hazardous measurements using pre-prepared samples	Medium

Phase 3	Raman / FTIR Spectroscopy	Molecular identification and vibrational spectroscopy where remote instrument APIs permit	Medium
Phase 3	X-ray Diffraction (XRD)	Supervised remote crystallographic measurements after on-site sample preparation and mounting	Medium
Phase 3	Materials Microscopy	Remote optical/digital microscopy and, where technically supported, supervised SEM imaging	Instrument-specific
Phase 3	Biology - Microbiology Observation	Remote imaging and quantitative observation of appropriately prepared, non-hazardous cultures/specimens	Medium
Phase 3	Biology - Molecular Biology Instrumentation	Remote acquisition from instruments such as plate readers and approved automated molecular-analysis systems, with on-site sample preparation	Instrument-specific
Phase 3	Chemistry - Chromatography	Supervised remote acquisition and analysis using HPLC/GC where autosamplers and secure remote interfaces are available	Medium
Phase 3	Thermal Analysis	Remotely supervised DSC/TGA and temperature-dependent characterization after sample preparation	Medium
Later	Robotics & Mechatronics	Remote robot control, autonomous systems, machine vision and control experiments	High
Later	Advanced Microscopy	Remote imaging, positioning, focusing and automated image acquisition	Instrument-specific
Later	Integrated Bio-Chemical Automation	Robotic liquid handling, automated assays and remote measurement workflows	Instrument-specific

6. End-to-End User Journey

AFRI RELAB will provide a consistent but discipline aware workflow from instrument discovery to experiment completion. Specific requirements will vary according to the instrument, sample type, safety requirements and host institution policies. The user journey will follow the steps below.

- a. Discover: Search the catalogue by instrument, technique, discipline, capability, location, access conditions and availability.
- b. Qualify: Complete relevant safety, biosafety, chemical-safety, ethics, IP and instrument-competency requirements.
- c. Reserve: Request instrument time, submit an experiment plan, identify samples/reagents where relevant, and specify accessibility or connectivity needs.
- d. Prepare: Use training modules and digital twins to learn the interface, validate permitted parameter ranges and rehearse the workflow.
- e. Sample handling: Where physical samples are required, trained host staff receive, verify, prepare and load approved materials before remote operation.
- f. Connect: Authenticate securely and enter the reserved virtual experiment room.

- g. Experiment: Control only approved parameters while software policies and independent hardware interlocks enforce safe operating limits.
- h. Observe: Follow the real experiment through synchronized video, instrument outputs and sensor telemetry, with accessible or low-bandwidth views as required.
- i. Acquire: Capture raw measurements together with instrument settings, timestamps, calibration status, sample metadata and environmental conditions.
- j. Analyze: Use optional AI and discipline-appropriate digital twins for visualization, uncertainty analysis, quality checks and theory-experiment comparison.
- k. Export: Download raw and processed data, metadata, experiment logs, calibration references and permitted video records.
- l. Close: Return the station to a verified safe state, record observations or faults, and release the resource.

7. Reference Technical Architecture

AFRI-RELAB will use federated architecture as shown in Figure 2. Central services provide discovery, identity, scheduling, accessibility, governance and research workspaces, while each host institution operates a secure laboratory gateway. All commands to physical instruments will pass through the host gateway; instruments are never exposed directly to the public internet.

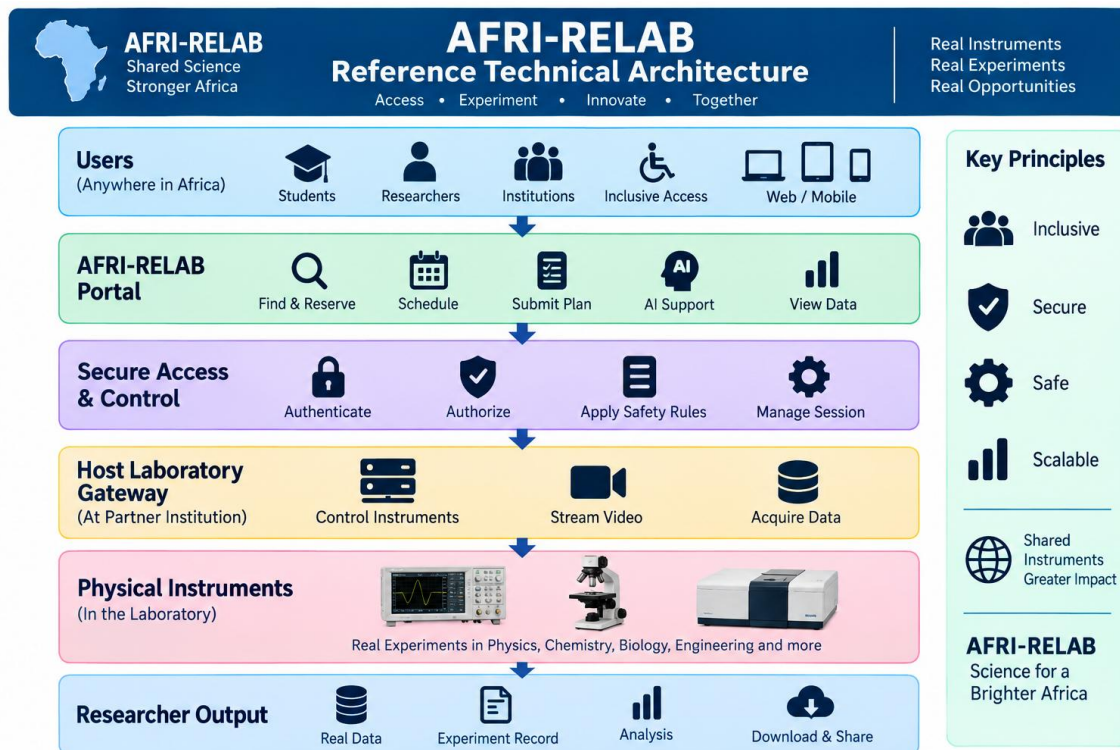


Figure 2. AFRI-RELAB reference technical architecture. The federated architecture connects remote users to physical scientific instruments through the AFRI-RELAB portal, secure access and control layer, and host-laboratory gateway. Researchers can remotely reserve and operate real instruments, observe experiments through live video, acquire real data, and access reproducible experimental records for analysis and sharing.

8. Platform Services

The AFRI RELAB platform will provide the shared digital services required to discover, access, operate and manage remote laboratory resources securely and efficiently. These services will support the complete research workflow while accommodating differences in instruments, disciplines, institutions and user needs.

- a. Federated identity, multi factor authentication and role based authorization.
- b. Searchable instrument and technique catalogue with capability, calibration, availability and access information.
- c. Reservation, queueing, quotas, access credits and equity priority mechanisms.
- d. Experiment plan submission, safety and ethics screening, and host approval workflows.
- e. Real time command, telemetry, event and instrument status channels.
- f. Adaptive multi camera video streaming with captions, audio descriptions and low bandwidth options.
- g. Research workspaces for raw data, metadata, provenance, controlled sharing and reproducibility records.
- h. AI laboratory assistance and discipline appropriate digital twin services.
- i. Sample, reagent and specimen logistics and chain of custody support where required.
- j. Incident reporting, maintenance status, calibration tracking and instrument health monitoring.
- k. Administrative analytics for utilization, access equity, reliability, scientific output and impact.

Together, these services will provide a common digital backbone for secure, accessible and scientifically traceable remote experimentation across the AFRI RELAB network.

9. Physical Laboratory Automation

Each remote station will operate as a bounded cyber physical system designed for its scientific discipline, instrument type and hazard profile. A station may integrate programmable instruments, edge controllers, data acquisition systems, cameras, sensors, controlled actuation and independent safety interlocks. For chemistry and biology, physical sample, reagent and specimen handling will remain under trained on site personnel unless validated automation is available.

The core automation architecture will include:

- a. Instrument interfaces: VISA/SCPI, vendor APIs, serial, USB, Ethernet, GPIB, OPC/IoT protocols, or validated LabVIEW/Python drivers.
- b. Edge control: local computer or industrial controller mediating commands, telemetry and recovery even during network interruption.
- c. DAQ and metadata: synchronized capture of experimental variables, environmental conditions and instrument state.
- d. Actuation: motorized stages, relays, switch matrices, autosamplers or robotic handling only where technically validated and safe.
- e. Biology/Chemistry handling: trained on-site staff perform activities that require direct handling, containment, reagent preparation or sample loading unless certified automation is available.
- f. Safety: hardware limits, containment and emergency controls remain effective if software, AI or connectivity fails.

- g. Recovery: automatic safe-state procedures follow timeout, abnormal readings, loss of connectivity or policy violation.

This architecture enables meaningful remote control while ensuring that safety critical functions remain independent of remote connectivity and AI systems.

10. Live Video and Observation

Live observation will support experimental awareness, verification and provenance by allowing remote users to observe relevant physical processes alongside instrument data. Where technically feasible, video feeds will be synchronized with measurements and instrument events to provide a traceable record of each experiment. Access to privacy sensitive, safety restricted or proprietary views will remain subject to host institution policies. Table 3 summarizes the proposed video and observation channels and their functions within AFRI RELAB.

Table 3. Live video and observation channel

Channel	Purpose
Overview camera	Shows the complete experimental station, physical changes and authorized on-site interventions.
Instrument camera	Shows displays, sample chambers, stages, status indicators or control panels.
Experiment/macro camera	Provides a close view of the sample, reaction, specimen, moving component or other observable phenomenon.
Microscope/specialized imaging feed	Supports biological microscopy, materials imaging, thermal imaging or other discipline-specific visualization.
Safety/containment view	Where appropriate, confirms enclosure, chamber or containment status without replacing machine-readable safety indicators.

Adaptive streaming will support HD video where bandwidth permits, lower-resolution or low-frame-rate streams for constrained connections, and periodic still images plus numerical telemetry for very low bandwidth. Safety-critical states will always be represented through machine-readable status and text, not video alone.

11. AI and Digital-Twin Layer

The AI and digital twin layer will support experiment planning, operation, analysis and interpretation without replacing human scientific responsibility or host laboratory authority. AI functions will operate within defined permissions and deterministic safety controls, with critical experimental actions remaining subject to authorization.

Digital twins will be adapted to each scientific domain. They may use physics based models where governing equations are available, chemistry informed models for reaction and transport processes, biology informed models for measurable biological systems, and hybrid data and mechanistic approaches where appropriate. Table 4 summarizes the principal AI components, their functions and authority boundaries.

Table 4. AI and digital twin components and authority boundaries

AI component	Function	Authority boundary
Laboratory Assistant	Explains procedures, instrument interfaces, scientific concepts and troubleshooting.	Advisory.
Accessibility Agent	Provides captions, descriptions, speech/text transformation and adaptive presentation.	Interface transformation only.
Experiment Agent	Translates approved user intent into proposed workflow steps or parameter changes.	Commands require authorization and policy validation.
Safety & Compliance Agent	Checks requests against operating envelopes, chemical/biosafety rules, session permissions and host policies.	May block; cannot override hardware or local safety authority.
Data Agent	Visualizes data, supports uncertainty/statistical analysis, quality checks and documentation.	Advisory; raw data remain immutable.
Digital-Twin Agent	Compares real measurements with model predictions and identifies meaningful discrepancies.	Advisory/predictive; model limitations are exposed.

A discrepancy between a digital twin and the physical experiment will not automatically be treated as an error. It may indicate noise, calibration effects, unmodeled physics or chemistry, biological variability, sample heterogeneity, or a scientifically important phenomenon.

12. Safety Engineering

AFRI RELAB will apply layered, discipline specific safety controls to all remote experiments. Remote users and AI services will operate only within predefined limits and will not have unrestricted control of laboratory equipment. Hazardous, containment sensitive or irreversible procedures will require additional authorization or remain under direct host laboratory control.

The safety framework will include:

- Defined operating limits for each instrument and experiment.
- Independent hardware limits for voltage, current, temperature, pressure, motion, radiation and power where applicable.
- Chemical compatibility, reagent and sample screening before remote experiments.
- Biological risk classification, containment and specimen handling procedures where required.
- Remote session stop, local emergency stop and technician override.
- Watchdog timers and automatic transition to a safe state following connectivity loss or system failure.
- Pre session self tests, calibration and status checks, followed by post session reset.
- Host controlled lockout, tagout and maintenance procedures.
- Auditable command and event logs with incident reporting.
- Formal hazard, biosafety and chemical safety assessment before experiments are approved for remote access.

These controls ensure that remote access expands scientific capability without weakening the safety authority and responsibilities of the host laboratory.

13. Cybersecurity and Trust Architecture

AFRI RELAB will integrate research information technology with laboratory operational technology, requiring security controls that protect users, unpublished research, experimental integrity, confidential data and physical equipment. Security will be designed into the platform and laboratory gateways rather than added after deployment.

The cybersecurity framework will include:

- a. Zero-trust principles and least-privilege access.
- b. Multi-factor authentication for researchers, technicians and administrators.
- c. Segmentation of public services, host gateways, laboratory networks and instrument-control networks.
- d. Mutual authentication between AFRI-RELAB services and host gateways.
- e. Encryption in transit and at rest.
- f. Verified software and configuration releases for laboratory gateways.
- g. Central audit logging with host-level monitoring and incident response.
- h. No direct public inbound connection to scientific instruments.
- i. Regular vulnerability assessment, patching, backup and recovery testing.
- j. Project-level isolation for confidential samples, configurations, datasets and results.
- k. Time-bounded session credentials and immediate revocation capability.

This architecture will provide secure remote access while preserving institutional control, research confidentiality, experimental integrity and protection of connected laboratory equipment.

14. Data, Reproducibility and Research Provenance

Every completed experiment will generate a structured, discipline appropriate experiment package to ensure that remote research is traceable, reproducible and auditable. The package will preserve the data, experimental conditions and processing history needed to understand and reproduce the work.

Each experiment package will include:

- a. Raw instrument files and machine-readable exported data.
- b. Instrument identifier, configuration, firmware/software and relevant method files.
- c. Calibration status and references.
- d. Approved parameter history and command/event log.
- e. Timestamps synchronized with sensor, environmental and video records.
- f. Sample/specimen/reagent identifiers and non-sensitive metadata where applicable.
- g. Relevant preparation, handling or chain-of-custody records.
- h. Digital-twin/model name and version where used.
- i. AI-assistance provenance where scientifically relevant.

- j. Processing scripts, workflows or analysis records generated on-platform.
- k. Persistent experiment identifier for internal traceability and, where appropriate, citation.

This framework will create a verifiable record from experiment preparation through data acquisition and analysis, strengthening reproducibility, research integrity and confidence in results generated through AFRI RELAB.

15. Governance and Federation Model

AFRI RELAB will operate as a federated network rather than as the centralized owner of participating laboratories. Host institutions will retain ownership of their equipment, local operational responsibility and final safety authority. Participation in the network will require adherence to common standards for scientific quality, access, calibration, cybersecurity, data governance, ethics, inclusion, maintenance, attribution, intellectual property and cost recovery.

The governance structure will combine network level coordination with institutional autonomy and local accountability. Table 5 summarizes the proposed governance bodies and their primary responsibilities.

Table 5. AFRI RELAB governance structure and responsibilities

Governance body	Primary role
AFRI-RELAB Steering Council	Strategy, membership, equity policy, partnerships and network standards.
Scientific & Instrumentation Committee	Remote readiness, scientific quality, calibration, method validation and experiment approval.
Safety, Biosafety & Cybersecurity Committee	Minimum safety/security controls, chemical and biological risk oversight, incidents and operational risk.
Inclusion & Accessibility Advisory Group	Co-design, accessibility standards and representation of marginalized users.
Data, Ethics & Research Integrity Committee	Data governance, ethics, provenance, confidentiality, reproducibility and responsible AI.
Host Laboratory Management	Local operation, sample handling, maintenance, technician support and final safety authority.
User Council	Researcher and learner feedback, service quality and community priorities.

16. Access, Scheduling and Equitable Allocation

AFRI RELAB will promote equitable access to shared scientific infrastructure. Because a purely first come, first served model could reproduce existing inequalities, scheduling will combine transparent reservations with mechanisms that prioritize fairness, inclusion and efficient use of available capacity.

The access framework will include:

- a. Reserved capacity for qualifying under-resourced institutions and marginalized users.
- b. Priority or subsidized credits for approved disability-access needs and time-sensitive postgraduate research.
- c. Fair-use quotas that prevent a small number of institutions from dominating scarce resources.
- d. Transparent service levels, approval criteria, cancellation rules and waitlists.
- e. Asynchronous or technician-assisted workflows for low-bandwidth users where scientifically and safely appropriate.
- f. Institutional memberships, sponsored access and reciprocal credits for partners contributing instrument time.

This approach will balance open access, scientific need and efficient instrument utilization while ensuring that limited resources are distributed fairly across the AFRI RELAB community.

17. Pilot at JOOUST

The JOOUST pilot will demonstrate the complete AFRI RELAB remote research workflow using a focused multidisciplinary set of laboratory stations. Existing equipment will be retrofitted where safe and technically feasible, reducing initial capital costs while demonstrating applications across Physics, Engineering, Chemistry, Biology, Environmental Science and Energy research.

The pilot will test remote instrument control, live observation, data acquisition, safety controls, user access, experimental provenance and reproducibility. Table 6 summarizes the proposed pilot stations, minimum configurations and demonstration capabilities.

Table 6. Proposed AFRI RELAB pilot stations at JOOUST

Pilot station	Minimum configuration	Demonstration
Remote Electronics	Programmable oscilloscope, signal generator, PSU, DMM, switching and 2-3 cameras.	Remote waveform generation, measurement and circuit characterization.
Remote Sensor/Environmental DAQ	DAQ, calibrated physical/environmental sensors, edge computer and camera.	Real-time environmental/physical measurement, calibration and uncertainty analysis.
Remote PV/Energy	PV module/test source, programmable load, voltage/current sensing and safe switching.	I-V characterization and energy-performance analysis.
Remote UV-Vis / Analytical Chemistry	Network/USB-controllable spectrometer, approved sample workflow and camera.	Remote absorbance/transmittance scans after on-site sample loading.
Remote Biological Microscopy	Digital microscope, motorized stage/focus where available, prepared low-risk specimens and imaging interface.	Remote specimen observation, image acquisition and quantitative image analysis.

18. Implementation Roadmap

AFRI RELAB will be implemented progressively, beginning with feasibility assessment and a minimum viable remote laboratory at JOOUST before expanding to national, regional and Pan African levels. Each stage will build on validated technical, scientific, safety, accessibility and governance requirements from the preceding stage. Table 7 presents the proposed implementation roadmap.

Table 7. AFRI RELAB implementation roadmap

Stage	Indicative period	Primary outcome
Feasibility and inventory	0-3 months	Multidisciplinary instrument inventory, remote-readiness assessment, co-design and safety/cyber/biosafety requirements.
JOOUST minimum viable remote lab	4-9 months	2-3 secure research-grade stations, portal, reservations, video, data capture and accessibility.
Expanded multidisciplinary pilot	10-18 months	3-5 stations spanning multiple disciplines, AI/digital twins, marginalized-user trials and validated SOPs.
Kenyan federation	18-30 months	Partner institutions contribute complementary scientific instruments under common standards.
East African network	30-48 months	Cross-border access, shared governance, expanded techniques and interoperable institutional services.
Pan-African scaling	48+ months	Regional hubs connected through common AFRI-RELAB technical, scientific and inclusion standards.

19. Work Packages for an Initial 18-Month Program

The initial 18 month program will be organized into eight interconnected work packages covering design, infrastructure, safety, AI, pilot validation and preparation for scale. Together, they will establish and evaluate the AFRI RELAB model at JOOUST while creating the technical and governance foundations for wider federation.

1. WP1: Co-design, inclusion and requirements

Engage researchers, learners, laboratory staff and marginalized communities; define accessibility, discipline-specific and institutional requirements.

2. WP2: Multidisciplinary instrument inventory and remote-readiness engineering

Assess candidate Physics, Chemistry, Biology, Engineering, Energy and Environmental instruments; document APIs, safety requirements, calibration, retrofit and maintenance needs.

3. WP3: Core digital platform

Develop identity, catalogue, reservations, experiment rooms, sample/workflow records, telemetry, research workspace and administration.

4. WP4: Laboratory gateway and automation

Build instrument adapters, DAQ, command broker, cameras, local automation, synchronized logging and safe-state control.

5. WP5: Safety, biosafety, cybersecurity and assurance

Develop threat/hazard models, containment and access controls, safety interlocks, incident response and validation.

6. WP6: AI, accessibility and multidisciplinary digital twins

Develop Agentic assistance, captions, audio descriptions, voice interaction and discipline-appropriate physics/chemistry/biology-informed twins.

7. WP7: Research pilot and evaluation

Conduct real remote experiments across selected disciplines and evaluate technical performance, scientific quality, usability, inclusion and research productivity.

8. WP8: Sustainability and federation preparation

Develop partner agreements, costing, access policies, governance, replication toolkit, funding strategy and scaling plan.

20. Monitoring, Evaluation and Learning

AFRI RELAB will use a monitoring, evaluation and learning framework to assess technical performance, scientific quality, equitable access, inclusion, research impact, safety and long term sustainability. Evidence from each implementation stage will inform continuous improvement and subsequent network expansion. Table 8 summarizes the key monitoring dimensions and example indicators.

Table 8. AFRI RELAB monitoring, evaluation and learning indicators

Dimension	Example indicators
Technical	Session success, latency, uptime, command failure, video availability and data completeness.
Scientific quality	Calibration compliance, repeatability, method validity, uncertainty documentation and reproducibility.
Access	Institutions, disciplines, regions and countries served; wait time; under-resourced participation.
Inclusion	Participation and completion by targeted marginalized groups; accessibility performance and reported barriers.
Utilization	Instrument-hours shared, completed experiments and unused capacity converted to research/learning use.
Research & training impact	Projects, theses, publications, collaborations, prototypes, trained users and grant applications.
Safety & security	Incidents, blocked unsafe commands, containment/safe-state performance and vulnerabilities remediated.
Sustainability	Cost per experiment, host cost recovery, memberships, reciprocal credits and external co-funding.

21. Sustainability and Business Model

AFRI RELAB will use a blended sustainability model that protects equitable academic access while generating recurring resources for instrument maintenance, consumables, connectivity, technical

personnel, calibration and cybersecurity. Sustainability will therefore combine public funding, institutional participation, cost recovery and commercial services rather than relying solely on user fees.

The model will include:

- a. Core grants and public research-infrastructure funding for platform development and equitable access.
- b. Institutional membership for participating universities, TVETs and research institutes.
- c. Reciprocal instrument credits for institutions that contribute verified remote-access capacity.
- d. Cost-recovery fees for consumables, sample/specimen preparation, calibration and technician-intensive workflows.
- e. Differentiated commercial rates for approved industry use, with a portion supporting academic and marginalized-user access.
- f. Sponsored access credits from governments, foundations, professional societies and industry.
- g. Training, certification and continuing-professional-development services.

Pricing will reflect the actual cost and complexity of each instrument and discipline. Consumable and staff intensive services, such as biological assays or chromatography, will therefore be costed differently from electronics or sensor experiments. Pilot data will be used to determine service costs, maintenance requirements and appropriate pricing before wider network expansion.

22. Intellectual Property, Ethics and Publication

Remote access will not imply surrender of research ownership. Agreements will distinguish instrument and platform ownership, user samples/specimens, user-generated data, jointly developed methods and AI/digital-twin outputs. Chemistry and biology workflows will include applicable ethics, biosafety, sample-transfer and disposal requirements. Confidential projects will use project isolation and defined retention policies. Publications should acknowledge the host facility and AFRI-RELAB where appropriate; authorship remains based on substantive scholarly contribution.

23. Key Risks and Mitigations

AFRI RELAB will manage technical, scientific, safety, cybersecurity, inclusion and sustainability risks throughout implementation. Risk controls will combine technical safeguards, institutional policies, human oversight and continuous monitoring. Table 9 summarizes the principal risks and mitigation measures.

Table 9. Key risks and mitigation measures

Risk	Mitigation
Unreliable internet	Edge control, adaptive streaming, low-bandwidth modes, watchdogs and safe-state recovery.
Unsafe remote commands	Bounded APIs, policy validation, hardware interlocks, technician override and competency requirements.
Chemical/biological handling risk	Approved low-risk workflows, on-site handling, containment, biosafety/chemical screening and restricted remote authority.
Instrument incompatibility	Remote-readiness audits; prioritize programmable instruments; retrofit only where safe and validated.
Low adoption	Co-design, real research pilots, training, institutional champions and demonstrable scientific value.
Digital exclusion	Reserved capacity, subsidies, accessible/mobile design, low-bandwidth modes and equity monitoring.
Cyberattack	Segmentation, MFA, encryption, gateway mediation, logging, patching and incident response.
Unsustainable maintenance	Cost recovery, memberships, host incentives, maintenance reserves and realistic service levels.
Research confidentiality/IP	Project isolation, access controls, agreements and configurable retention.
Overreliance on AI	Human responsibility, transparent provenance, advisory AI and deterministic safety controls.

24. Indicative Pilot Budget Framework

The earlier Physics eLabs AI prototype provides a useful costing foundation, but AFRI RELAB requires a broader multidisciplinary and research grade infrastructure. Final costs will be determined following the JOOUST instrument inventory, remote readiness assessment, technical design and supplier quotations. Table 10 presents the indicative allocation for the pilot.

Table 10. Indicative AFRI RELAB pilot budget framework

Budget area	Indicative share
Instrument retrofit, controllers, DAQ, automation and safety/containment	25-30%
Platform/software engineering and instrument integrations	18-22%
Video, edge computing, networking and storage	8-12%
AI, accessibility and multidisciplinary digital twins	10-15%
Cybersecurity, safety/biosafety testing and assurance	6-10%
Technical personnel and research assistants	10-15%
Co-design, marginalized-user participation and evaluation	5-8%
Training, partnerships and dissemination	4-7%
Contingency and operations	5-8%

Capital equipment should be added only where a priority pilot capability cannot be created from existing suitable infrastructure. The first implementation should maximize safe retrofitting and sharing of instruments already available at the host institution.

25. Partnership Strategy

Partnerships should be developed in layers: marginalized-user and disability organizations for co-design; JOOUST science and engineering departments for the multidisciplinary pilot; Kenyan universities and research institutes for federation; regional institutions for cross-border scaling; and telecommunications, cloud, instrumentation and automation partners for enabling technology. Funders, governments and scientific networks will be engaged to support equitable access and sustainability. Each host laboratory will complete a common readiness, safety, data and governance assessment before joining.

26. Expected Outputs After the Initial Program

The initial program will deliver a validated AFRI RELAB pilot and the technical, scientific and governance foundations required for wider expansion. Expected outputs include:

- a. Operational AFRI-RELAB pilot portal and secure host-laboratory gateway.
- b. At least three, with a target of five, research-capable remotely controlled stations spanning multiple scientific disciplines.
- c. Multi-camera live observation with accessible and low-bandwidth modes.
- d. Structured research-data and provenance packages for completed experiments.
- e. Accessible interfaces validated with marginalized users.
- f. Agentic AI laboratory assistant operating within defined authority boundaries.
- g. Discipline-appropriate digital twins for selected Physics, Chemistry, Biology, Engineering or Energy experiments.
- h. Validated safety, biosafety, cybersecurity, data-governance and federation standards.
- i. Research and education use cases demonstrated with partner institutions.
- j. Replication toolkit for additional African host laboratories.
- k. Kenya-to-East-Africa-to-pan-African scaling and financing strategy.

Together, these outputs will demonstrate the technical feasibility, scientific value, safety and scalability of AFRI RELAB while providing a practical foundation for its development into a federated African remote research infrastructure.

27. Long-Term Network Model

At maturity, AFRI-RELAB will function as a searchable continental map of remotely accessible scientific capability. Researchers will search by technique or scientific need rather than by institution, identify qualified facilities and access conditions, complete required preparation, reserve capacity, and remotely perform or supervise approved experiments. Participating institutions contribute selected capacity without relinquishing ownership, while common standards create a trusted and consistent user experience across disciplines and borders.

28. Research and Innovation Opportunities

Beyond providing shared laboratory access, AFRI RELAB will create a platform for multidisciplinary research and innovation at the intersection of experimental science, AI, digital twins, automation and equitable research infrastructure. Key opportunities include:

- a. Remote experimental science and cyber-physical laboratory research.
- b. Physics-, chemistry- and biology-informed AI and digital-twin validation using real experiments.
- c. AI-assisted spectroscopy, microscopy, electrochemistry, sensing and materials characterization.
- d. Low-bandwidth teleoperation and edge intelligence for resource-constrained environments.
- e. Human-AI collaboration in scientific experimentation and accessible laboratory interaction.
- f. Federated research infrastructure and equitable scientific-resource allocation.
- g. Automated calibration, instrument-health monitoring and predictive maintenance.
- h. Reproducible remote experimentation and machine-actionable laboratory provenance.
- i. African experimental datasets for scientific machine learning.
- j. Cross-institution postgraduate supervision, practical training and interdisciplinary collaboration.

These opportunities position AFRI RELAB not only as shared scientific infrastructure, but also as a research platform for developing and validating new approaches to remote, intelligent and inclusive experimental science.

29. Immediate Next Steps

The immediate priority is to translate the AFRI RELAB concept into a validated multidisciplinary pilot at JOOUST and establish the partnerships required for subsequent federation and scaling. The following actions are proposed:

- a. Establish AFRI RELAB as the multidisciplinary umbrella initiative, with Physics eLabs AI as the first flagship program.
- b. Inventory candidate Physics, Chemistry, Biology, Engineering, Energy and Environmental instruments at JOOUST, documenting their condition, interfaces, calibration and software requirements.
- c. Assess instruments for remote readiness, scientific value, inclusion potential, safety and retrofit requirements.
- d. Select two to three instruments for the minimum viable demonstrator, followed by expansion toward five multidisciplinary stations.
- e. Define the operational, safety, biosafety, chemical safety and data requirements for each selected station.
- f. Develop and validate the secure workflow from reservation and authentication through remote experimentation, synchronized observation, data acquisition and reproducible experiment packaging.
- g. Establish a co design group involving researchers, laboratory technologists, disciplinary experts, under resourced institutions and users with accessibility needs.
- h. Finalize governance, intellectual property, ethics, data, safety, biosafety and cybersecurity frameworks.
- i. Identify Kenyan partner laboratories with complementary instruments for the first federation demonstration.

- j. Use evidence from the pilot to pursue research infrastructure, scientific capacity, inclusion and digital transformation funding.

These actions will move AFRI RELAB from concept development to a demonstrable research infrastructure with measurable scientific, technical and inclusion outcomes.

30. Conclusion

AFRI RELAB provides a practical pathway for transforming geographically dispersed laboratory resources into shared African scientific infrastructure. It integrates real experimentation, secure remote access, synchronized observation, AI, digital twins, accessibility, research provenance and federated governance within a multidisciplinary platform. Beginning with a focused pilot at JOOUST, AFRI RELAB will demonstrate safe, reproducible and inclusive remote research across Physics, Chemistry, Biology, Engineering, Energy and related disciplines before expanding through institutional partnerships. With Physics eLabs AI as its first flagship program, AFRI RELAB extends the concept from a single discipline to a broader continental vision: enabling researchers and learners to access the scientific capabilities they need regardless of where the instruments are physically located. In doing so, AFRI RELAB can increase utilization of existing infrastructure, strengthen collaboration and advance equitable access to experimental science across Africa.

31. Appendices

Appendix A. Relationship Between AFRI-RELAB and Physics eLabs-AI

Dimension	Physics eLabs-AI	AFRI-RELAB
Primary positioning	Inclusive Physics and Engineering laboratory education.	Pan-African shared multidisciplinary research and education infrastructure.
Core users	Students, particularly underserved learners and students with disabilities.	Researchers, postgraduate students, educators, engineers, scientists, innovators and marginalized users.
Scientific scope	Initial Physics, electronics and mechanics experiments.	Physics, Chemistry, Biology, Engineering, Materials, Energy, Environmental Science, Biotechnology and future disciplines.
AI	Inclusive Agentic AI laboratory assistant.	Network AI services plus experiment, safety/compliance, accessibility, data and digital-twin agents.
Digital twins	Learning and theory-experiment comparison.	Training, experiment planning, prediction, validation and research interpretation using discipline-appropriate models.
Institutional model	Initial JOOUST platform scalable to universities.	Federated multi-institution and ultimately multinational network.
Data model	Experimental learning data and outputs.	Research-grade raw data, calibration, provenance, confidentiality, sample metadata and reproducibility.
Long-term outcome	Inclusive African Physics and Engineering eLabs network.	Continental remote scientific instrumentation and experimentation network.

Appendix B. Minimum Remote Station Standard

- a. Documented instrument identity, model, interface, scientific capability and calibration status.
- b. Local secure edge gateway; no direct public exposure of the instrument.
- c. Defined remote command set, permissions and parameter limits.
- d. Independent safety controls and documented safe-state behavior.
- e. Discipline-appropriate chemical, biological, electrical, mechanical or other hazard controls.
- f. At least one experiment-view camera, with additional views where scientifically necessary.
- g. Machine-readable telemetry and timestamps synchronized with experiment events.
- h. Role-based authorization and auditable session logs.
- i. Raw-data export plus structured experimental and sample/specimen metadata.
- j. Accessible web/mobile interface and low-bandwidth operating mode.
- k. Local technician SOPs for setup, sample/reagent/specimen handling, calibration, faults and emergency intervention.

Appendix C. Source Foundation

AFRI-RELAB builds on the supplied Physics eLabs-AI concept, which establishes the foundational model of inclusive remote access to real instruments, live video, real data acquisition, Agentic AI, digital twins, accessible interfaces and an initial JOOUST implementation. The umbrella initiative extends that foundation into a multidisciplinary, research-grade and federated African infrastructure while retaining Physics eLabs-AI as its first flagship component.

References

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