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## **D4.2 Competence framework and modular curricula for general and targeted training on digital technologies**

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## Executive summary

This deliverable operationalises a scalable capacity-building model, by aligning academic training with the concrete requirements of modern digital economies and evolving research infrastructures. The foundational architecture detailed in **Deliverable D4.2** is built upon three pillar outcomes:

**Evidence-Based Framework Alignment:** Grounded in primary survey data and stakeholder consultations from five partners (Cameroon, Kenya, Senegal, South Africa, and Tunisia), the project identified curriculum gaps in advanced technical domains—specifically AI, Data Science, Cloud Computing, and Cybersecurity. To resolve these deficiencies globally, DIGITAfrica introduces a standardized, multi-tier competence framework (Foundation, Practitioner, and Architect/Manager) designed to map directly to international and regional qualification standards, notably the European Qualifications Framework, the European e-Competence Framework, and the African Continental Qualifications Framework.

**Blueprint-Centric Modular Curricula:** The strategic intervention translates these competency definitions into "stackable," micro-credentialed educational tracks. Rather than attempting full-degree reconstructions, the curriculum is optimized for flexible, low-resource deployment, eventually personalized, focusing tightly on the project's technical operational targets: the *Edge AI/ML Blueprint* and the *Heterogeneous Networking Blueprint*. This curriculum model was successfully validated through a functional "Proof of Concept" pilot at the DIGITAfrica Winter School in Kenya (March 2026).

**Institutional Sustainability and Synergies:** To ensure continuity beyond the project lifecycle, the training ecosystem avoids duplication by dynamically expanding upon existing European excellence, acting as a regional extension of the **SLICES** and **SoBigData Academies**. Long-term regional uptake relies on an institutional "Train-the-Trainer" model. Permanent African partner universities will act as autonomous "Founding Nodes," utilizing verifiable digital badges (Open Badges Standard) to achieve cross-border credit portability, stimulate professional retention, and ensure pan-African workforce recognition.

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## Abbreviations

Abbreviation	Definition
5G	Fifth Generation
6G	Sixth Generation
ACQF	African Continental Qualifications Framework
AI	Artificial Intelligence
AUC	African Union Commission
e-CF	e-Competence Framework
ECTS	European Credit Transfer and Accumulation System
EDSF	EDISON Data Science Framework
EQF	European Qualifications Framework
ETF	European Training Foundation
EU	European Commission
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HEC	Higher Education Commission
HEI	Higher Education Institutions
HPC	High Performance Computing
ICT	Information and Communications Technology
IoT	Internet of Things
KNQA	Kenya National Qualifications Authority
LMS	Learning Management System
MCQ	Multiple Choice Questions
ML	Machine Learning
MOOCs	Massive Open Online Courses
NLP	Natural Language Processing
NQA	National Qualifications Authority
NQF	National Qualifications Framework
OECD	Organisation for Economic Co-operation and Development
RI	Research Infrastructures
SAQA	South African Qualification Authority
SDN	Software Define Networking
SLICES	Scientific Large-Scale Infrastructure for Computing/Communication Experimental Studies
UNESCO	United Nations Educational, Scientific and Cultural Organization

# 1 Introduction

The high level of unemployment of graduates holding qualifications in digital sciences across Africa is compounded by the **mismatch** between **training offered** at universities and **skills demanded** by industry. This is being amplified by the rapid change of technology that makes it impossible for universities to revise mainstream curricula to accommodate new technology concepts. Failing to address the matching of training to skill demand will lead African graduates to take up jobs that often require lesser qualifications in their home countries and sometimes abroad, a trend that contributes to brain drain.

To bridge the gap, WP4 develops a framework that supports capacity building for students and young graduates to enable them gain relevant digital sciences skills that are in demand by potential employers. This report, **D4.2 - Competence framework and modular curricula for general and targeted training on digital technologies** directly contributes to DIGITAfrica the **project objective #3: Develop capacity building in Digital Sciences**. It created a framework that will facilitate targeted training to equip students and recent graduates with skills through life-long learning. WP4's objective is achieved by capitalising on the expertise and competencies of European and African partners, thereby addressing the needs and gaps identified in WP1. This objective is guided by the capacity-building and training experience gained by SLICES and SoBigData Academies. Notably, WP4 places a higher priority on skills needed by female and young researchers.

This deliverable builds upon **D4.1 - Guidelines for Female and Young Researchers** by documenting the process used to develop training curriculum for short courses that leads to the award of micro-credentials. The approach adopted in this deliverable is to design curricula and micro-credentials focused on digital technologies to exploit and enhance the research infrastructure being designed by DIGITAfrica project partners. The training requirements are further developed by feedback collected during the winter school held in Kenya.

This report presents an evidence-based methodology and the toolkits used in the development of the modular curricula. This methodology draws upon inputs from WP4 surveys and consultations, stakeholder engagement sessions and outcomes, as well as secondary desk research from relevant EU and African policy frameworks. It first presents a framework that defines competence levels for micro-credential training; this is aligned to competence frameworks adopted in Europe, specifically the **European Qualification Framework (EQF)** and **European e-Competence Framework (e-CF)**. It presents a comprehensive structure incorporating relevant thematic areas, applicable courses training courses, mode of teaching, and discussions on assessment methods. The thematic areas were defined to map to DIGITAfrica infrastructure blueprints; the **Edge AI/ML Blueprint** and the **Heterogeneous Networking Blueprint**.

The deliverable proceeds to present the implementation of a **winter/summer school** on digital sciences. The **Blueprint-aligned curriculum for the school** is presented as well as logistic requirements. Finally, results of a **survey conducted with student participants** are presented and discussed.

Micro-credentials provide the means to prove competence and skills in a specific domain after a short learning experience<sup>1</sup>. The term generally refers to the award itself and the training program that leads to awarding the credential. There is increasing interest in micro-credentials among education institutions and governments<sup>2</sup>. To ensure sustainability, it is important to establish a standard that guides development of training courses that lead to award of micro-credentials. In addition, it is important to have a framework that provides clarity on the level of competence covered by each micro-credential. The micro-credentials approach presented in this deliverable is mapped to SoBigData Academy and SLICES training and schools, demonstrating reuse, efficiency, and complementarity, thereby avoiding duplication and strengthening EU RI alignment.

This report presents the development of a competence framework for micro-credential training in digital sciences. As part of WP4 activities, specifically **Task 4.3 - Training courses, workshops, and winter/summer schools**, the training curriculum for the first winter school that was organised in Kenya (one of the African partner countries) is presented together with information criteria for certificate award. The developed competence framework, that is aligned to EQF and e-CF is also presented. The report creates a pathway for **D4.3 - Proposed Qualification and credentials on digital technologies competences and skills** that will report on **Task 4.4 - Qualifications and micro-credentials**.

The report also presents implementation considerations for micro-credential training. It concludes by presenting sustainability recommendations to ensure adoption by HEIs in mainstream curriculum.

## 2 Methodology and Inputs

This chapter presents the methodology used to develop the competence framework and modular curriculum for training that would lead to the award of micro-credentials in digital sciences.

### 2.1 Introduction and Background

The development of a valid competence framework for micro-credential training in digital sciences calls for an evidence-based approach to determination of training requirements and training approaches. Micro-credentials should be designed considering a broad range of beneficiaries, contexts. They need to be mapped to education systems at various National Qualification Framework (NQF) levels. Important features include being recognised by education and training organisations and trusted by employers<sup>3</sup>.

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<sup>1</sup> OECD, “Micro-credential innovations in higher education: Who, What and Why?” (2021) 39 Website; [https://www.oecd.org/content/dam/oecd/en/publications/reports/2021/09/micro-credential-innovations-in-higher-education\\_c323077b/f14ef041-en.pdf](https://www.oecd.org/content/dam/oecd/en/publications/reports/2021/09/micro-credential-innovations-in-higher-education_c323077b/f14ef041-en.pdf) (Accessed:1/6/2026)

<sup>2</sup> Website: <https://knqa.go.ke/kenya-takes-a-huge-step-in-developing-the-national-micro-credentials-framework/> (Accessed:27/5/2026)

<sup>3</sup> ACQF, “Handbook on Micro-credentials” (2024) Website; [https://acqf.africa/capacity-development-programme/training-modules/micro-credentials-handbook/@@display-file/file/Micro-Credentials%20Handbook%20ACQF\\_FINAL%20Version%20Full\\_WEB\\_EN.pdf](https://acqf.africa/capacity-development-programme/training-modules/micro-credentials-handbook/@@display-file/file/Micro-Credentials%20Handbook%20ACQF_FINAL%20Version%20Full_WEB_EN.pdf)

Adopting a competence framework will distinguish micro-credentials from other alternative credential including academic certificates, industry certifications and digital badges. At the European level there has been effort to promote use of micro-credential across member states, in order to support lifelong learning and employability. This effort involves standardising and creating a common framework for defining, designing and issuing micro-credentials and ensure cross-border recognition, comparability and portability. To ensure they meet established criteria for skills, knowledge and competencies, member states are encouraged to align micro-credentials with NQF levels. This will enable the micro-credentials to meet EQF standards<sup>3</sup>. A number of principles for the design and issuance of micro-credentials are defined including quality, relevance, valid assessment, learning pathways, recognition, and learner centred.

At the African level, there are indications of interest to design and issue micro-credentials. However, most effort is at individual country level. A number of countries that have an NQF have some form of alignment of micro-credentials to the NQF. Eswatini maps micro-credentials to all NQF levels, while in Kenya they are mapped up to level 3<sup>3</sup>. In many countries micro-credentials are associated with technical and vocational education. In Mauritius, micro-credentials were included in the 2020-2025 strategic plan of the HEC. Both Kenya and South Africa have issued policies for adoption of partial qualifications. DIGITAfrica builds on these initiatives to develop a competence framework for designing micro-credentials in digital sciences.

To determine the feasible process for designing a competence framework and curriculum for micro-credentials, a survey targeting students and professors in partner countries in Africa was conducted. In addition, a stakeholder engagement exercise targeting policy makers and industry in Africa was conducted.

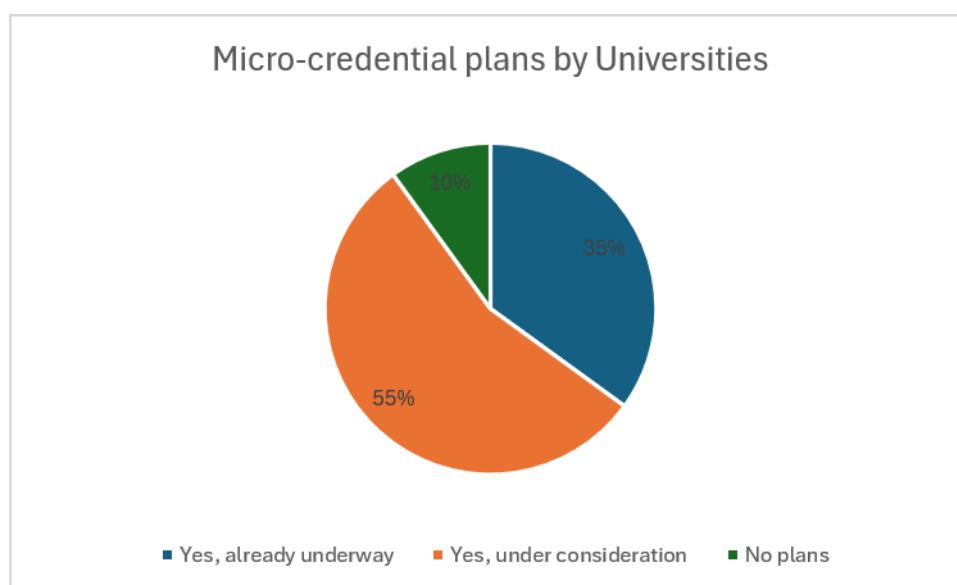
## 2.2 WP4 Survey of Professors

A survey was conducted targeting professors from the partner countries (Cameroun, Kenya, Senegal, South Africa, and Tunisia) aimed at establishing trends in adoption of micro-credentials in Africa. 24 professors participated in the survey. The survey established that the following digital skills courses have been integrated into mainstream curricula of universities from those countries; computer programming (93.8%), database management (87.5%), Machine learning and AI (68.8%), big data, network administration, cloud computing, telecommunications, data analysis and visualization (68.8%), cybersecurity principles (62.5%), web development (81.3%) among other digital science courses. This information was critical for determining the courses included in the modular curriculum created for capacity building events of WP4. This was also useful for inclusion in the competence framework skill level mapping.

The survey also established avenues used by students at the universities to acquire digital skills. The leading avenues include practical lab sessions (93.8%), project-based learning (75%), theoretical lectures (68.8%), internships and apprenticeships (75%), and self-study assignments (62.5%). The least used avenues included industry guest speakers (37.5%), online modules/eLearning platforms (37.5%), and student clubs (50%). Understanding of digital skilling avenues is necessary when designing a curriculum since the mode of training delivery should be specified.

In addition, professors mostly preferred the following modes of training for supporting skills development using micro-credentials; blended learning involving a mixture of online and in-person classes, and industry-led training programs. These had a score of 75% and 68.8% respectively. In addition, professors also had preference for intensive in-person workshops, project-based learning with real-world applications, and certification focused courses. These modes had a score of 50% to 56.3%. At 43.8% the mode of learning that was least preferred by professors was fully online modules. This data was also used for specifying the mode of training for micro-credentials in digital sciences.

As shown in Figure 1, 90% of participating professors stated that their universities had plans or interest to include digital science micro-credentials in the main curriculum. However, none of the universities had integrated micro-credentials in the main curriculum. Instead, the universities offer standalone alternative credentials where certificates are awarded to participants. The sustainability of micro-credential training in Africa will greatly depend on involvement by universities. The fact that most universities are considering introducing micro-credential training increases the chance of the adoption. The offering of alternative credentials already lays the required foundation to formally integrate them into the mainstream curriculum, something that would be possible if a competence framework existed.



*Figure 1: Plans to offer micro-credentials by universities in Africa*

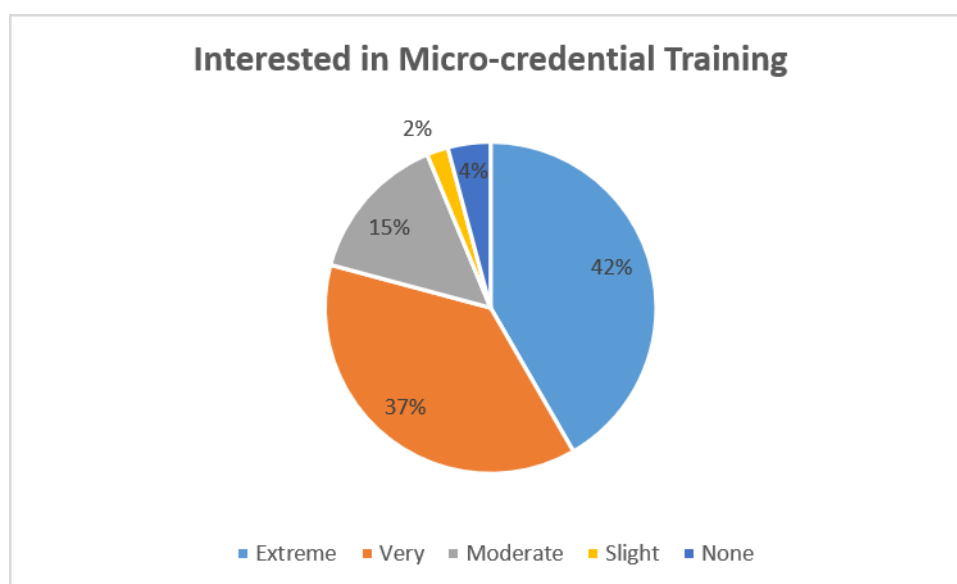
## 2.3 WP4 Survey of Students

The survey on students was designed to establish, from the learner perspective, the level of interest in micro-credentials and in addition the preferred approach for undertaking micro-credential training. 48 students from the partner countries (Cameroun, Kenya, Senegal, South Africa, and Tunisia) participated in the survey. The survey was administered in English and French to reach a wide audience since the two languages are official in the partner countries.

Students mainly acquired digital sciences skills through formal university courses (87.5%), self-taught using tutorials and personal projects (73%), and by taking online courses (54%).

The least used avenues for gaining the skills include professional mentorship (12%), attending workshops or bootcamps (34%), and undertaking internships (37.5%). This data guided discussions that led to recommendations of the avenues of learning and training delivery for the developed curriculum.

As shown in Figure 2, 79% of students were very and extremely interested in taking short, focused (micro-credential) courses to develop specific digital skills to enhance their employability. 15% had moderate interest, whereas those with slight and no interest at all formed 2% and 4% respectively. To be successfully administered, the micro-credential curriculum must learner-centred and be anchored on interest from the target groups. The survey data shows a clear need for micro-credentials in digital, especially considering the domain is fact changing and requires re-skilling through approaches that are focused and cost-effective.



*Figure 2: Interest in Micro-credentials by Students in Africa*

In terms of the specific digital skill areas students would be most interested to learning through micro-credentials, the highest ranked included advanced computer programming (60.9%), cloud infrastructure management (56.5%), cybersecurity specialisations (52.2%), artificial intelligence (52.2%), and advanced data analytics and Machine Learning (43.5%). This data guided the determination of subjects that were included in the modular curriculum as well as offered at during the winter school in Kenya.

With respect to the modes of learning preferred by students, project-based learning led at 60%, online self-paced was preferred by 40% of students. 40% of students also preferred blended learning (a mixture of online and in-person sessions), instructor-led online sessions attracted 30% of students, short intensive in-person workshops interested 28% of students, while evening and weekend classes were desired by 25% of students. The views by students and those given by professors were analysed to determine a convergence point that would guide modes of delivery that can be adopted by universities in implementing micro-credential training.

## 2.4 Consultation Workshops and Meetings

Two consultation workshops that brought together DIGITAfrica partners were held in Cape Town, South Africa and Tunis, Tunisia. In addition, a plenary meeting was held in Nice, France in November 2025. Each workshop enabled partners to review the progress of each work package, and exchange to support subsequent activities. Partners reviewed the linkages between and among the work packages. With respect to D4.2, activities of WP1 and WP2 were identified as inputs of WP4. Whereas the activities of WP4 were determined to be inputs of WP3 and WP6. Decisions on the design of blueprints were also made.

At the Cape Town workshop held from 23-25 April 2025, the definition of micro-credentials was discussed in order to develop consensus on the one to be adopted for DIGITAfrica. In addition, the lifecycle of micro-credentials was presented and reviewed. This is the full process from designing to awarding micro-credentials. An assessment of different qualification frameworks was conducted with focus on their suitability for micro-credentials. This included the European Qualification Framework (EQF), the Digital Competence Framework for Citizens (DigComp), and European e-Competence Framework (e-CF). This information was utilized in designing the competence framework micro-credentials under the DIGITAfrica project.

Experiences from SLICES academy and in addition So-Big-Data academy were shared. This included the role of TheNetworkingChannel. This was important in guiding organizing of the winter school held in Kenya in March 2026. The workshop also explored micro-credential development guidelines, training delivery practices, and the assessment methods and validation of micro-credentials. This report adopts the first two, whereas the last two items will be incorporated in WP4 D4.3 - Proposed Qualification and credentials on digital technologies and skills.

Finally, the Cape Town workshop explored a range of established micro-credentials as well as major digital technology themes and their respective application domains. The initial list of proposed micro-credential courses for DIGITAfrica was presented. A refined set of proposed micro-credential courses was presented at the Tunis workshop.

The Tunisia workshop was held from 27-29 April 2026. The courses for each proposed technology theme for general training in digital sciences were presented and discussed. Alignment of the courses with established needs and gaps was also presented. Similar alignment with blueprints for DIGITAfrica was done; in addition, refinement of the mode of delivery was achieved. The proposed template for micro-credential curriculum was presented as well as selected course outlines; these included samples for courses that were delivered at the winter school in March 2026. The plenary meeting held in Nice, France in November 2025 focused on review of the progress of WP4 activities including development of the competence framework and micro-credential curriculum.

## 2.5 Relevant EU and African policy frameworks

The competence framework presented in this report is adapted from a combination of the EQF and e-CF.

The **European Qualifications Framework (EQF)** seeks to support cross-border mobility of learners and workers, promote lifelong learning and professional development across Europe<sup>4</sup>. It is an 8-level framework, with levels increasing according to proficiency, that is learning-outcomes based and serves as a translations tool for national qualifications frameworks (NQF) for all types of qualifications. It enables determination of what a person knows, understands and is able to do. This improves the transparency, portability and comparability of qualifications across borders. A summary of EQF levels is shown in Table 1.

*Table 1: Summary of EQF Levels*

Competence Level	Type of Knowledge (Qualification)	Work Ability
Level 1	Basic knowledge	Simple tasks
Level 2	Basic factual knowledge	Routine work
Level 3	Principles and processes	Responsibility for tasks
Level 4	Broad knowledge	Self-management
Level 5	Specialized knowledge	Supervision
Level 6	Advanced knowledge (Bachelor degree)	Complex tasks
Level 7	Forefront of knowledge (Master level)	Critical awareness
Level 8	Frontier of a field (Doctorate)	Original research leadership

**European e-Competence Framework (e-CF)** classifies 40 competences for the ICT professionals. It establishes a common language for competences, skills and proficiency levels across Europe. Competences in the e-CF are organised according to five ICT business areas and related to EQF<sup>5</sup>. It is a work-oriented sector specific implementation of EQF. By supporting the definition of jobs, training courses, qualifications, career paths, formal and non-formal learning paths, certifications, it provides a shared reference for ICT professionals, organisations, recruiters, trainers, professional associations and others. The five e-Competence Areas of e-CF are Plan, Build, Run, Enable, Manage. They are accompanied by five proficiency levels i.e., Level 1 (Assist), Level 2 (Apply), Level 3 (Enable), Level 4 (Ensure/Advise), and Level 5 (Initiate/Influence). These proficiency levels are mapped to EQF level 3 to level 8 respectively.

<sup>4</sup> EU, “The European Qualifications Framework: supporting learning, work and cross-border mobility”, (2018) Website: <https://ec.europa.eu/social/BlobServlet?docId=19190&langId=en>; ISBN 978-92-79-80382-6, doi:10.2767/385613

<sup>5</sup> European e-CF, “European ICT Professional Role profiles Version 2”, (2018) Website: [https://cdn.prod.website-files.com/6736197d14ecfed214a43038/675d6f962f799cf7e40c9497\\_European-e-Competence-Framework-3.0\\_CEN\\_CWA\\_16234-1\\_2014.pdf](https://cdn.prod.website-files.com/6736197d14ecfed214a43038/675d6f962f799cf7e40c9497_European-e-Competence-Framework-3.0_CEN_CWA_16234-1_2014.pdf)

EDISON Data Science Framework (EDSF) is a collection of documents that define the Data Science profession; namely Data Science Competences Framework (CF-DS), Data Science Body of Knowledge (DS-BoK), Data Science Model Curriculum (MC-DS), and Data Science Professional Framework (DSPP)<sup>6</sup>.

The **African Continental Qualifications Framework (ACQF)** is an initiative of the African Union towards ensuring a harmonized qualification framework across the continent. It is meant to enable the African continent to respond to skills, mobility and development challenges. It will enhance the inclusiveness of qualifications, increase mobility of workers, support regional integration and enhance opportunities for exchange and improvements across AU member states<sup>7</sup>. It was created through a collaboration of the African Union Commission (AUC), EU, the GIZ and the European Training Foundation (ETF)<sup>8</sup>. The ACQF defines ten levels of competence for three domains: knowledge, skills and autonomy and responsibility<sup>9</sup>.

In the ACQF knowledge domain, the levels are as follows Level 1 (Simple), Level 2 (Basic), Level 3 (factual and operational), Level 4 (technical knowledge), Level 5 (substantial depth), Level 6 (specialization), Level 7 (advanced analytical), Level 8 (complex knowledge), Level 9 (mastery), and Level 10 (knowledge contribution). In the skills domain, the levels are Level 1 (Simple), Level 2 (Basic), Level 3 (practical), Level 4 (well-developed), Level 5 (some specialisation), Level 6 (analyse), Level 7 (initiative), Level 8 (research), Level 9 (innovation), and Level 10 (evaluate)<sup>9</sup>.

At national level, the **Kenya National Qualifications Authority (KNQA)** is developing a micro-credentials framework to strengthen the country's education and skills development<sup>10</sup>. This is being done with the collaboration of the International Labour Organization (ILO) and the Commonwealth of Learning (CoL). A key intention is to integrate micro-credentials into the national qualifications system.

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<sup>6</sup> EDSF, "The EDISON Data Science Framework" (2017) Website: [https://edison-project.eu/sites/edison-project.eu/files/attached\\_files/node-488/edison-general-introduction-edsf.pdf](https://edison-project.eu/sites/edison-project.eu/files/attached_files/node-488/edison-general-introduction-edsf.pdf)

<sup>7</sup> ETF, "Rolling out the African Continental Qualifications Framework" (2025) Website: <https://www.etf.europa.eu/en/news-and-events/news/rolling-out-african-continental-qualifications-framework>

<sup>8</sup> KNQA "African Continental Qualifications Framework" (2020), Website: <https://knqa.go.ke/wp-content/uploads/2024/07/A-MAPPING-STUDY-TO-FORMULATE-THE-AFRICAN-CONTINENTAL-QUALIFICATIONS-FRAMEWORK-ACQF-KICKS-OFF.pdf>

<sup>9</sup> AU, "African Continental Qualifications Framework: Thematic Brief 10" (2022), Website: [https://acqf.africa/resources/policy-guidelines/acqf-level-descriptors/acqf-level-descriptors-article-newsletter-1-march-2022/@@display-file/file/ACQF\\_CDP%2010\\_Level%20descriptors\\_Article%20Newsletter%201.pdf](https://acqf.africa/resources/policy-guidelines/acqf-level-descriptors/acqf-level-descriptors-article-newsletter-1-march-2022/@@display-file/file/ACQF_CDP%2010_Level%20descriptors_Article%20Newsletter%201.pdf)

<sup>10</sup> KNQA, "Kenya Takes a Huge Step in Developing the National Micro-Credentials Framework" (2026) Website: <https://knqa.go.ke/kenya-takes-a-huge-step-in-developing-the-national-micro-credentials-framework/>

## 2.6 Reference initiatives

Reference was made to research organisations that offer focused training in digital sciences and award a credential to participants. This provided real-life understanding of how micro-credential training under DIGITAfrica could be organised.

The **Netherlands eScience Center** organises workshops covering digital skills needed to put reproducible research into practice<sup>11</sup>. It offers freely all training material used in the workshops. The materials are hosted on github; a platform that has been proposed for use to host learning material for DIGITAfrica training courses. The center uses several modes for training delivery including in-person workshops, and online workshops.

The **Barcelona Supercomputing Centre (BSC)** organises and hosts seasonal schools aimed at advanced students and which provide short-term intensive hands-on experience programmes on specialised areas of interest that are linked to the usage of High-Performance resources<sup>12</sup>. This includes week-long training aimed at enriching the skills of researchers, graduate students and teachers. The centre also offers training through workshops. Modes of training delivery include in-person, online, and hybrid sessions.

The **SoBigData Academy** provides training and capacity-building services aimed at developing skills in responsible data science. Launched in 2024, the Academy offers free, high-quality online education through a series of Massive Open Online Courses developed in collaboration with leading European institutions. Courses combine interactive lessons, personalised learning paths, hands-on practice using the SoBigData RI Jupyter environment and external tools, self-assessment activities, and certification.

Currently, the Academy hosts twelve courses covering topics from basic programming and statistics to data mining, machine learning, deep learning, and ethical and legal aspects of data science. The catalogue of courses is continuously evolving, with new modules planned. The Academy also collaborates with GEANT Academy<sup>13</sup> to develop joint educational paths and leverage complementary training offerings.

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<sup>11</sup> NL eScience, Website: <https://www.esciencecenter.nl/digital-skills/>

<sup>12</sup> BSC, Website: <https://www.bsc.es/education/seasonal-schools>

<sup>13</sup> <https://geant.org/>

## 3 Identified Training Needs and Target Groups

The training needs and applicable target groups are presented in this section. It builds on the report presented for **D4.1 - Guidelines for Female and Young Researchers**. The most overarching DIGITAfrica training needs are skills development in:

- Artificial Intelligence (AI)
- Machine Learning (ML)
- Big Data
- Cloud Computing
- 5G networks
- DevOps
- Cybersecurity

In addition, access to Research Infrastructure (RI) to support gaining of hands-on skills is a key requirement. The following RI is needed:

- Computer science lab equipment
- Cloud computing resources
- IoT labs
- High speed internet connection
- High-Performance Computing (HPC) infrastructure

The identified target groups for capacity building under the DIGITAfrica project are:

- Students and early-career researchers
- Researchers and data scientists
- Research Infrastructure operators and technical staff
- Policy makers, institutional managers, and innovation actors

### 3.1 Requirements gathering and definition validation

In the survey of students conducted as part of **WP4 Task 4.1 - Identification of the priority needs**, the most important digital sciences skills were established. They included skills in:

- Computer science fundamentals
- Computer programming
- Artificial intelligence
- Machine learning
- Cybersecurity
- Web development
- Cloud computing
- Telecommunications e.g. 5G networks.

Understanding of skills students considered to be important steered development of the competence framework and curriculum to focus on training that would support capacity building in those skills.

The survey also established skills whose **training was missing in the university curriculum**. Several respondents mentioned a lack of training in Artificial Intelligence (AI), including specific areas such as Natural Language Processing (NLP), Large Language Models (LLM), Big Data, and data management. Respondents also felt there was a gap in education concerning GenAI and In-depth Data Analytics. In addition, cybersecurity skills and mastery of Cloud Computing tools and technologies (AWS, Azure, Google Cloud) are considered essential and are absent from current training.

Other specific skills in demand areas included DevOps and the concrete applications of mathematics in computer science. A finding of importance was that responses highlighted the **lack of practical experience and internship opportunities**, noting that the training is more theoretical. It was also mentioned that some **programs or courses are outdated** and no longer current. In addition to data on the most important skills, this survey data was of great importance in selecting the courses for inclusion in the curriculum for general and targeted training. Some of the courses in the developed curriculum were administered at the **DIGITAfrica winter school** that was held in Kenya in March 2026.

## 3.2 Guidelines for Female and young researchers

D4.1 stressed the importance of inclusive and accessible training opportunities for female and young researchers, highlighting barriers related to digital access, representation, mentoring opportunities, and participation in advanced digital research activities. The deliverable recommended targeted educational and policy measures to strengthen diversity and participation in digital sciences across African partner countries.

## 3.3 Demand analysis towards DIGITAfrica

The analysis presented here highlights the need for structured and competence-based training pathways capable of supporting the emergence of a pan-African RI ecosystem in Digital Sciences. Deliverable - D1.1 Demand analysis towards DIGITAfrica - provides a comprehensive overview of the existing digital research infrastructure landscape across five African partner countries—Tunisia, Senegal, South Africa, Kenya, and Cameroon—while also capturing the demand and strategic needs of their research and innovation ecosystems through stakeholder consultations. It highlights a heterogeneous and fragmented RI landscape, with strong engagement in fields such as artificial intelligence (AI), data science, high-performance computing (HPC), and Internet of Things (IoT), but also reveals significant gaps in hardware availability, digital infrastructure, technical staff, and funding. It emphasised the increasing demand for digital competences related to AI, data science, cloud and distributed computing, cybersecurity, digital experimentation platforms, and data management. It also identified challenges linked to limited research infrastructure capacities, unequal access to resources, and the need to better align academic training with labour market and research needs.

The country-specific analyses underscore critical needs, including improved access to testbeds and experimental platforms, stable and high-speed connectivity, and human capital development to retain skilled researchers. To complement the supply-side analysis, a stakeholder workshop was held in Cape Town in April 2025, gathering over sixty participants from academia, policy, and industry. Participants emphasized the need for federated, accessible, and interoperable digital RIs that can support cross-disciplinary and

cross-border research collaboration. Stakeholders also expressed strong demand for open science platforms, data-sharing tools, and AI-powered research environments that could operate across national boundaries.

In addition, we conducted parallel surveys of Professors/Lecturers and Students in Cameroon, Kenya, Senegal, South Africa and Tunisia to figure out needed digital skills for university programs. Data from African universities shows that while foundational digital literacy is strong, there are critical shortages in the advanced skills needed for the digital economy. Both groups highlighted five consistent insights:

1. Curriculum alignment with ICT priority sectors: Strongly covered courses such as Web Development, Computer Science Fundamentals, Advanced Digital Literacy, and foundational digital skills while Telecommunications and Mobile App Development are moderately covered.
2. Skills gaps are concentrated in advanced digital domains: several courses such as AI/ML, Cloud Computing, Cybersecurity, Data Science, IoT, advanced digital skills, and Blockchain show the weakest competence and curriculum coverage. The most critical skills gaps are concentrated in AI/ML, data, cybersecurity, cloud, plus robust programming. Therefore, students and staff agree these are the highest-priority areas for training and micro-credentials.
3. Curricula are not fully aligned with industry needs: professors rate curriculum alignment as moderate while students report relying heavily on self-learning and online resources to fill gaps. Additionally, a lack of practical, hands-on exposure limits employability.
4. Structural barriers limit both teaching and learning: professors highlighted challenges related to infrastructure, training, materials, and industry collaboration, while students pointed to obstacles such as cost, limited mentorship, time constraints, and outdated curricula.
5. Strong demand for micro-Credentials: students express high demand for short, practical training programs that offer formal recognition. Professors view the adoption of micro-credentials as a key strategy to modernize academic offerings and directly enhance student employability. For instance, students want micro-credits in exactly the high-value emerging areas such as advanced programming, cloud, AI ethics, cybersecurity, blockchain, advanced analytics, digital entrepreneurship, UI/UX. This strongly supports a micro-credential strategy focused on cutting-edge, job-relevant specializations rather than basic skills. Therefore, micro-credentials must confer official, employer-recognized certificates to be attractive. In addition, DIGIT Africa should play a strategic role in fostering the development of a pan-African certification and recognition framework, aimed at ensuring cross-border comparability, portability, and mutual recognition of micro-credentials.

Furthermore, Deliverable - D4.1 Guidelines female and young researchers - provides an assessment of the current gender digital divide across the DIGITAfrica partner countries, namely Tunisia, Senegal, Kenya, South Africa and Cameroon. The findings highlight significant and persistent practical challenges across four interrelated dimensions:

- Access and infrastructure, limiting fair participation in digital learning and research activities.
- Education and skills development, including unequal access to advanced digital training opportunities.
- Policies and government, here are gaps in gender-responsive digital and innovation policies.
- Continuous support and empowerment, particularly in mentoring, career progression, and sustained capacity-building mechanisms.

There is a clear need to align students' growing demand for concise, credentialed, and practice-oriented training with faculty perspectives on curriculum innovation. Therefore, the ability and pedagogical resources developed through initiatives like the SoBigData Training program, including the SoBigData Schools and Academy, can serve as a foundational model for developing educational resources, integrating research and education, fostering a more robust and collaborative research ecosystem across the west Africa region.

### 3.4 Winter School student feedback

Training needs were further identified during the winter school held at Strathmore University in Kenya. Additional feedback collected during the winter school confirmed strong interest in practical and hands-on training activities, particularly in emerging digital technologies and AI-related experimentation environments. Participants also expressed the need for flexible learning formats combining theoretical foundations with applied exercises and project-oriented learning. The winter school offered two tracks; an AI and Big Data track that aligns to the Edge AI/ML blueprint, and a Networking and Cloud Computing track that aligns with the Heterogeneous Networking blueprint. It was attended by 40 students and 4 early career professionals. 59% of the participants participated in the survey administered at the end of the winter school program. The satisfaction score of the winter school was 4.62 out of 5.

There was a panel discussion during the summer school, where AI and employability, micro-certifications and opportunities for young and female researchers were discussed. Key lessons learnt include students' interest in practical exercises to enhance understanding of new concepts. In addition, students require access to software platforms and availability of fast internet access. Spending more time on explaining difficult concepts in AI and Networking was a key requirement. This would be addressed by enabling self-paced learning using content hosted on a Learning Management System.

## 3.5 Categorisation of Target Groups

Based on the identified needs, the following main target groups were considered:

- Students and early-career researchers requiring introductory and intermediate competences in digital technologies, data analysis, AI, and research infrastructures;
- Researchers and data scientists seeking advanced and specialised skills for data-intensive and collaborative research activities - this includes professors;
- Research Infrastructure operators and technical staff needing operational competences related to infrastructure deployment, maintenance, experimentation platforms, and digital services;
- Policy makers, institutional managers, and innovation actors interested in governance, sustainability, ethics, and strategic deployment of digital infrastructures.

## 3.6 Regional and Institutional Considerations

Significant regional and institutional disparities are highlighted across participating countries. Differences in internet connectivity, access to computing resources, language diversity, institutional capacities, and digital maturity levels may directly influence training accessibility and adoption. Consequently, the proposed training framework adopts a modular, flexible, and blended approach that can be adapted to local institutional realities while maintaining coherence with the broader DIGITAfrica vision and KR3 objectives.

The survey of students revealed the following critical digital science skills needs per region.

- Central Africa: Data science, AI, Cloud, Computer programming
- East Africa: AI/ML, Cloud, Cybersecurity, advanced computer programming
- West Africa: Data science, AI, Big Data
- North Africa: AI/ML, Cloud, Cybersecurity, Digital marketing
- Southern Africa: Big Data, Cloud, Cybersecurity, IoT

DIGITAfrica proposes a training-of-trainers approach to support development of micro-credential curriculum suited to needs of each region in Africa. Academic staff at the five partner institutions would be the first to be trained. These would then organise and implement training of more trainers in their region.

# 4 Training and Education Model for DIGITAfrica

This report presents the qualifications framework that has been developed for micro-credential training under the DIGITAfrica project. It also presents the modular curriculum for facilitating general and targeted training in digital technologies. The qualifications framework features

## 4.1 From Needs Assessment to Structured Implementation

While earlier phases of the project (Task 1.1) mapped the existing "digital gap," D4.2 establishes the operational framework to close it. Stakeholder consultations in D1.1

revealed a **shortage of structured training programs** and significant **gaps in technical staff**, with some institutions averaging fewer than two technical support members. In the context of DIGITAfrica project, we propose a dynamic training model ecosystem that is designed to address the **human capital development** needs required to retain skilled researchers and bridge the divide between African talent and state-of-the-art digital infrastructures like SLICES and SoBigData.

## 4.2 Proposed Training Approach and Core Principles

The DIGITAfrica training model is designed as a **lightweight and flexible framework**. Given the project's scope, the immediate focus is on creating a functional "Proof of Concept" directly linked to the project's two technical Blueprints. However, the model is built on four core pillars that allow for organic expansion as resources grow:

- **Modular and "Stackable" Design:** To maximize limited resources, training is not delivered as a full degree but as "stackable" modules. During the project lifecycle, these are strictly focused on **AI/Data Science** and **Heterogeneous Networking**. This modularity ensures that after the project ends, new thematic areas can be added easily without redesigning the entire system.
- **Inclusiveness through Low-Resource Design:** Recognizing the constraints of connectivity and hardware, the model prioritizes:
  - **Low-Bandwidth Accessibility:** Content is optimized for easy download or offline use to counter unstable internet connections.
  - **Open-Source Foundations:** By leveraging open-source tools and commodity hardware, we ensure that training is not dependent on expensive licenses that the project or partners cannot sustain long-term.
- **Blueprint-Centric Delivery:** To ensure immediate relevance, training is anchored to the **DIGITAfrica Blueprints**. This "Playground-first" approach means learners gain hands-on experience with the project's specific technical deployments (5G and AI nodes), ensuring high impact even with a targeted number of modules.
- **Strategic Bootstrapping with EU Academies:** During the DIGITAfrica lifecycle, the model will adopt selected modules from the **SLICES and SoBigData Academies**. This allows the project to leverage existing, high-quality training materials to "bootstrap" its implementation. DIGITAfrica training model will act as a regional extension of European academies, tailoring excellence to African realities, such as the need for **local data sovereignty** and **dynamic spectrum management**. By offering a rich library of proven materials, the model establishes itself as a serious and attractive resource for Pan-African use, allowing everyone—from students to senior researchers—to customize their paths in high-demand fields like AI, Data Science, and IoT.

## 4.3 Competence Framework: Priority Modules by Target Role

The DIGITAfrica Competence Framework is inspired by existing competence framework such EQF and e-CF, and EDSF. It is designed as a specialized extension of these international standards, tailoring them to the unique requirements of federated Research Infrastructures.

By utilizing these seminal frameworks, DIGITAfrica ensures that its proposed model remain globally compatible while addressing specific African gaps.

DIGITAfrica defines a competence framework that features three competence levels that are coupled to three EQF levels as well as three e-CF levels. This is illustrated in Table 2.

*Table 2: DIGITAfrica Micro-credential Competence Framework Levels*

DIGITAfrica Micro-credential Competence Level	EQF	e-CF
Level 1 (Foundation)	Level 3 (Responsibility for tasks)	Level 2 (Apply)
Level 2 (Practitioner)	Level 4 (Self-management)	Level 3 (Enable)
Level 3 (Architect/Manager)	Level 5 (Supervision)	Level 4 (Advise)

- **Foundation:** Introductory modules focusing on Open Science literacy and basic digital tools.
- **Practitioner:** Advanced technical modules requiring a capstone project performed on the DIGITAfrica Playground (e.g., successfully configuring a network slice).
- **Architect/Manager:** Focused on the governance and technical sustainability of Research Infrastructures.

To ensure the DIGITAfrica infrastructure is effectively used and sustained, the framework identifies three **Target Roles**. Each role is mapped to specific modules within the Technical and Governance pillars. This is illustrated in Table 3.

*Table 3: Target Roles and Modules*

Target Role	Technical Pillar (The "What")	Governance & Ethics Pillar (The "How")
<b>1. The Digital Researcher</b> ( <i>End Users: PhDs, Scientists</i> )	<b>AI &amp; Data Science:</b> Large-scale data processing and AI training at the "Edge"; NLP for African languages.	<b>Responsible AI &amp; FAIR:</b> Bias detection in African datasets; FAIR Data principles for Pan-African research.
<b>2. The RI Operator</b> ( <i>Technical Staff: IT Engineers</i> )	<b>Infrastructure &amp; Networking:</b> Virtualization (Docker/K8s), SDN, 5G/6G architecture, and HPC cluster management.	<b>Open Science Management:</b> Technical management of Open Access repositories and shared infrastructure protocols.
<b>3. The Policy Lead</b> ( <i>Decisions: Deans, Lab Directors</i> )	<b>Strategic Overview:</b> Understanding the capabilities of the Edge-Cloud continuum and AI Blueprints.	<b>Legal Frameworks:</b> Data Sovereignty, the <b>Malabo Convention</b> , and cross-border data flow regulations.

## 5 Micro-credentials Modular Curriculum and Certification Approach

Micro-credentials represent a key innovation within WP4, serving as the bridge between modular training, infrastructure use, and long-term career recognition. By focusing on "stackable" units of learning, DIGITAfrica proposes a flexible solution to the high-level digital skills gap identified in the D1.1 Demand Analysis. This report presents modular curriculum created for DIGITAfrica capacity building training activities. It also presents sample course outlines, that were utilised for content development and training for the DIGITAfrica winter school held in Kenya in March 2026.

### 5.1 Modular Curriculum for General and Targeted Training

The DIGITAfrica Competence Framework was translated into a set of "Thematic Tracks" designed for stackability. While the model is flexible to support general training, the immediate implementation targets on the project's core technical Blueprints (Edge AI/ML Blueprint and the Heterogeneous Networking Blueprint). The initial defined curriculum comprised seven groups of specialisations shown in Figure 3. The circle on some items highlights the topics that DIGITAfrica partners are currently covering (e.g., where they pose expertise or teaching materials that could be used or adapted for the project). The next step was development of three tracks for general training as well as two tracks for targeted training in digital sciences.

<b>Next Generation Wireless Networking for Africa Development</b> MC1 – 5G and 6G Fundamentals MC2 – Understanding Spectrum and Spectrum Policy MC3 – Low-Cost Network Deployment MC4 – Rural and Community Networks Design MC5 – Sustainable and Energy-Aware Networks	<b>Data Governance / Data Management (Data Science &amp; Analytics)</b> MC1 – Data Sources, Data Collection and Data Integrity ● MC2 – Ethical and Professional Data Storage Practices ● MC3 – Principles of Data Conversion for Non-Digital Data ● MC4 – Software Tools for Modern Data Analysis, Interpretation, and Presentation ●	<b>Cloud Computing for Africa Innovation</b> MC1 – Cloud Computing Architectures and Services ● MC2 – Cloud Hosting of Digital Services ● MC3 – Connecting to the Cloud in Low Bandwidth Settings ● MC4 – Economics of Affordable Cloud Services ●
<b>IoT for African Societies</b> MC1 – IoT Experimentation: Hardware Tools and Software MC2 – Sensing and Sensor Deployment in Mixed Resource Environments MC3 – Powering IoT Devices in the African Continent MC4 – Networking IoT Devices MC5 – IoT Data Collection and Storage	<b>Artificial Intelligence – Data Driven Solutions for Africa Innovation</b> MC1 – Foundation and Understanding Open Data Platforms MC2 – Data Collection, Local Sourcing, and Storage MC3 – Data Cleaning and Preparation for Context Representation ● MC4 – Applied ML and AI for African Societies ● MC5 – Visual Storytelling Techniques for Impact ●	<b>Research Design and Methodology</b> MC1 – Research Question Formulation for Different Settings ● MC2 – Adopting Research Methodologies for Different Research Settings ● MC3 – Designing, Planning, and Scaling Experiments in Digital Sciences MC4 – Research Ethics and Professionalism ● MC5 – Incorporating Indigenous Knowledge into Research
		<b>Cybersecurity</b> MC1 – Design and Validation of Cybersecurity Protocols MC2 – Cybersecurity for Low-Resource Nodes MC3 – Applied Application Security for Researchers & Engineers MC4 – AI-Powered Threat Detection and Response

Figure 3: Initial Proposed Micro-Credential Specialisations

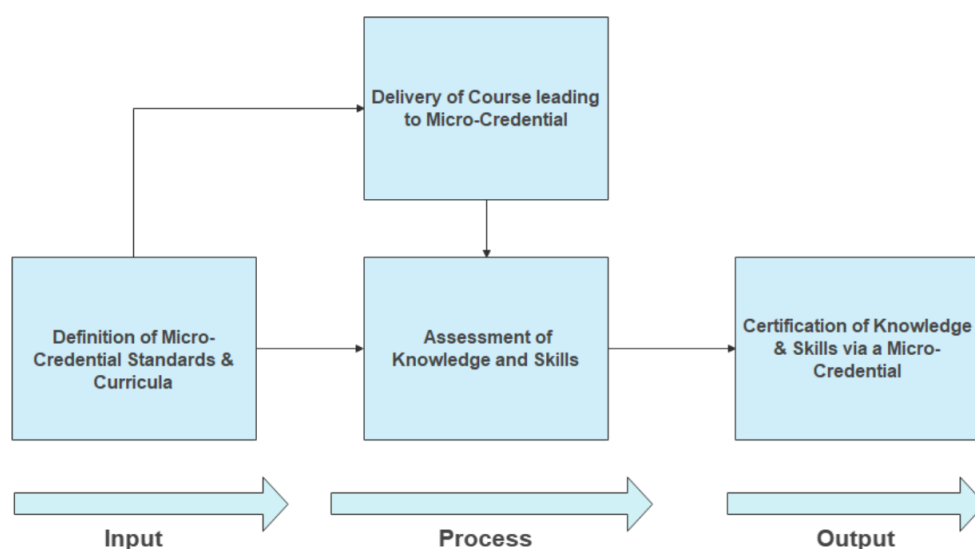
The three tracks defined for general training in digital sciences are:

- **Next-Generation Connectivity:** Network Automation (Ansible/Python), SDN, IoT, and 5G/6G orchestration.
- **Advanced Data Sciences:** Distributed AI, Edge-Cloud continuum, and NLP for African languages.
- **Data Stewardship:** FAIR principles, Open Science management, and regional data privacy (the Malabo Convention).

The two training tracks defined to support targeted blue-print centric curriculum development are:

- **AI and Big data:** AI for researchers, Deep Learning, Reinforcement Learning, Big data and AI.
- **Networking and Cloud Computing:** Network Automation (Bash/Ansible/Python), Cloud provisioning (Terraform), Cloud computing, 5G networks.

As shown in Figure 4, curriculum development is the first process of micro-credential implementation. A key component of the curriculum is the course outline; it contains Course Name, Prerequisites, Lecture hours, Purpose of the course, Expected Learning Outcomes, Course Content, Mode of delivery, Reference Materials and Links.



*Figure 4: The Micro-credential Process Map<sup>14</sup>*

Course outlines for the blue-print centric targeted training at the DIGITAfrica 2026 winter school held in Kenya are presented in Appendix 1. In addition, course outlines for blue-print centric general training in digital sciences are presented in Appendix 2.

## 5.2 Certification Approach

Certification of DIGITAfrica micro-credentials will be developed under **T4.4 - Qualifications and micro-credentials** and presented in **D4.3 - Proposed Qualification and credentials on digital technologies competences and skills**. Requirements to be met include that credentials (certificates/badges) should be verifiable, portable, and industry aligned. The award of a certificate occurs at the end of the micro-credential training, normally after assessment of knowledge and skills. This is illustrated in Figure 4. The assessment approach for each micro-credential will be defined and documented in the report for D4.3. Participants of the DIGITAfrica winter school of 2026 in Kenya were awarded paper certificates of participation. Lack of assessments at the winter school was the reason for awarding a certificate of participation instead of a certificate of merit.

## 6 Articulation with Existing RI Academies

DIGITAfrica builds on the experience by some reference initiatives in Europe. The reference initiatives include SoBigData Academy and SLICES. These two initiatives were referred to in developing the curriculum.

### 6.1 SoBigData Academy

The SoBigData Academy is an educational and training initiative of the broader SoBigData Research Infrastructure, a European open-science project focused on big data, artificial intelligence, and social mining. The academy provides online courses, workshops, MOOCs, summer schools, and hands-on training programs designed to develop responsible data science skills for students, researchers, professionals, industries, and public organizations. Its training emphasizes ethical and privacy-aware use of data, while covering topics such as machine learning, data analytics, visualization, databases, social network analysis, and AI applications in society. The academy supports open and lifelong learning by offering flexible, self-paced educational resources aligned with European values of fairness, transparency, and responsible innovation.

The academy organized two summer schools in June 2025 and June 2026 respectively, in which two students per year from DIGITAfrica partner universities in Africa participated.

### 6.2 SLICES

The SLICES platform (Scientific Large-Scale Infrastructure for Computing/Communication Experimental Studies), coordinated with the involvement of Sorbonne University, is a major European research infrastructure designed to support large-scale experimentation in digital sciences, including 5G/6G networks, cloud computing, Internet of Things (IoT), distributed systems, and high-performance computing. Developed as the first European “scientific instrument” for digital networking research, SLICES provides researchers, universities, and industries with an open, programmable, and distributed testbed for validating new communication technologies and digital services under realistic conditions. The platform is supported through the European ESFRI roadmap and involves collaboration among more than 100 universities and research centers across Europe, with applications in smart cities, future wireless networks, cybersecurity, and sustainable digital infrastructure research.

## 7 Implementation Considerations

A full implementation of micro-credential training should cover all processes of the lifecycle shown in Figure 4. The first process, Definition of Micro-credential standards and curricula, has been implemented. DIGITAfrica adopted the European commission definition<sup>1</sup> of micro-credentials. Standards (qualifications framework) and curriculum for micro-credentials developed for DIGITAfrica are presented in this report. Further development of curricula for more micro-credentials will be done in collaboration with HEIs that will offer the training and certification. This will involve collaboration with African NQAs to incorporate micro-credentials in their NQF through coordination of ACQF. To allow micro-credentials to be accepted as elective credits in master's or PhD programs, **Academic Mapping to ECTS** and related frameworks will be done by standardizing workloads (e.g., 25-30 hours = 1 ECTS). The second process of the micro-credentials' framework is delivery of course leading to micro-credential.

To implement micro-credential course delivery, DIGITAfrica organized a winter school at Strathmore University in Kenya, in March 2026. This was an event under WP4 4.3 - Training courses, workshops, and winter/summer schools, where the developed modular curriculum for targeted training was used. Training was delivered through two blueprint-centric specialisation tracks; the first track covered AI and Big data, and the second track covered Networking and Cloud Computing. Trainers hosted training material on various platforms including GitHub and Google Drive. To support self-paced training, DIGITAfrica will create a GitHub page where training materials and lab manuals will be posted and made available to the public. Management of user personal data will be governed by GitHub terms and conditions.

The following training needs for students, female and young researchers were integrated in curriculum specifications and implemented at the winter school:

- Courses offering identified priority digital skills
- In-person course delivery
- Hands-on practical sessions
- Access to lab equipment
- Creation of micro-credential course outlines for targeted training

At the end of the winter school, participants provided feedback including an evaluation of the trainers. The information was adopted for further development of capacity building initiatives, including implementation considerations.

HEIs in Africa will be guided and supported to offer micro-credential training, either as alternative credentials or integrated in the main curriculum. Survey results showed high interest among HEIs in Africa to offer micro-credential training; refer to Figure 1. Each participating HEI will create or use their existing Learning Management System (LMS) to host micro-credential training material.

Creating and maintaining a DIGITAfrica managed LMS was discussed at the workshops in Cape Town and Tunis. This option would ensure the development of a secure user management system, an advanced learning management features, an assessment and certification engine, a digital credential system, and real-time reports and analytics system. For

scalability, the DIGITAfrica LMS would be hosted at a public cloud or an Africa-based private cloud. However, this option depends on availability of funds in the short to medium term.

The third process in micro-credential lifecycle is assessment of knowledge and skills. DIGITAfrica has evaluated the following assessment types. Performance-based assessment, project-based assessment, practical demonstration, virtual labs, online quizzes & exams, e-portfolios, self-assessment, and industry validation. Performance-based, project-based and practical demonstrations will be utilised during workshops, winter/summer schools. Whereas virtual labs, e-portfolios, self-assessment, and online quizzes e.g. MCQs will be integrated into the LMS. Industry validation can be implemented by HEIs that collaborate with industry for micro-credential training. Certification via a micro-credential is the last process of the micro-credential framework.

DIGITAfrica will implement mechanisms for verification of micro-credentials across Africa, regardless of the awarding institution. We intend to investigate the utilisation of the Open Badges Standard. These digital badges will be:

- **Tamper-proof:** Blockchain-verifiable metadata embedded in the digital certificate.
- **Portable:** Researchers will own their badges in a personal digital wallet, independent of the project's central infrastructure.
- **Industry-Aligned:** Curricula will be co-reviewed by strategic partners to ensure skills match the needs of the African tech sector.

The implementation strategy will ensure **Gender-Targeted Outreach** by directly addressing the **stark gender disparity in unemployment** (e.g., 20.45% for women vs. 12.82% for men in some regions) by reserving mentorship tracks for women and early-career researchers.

## 8 Sustainability and Uptake

Training and education activities are a key pillar for the long-term sustainability of DIGITAfrica. Rather than treating capacity building as a standalone or peripheral project output, DIGITAfrica treats it as an integral part of how digital research infrastructures are deployed, maintained, and evolved across Africa. This approach is consistent with established European and African Research Infrastructure (RI) sustainability principles, which recognise human capacity as being as essential as technical infrastructure<sup>15</sup>.

In this context, the development of micro-credentials and modular curricula goes beyond an educational deliverable. It is intended as a practical sustainability mechanism to ensure that knowledge transfer is structured, portable, and embedded within institutions over time. This perspective aligns with OECD's Micro-credentials for Lifelong Learning and Employability: Uses and Possibilities, which highlights micro-credentials as an effective way to support evolving skills ecosystems beyond the lifecycle of individual projects, particularly

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<sup>15</sup> CODATA, "African Open Science Platform" Website: <https://codata.org/initiatives/making-data-work/global-open-science-cloud/african-open-science/>, Accessed on 7-June-2026

in settings where institutional capacity is still developing<sup>16</sup>. It is also consistent with the UNESCO Recommendation on Open Educational Resources, which emphasises the importance of open, reusable, and institutionally integrated learning materials as a basis for sustainable and equitable capacity development<sup>17</sup>.

Training contributes to sustainability in four interlinked dimensions:

- i. Operational sustainability: enabling local technical teams to deploy and maintain infrastructure components (compute, data services, blueprints).
- ii. Adoption sustainability: increasing the uptake of DIGITAfrica blueprints through hands-on training and applied use cases.
- iii. Institutional sustainability: embedding skills development within universities and research centres.
- iv. Ecosystem sustainability: fostering cross-border communities of practice that persist beyond project funding cycles.

This broad approach is consistent with African capacity-building ecosystems such as H3ABioNet<sup>18</sup> and WACREN's Africa Training Initiative<sup>19</sup>, where training has long been coupled with infrastructure operation rather than treated as a separate workstream.

## 8.1 Multi-Level Capacity Building for Long-Term Uptake

DIGITAfrica adopts a multi-level capacity-building model that reflects best practices in both European RI ecosystems (e.g. ELIXIR training frameworks, EOSC Skills Strategy<sup>20</sup>) and African distributed infrastructure initiatives.

- **Individual level:** At the individual level, the micro-credentials and curriculum framework is aimed at students, early-career researchers, and technical staff within African partner institutions. The learning pathways are designed to support the development of verifiable, competency-based skills in areas such as AI, data infrastructures, and distributed systems, combining applied modules delivered through summer schools, technical workshops, and online learning environments. In line with UNESCO's recommendations on micro-credentials, these learning units are designed to be stackable, allowing learners to progressively build more comprehensive qualifications, and portable, so that their recognition is not limited to a single institution or country<sup>21</sup>. This is particularly relevant in the African context,

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<sup>16</sup> OECD, "Micro-credentials for Lifelong Learning and Employability: Uses and Possibilities", (2023) Website: [https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/03/micro-credentials-for-lifelong-learning-and-employability\\_13dd81a9/9c4b7b68-en.pdf](https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/03/micro-credentials-for-lifelong-learning-and-employability_13dd81a9/9c4b7b68-en.pdf)

<sup>17</sup> UNESCO, "Recommendation on Open Educational Resources", (2019) Website: <https://www.unesco.org/en/legal-affairs/recommendation-open-educational-resources-oeer>

<sup>18</sup> H3ABioNet, "eaching wider audiences through a multi-faceted approach including online training" Website: <https://www.h3abionet.org/training/online-training>, Accessed on 8 June 2026.

<sup>19</sup> ATI, "Building the capacity required to operate research and education digital infrastructure across Africa – structured training for engineers, system administrators, and cybersecurity professionals.", Website: <https://wacren.net/en/ati/>, accessed on 8 June 2026.

<sup>20</sup> skills4eos, "Skills for the European Open Science commons: creating a training ecosystem for Open and FAIR science", Website: <https://www.skills4eos.eu/>, Accessed on 8 June 2026

<sup>21</sup> UNESCO, "Towards a common definition of micro-credentials", Website: <https://unesdoc.unesco.org/ark:/48223/pf0000381668>, Accessed on 8 June 2026

where mobility across institutions and regions is common, and where flexible, interoperable forms of certification can better support career development and cross-border collaboration.

- **Institutional level:** At the institutional level, the framework focuses on embedding micro-credential modules within university curricula and continuing professional development programmes. In addition to curriculum integration, this level also aims to reinforce institutional capacity to design, deliver, and quality-assure training related to research infrastructure management, while supporting universities in taking full ownership of both content development and credential issuance. This approach is consistent with the CARTA<sup>22</sup> model, where sustainability is achieved by gradually transitioning from externally supported training activities to programmes fully embedded within institutional structures. DIGITAfrica builds on this experience by linking curriculum institutionalisation with formal micro-credential frameworks, enabling institutions to issue recognised qualifications rather than informal certificates. As highlighted by UNESCO-IESALC<sup>23</sup>, this distinction is important for reinforcing trust in alternative and non-traditional learning pathways, particularly among employers and public institutions.
- **Ecosystem level:** At the ecosystem level, the curricula and micro-credentials framework is designed to align with ongoing initiatives led by ministries of higher education and digital transformation, regional organisations such as UEMOA and African Union bodies, as well as research networks and NRENs working on skills development and digital infrastructure. Rather than introducing parallel structures, the framework builds on and complements existing policy efforts aimed at improving coordination and recognition of digital skills across borders. This approach is consistent with the African Union Digital Transformation Strategy<sup>24</sup>, the African Continental Qualifications Framework<sup>3</sup>, and EU-Africa Digital Economy partnerships, all of which highlight the importance of portable and recognised credentials as enablers of sustainable digital capacity development.

## 8.2 Hybrid Sustainability Model for DIGITAfrica

Building on these lessons, DIGITAfrica proposes a hybrid sustainability model in which micro-credentials and curricula act as a connecting layer between public ownership, institutional co-financing, service-based mechanisms, and private sector participation.

DIGITAfrica's training ecosystem covering curriculum repositories, micro-credential frameworks, and assessment components is anchored in several complementary layers. Universities and higher education institutions act as primary hosts for curriculum delivery and credential issuance. National research infrastructures help ensure alignment with national priorities and operational realities. Research and education networks provide

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<sup>22</sup> CARTA, "Building a vibrant multidisciplinary African Academy that leads world", Website: <https://cartafrica.org/>, Accessed on 8 June 2026

<sup>23</sup> UNESCO-IESALC, "UNESCO IESALC releases key study on microcredentials and their impact on higher education in Latin America and the Caribbean", Website: <https://www.iesalc.unesco.org/en/articles/unesco-iesalc-releases-key-study-microcredentials-and-their-impact-higher-education-latin-america>, Accessed on 8 June 2026

<sup>24</sup> African Union, "THE DIGITAL TRANSFORMATION STRATEGY FOR AFRICA", Website: <https://au.int/sites/default/files/documents/38507-doc-dts-english.pdf>

coordination and implementation support for training activities, while public institutions and ministries contribute policy alignment and recognition.

This multi-layered anchoring reflects established ESFRI principles and African research infrastructure practices, where public ownership is key to ensuring continuity and equitable access. It is also consistent with UNESCO's view that micro-credential systems require a strong public institutional foundation to achieve legitimacy and trust at scale.

Within this structure, public-private partnerships play a complementary role in ensuring that curricula and micro-credentials remain relevant to labour market needs and maintain long-term value beyond academic contexts. As highlighted in UNESCO's analysis of micro-credential ecosystems, industry involvement in defining learning outcomes is a key factor in ensuring employer recognition and uptake, which in turn strengthens the sustainability of training programmes.

The sustainability of micro-credential and curriculum programmes is further reinforced through shared responsibility across participating institutions. Membership or subscription-based access to shared curriculum resources, co-financing of content development and quality assurance activities, and joint support for training delivery help distribute costs while maintaining coherence and quality across the network. This approach is consistent with emerging European service-oriented research infrastructure models<sup>25</sup> and with established African NREN-based collaboration structures<sup>26</sup>.

In parallel, DIGITAfrica explores complementary service-based mechanisms to support longer-term financial viability. These include certified training services for external organisations, managed access to DIGITAfrica learning environments and sandbox infrastructures, and fee-based advanced micro-credential offerings targeting professional development markets. The increasing demand for verifiable digital skills across employers, public administrations, and international organisations in Africa indicates a growing space for such service-oriented approaches, as also reflected in UNESCO's analysis of global micro-credential ecosystems<sup>27</sup>.

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<sup>25</sup> EOSC, "EOSC Symposium 2021 Report", Website: <https://zenodo.org/records/5176089>, Accessed on 8 June 2026

<sup>26</sup> WACREN, 2023, Website: <https://wacren.net/en/event/wacren-2023-in-accra/>, Accessed on 8 June 2026

<sup>27</sup> UNESCO, "Global Education Monitoring Report, Technology in education", 2023, Website: <https://www.unesco.org/en/articles/2023-global-education-monitoring-report-technology-education-tool-whose-terms>, Accessed on 8 June 2026

To move beyond "one-off" training workshops, the DIGITAfrica model focuses on **Institutional Sustainability**. This calls for collaboration with HEIs in Africa. DIGITAfrica will build capacity at the institutions to enable them to manage all processes of the micro-credentials' framework. The sustainability approach of the model involves:

- **Train-the-Trainer:** Empowering African faculty to manage micro-credential training and certification at their institutions.
- **Platform Integration (Open LMS)<sup>28</sup>:** Hosting curricula on a Learning Management System integrated with the **DIGITAfrica Playground**, ensuring certification is tied to verified technical "Proof of Work."
- **Cross-Infrastructure Mentorship:** Incorporating a "Shadowing Program" where junior researchers work alongside European RI operators (SLICES/SoBigData/GreenDIGIT), providing the human mentorship necessary to validate high-level Practitioner competencies.

A phased expansion strategy will be adopted to allow development and gradual implementation of micro-credential training in collaboration with HEIs across Africa. Sustainable micro-credential training will mitigate **brain drain of ICT engineers** and ensure knowledge remains within local ecosystems.

### 8.3 Sustainability via "Founding Nodes"

The proposed sustainability strategy relies on a three-phase transition:

- **Phase I (Incubator):** The consortium defines the "Gold Standard" for blueprint-linked modules during the project lifecycle.
- **Phase II (The Trust Protocol):** African partner institutions (Strathmore, UCAD, UCT, etc.) are expected to sign a Memorandum of Understanding (MoU) to act as permanent "Institutional Anchors" responsible for issuing and recognizing badges.
- **Phase III (Expansion):** Post-2027, the framework is designed to be open, allowing new African institutions to join the network by adhering to the established quality standards.

A policy on adoption of micro-credentials being developed by DIGITAfrica will be discussed at *the High-Level Policy Forum*, which brings together stakeholders from academia, government, and funding organisations to discuss strategic priorities for strengthening digital research and innovation ecosystems across Africa and Europe. Acceptance of the policy is essential for driving uptake of micro-credential training by DIGITAfrica partner countries and eventually more countries in Africa.

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<sup>28</sup> <https://www.openlms.net/>

## 8.4 Financial Sustainability Considerations

DIGITAfrica will explore a complementary service-based mechanisms to support longer-term financial viability. These include certified training services for external organisations, managed access to DIGITAfrica learning environments and sandbox infrastructures, and fee-based advanced micro-credential offerings targeting professional development markets. The participating HEIs could charge a fee to support training and LMS hosting.

In the initial phase, the development and piloting of these mechanisms will continue to rely on Horizon Europe funding, African Union digital transformation initiatives, bilateral cooperation programmes, and international research funding agencies. These sources remain essential for design, validation, and early deployment, while institutional, network-based, and service-oriented mechanisms are expected to progressively take on a larger share of long-term sustainability.

## 8.5 Role of Microcredentials Within the Sustainability Model

Micro-credentials are the formalisation layer of the DIGITAfrica training ecosystem. They help transform training activities which are often time-bound and project-dependent into structured, recognised, and transferable learning outcomes that retain value beyond a specific funding cycle.

Within the sustainability model, micro-credentials fulfil several complementary functions. They help formalise operational knowledge by translating infrastructure deployment and management skills into portable and verifiable qualifications that remain meaningful across institutional contexts. They also support adoption by providing a clear form of recognition for engagement with DIGITAfrica tools, blueprints, and training activities, thereby linking participation to tangible professional value.

In addition, micro-credentials facilitate institutional integration by giving universities and research centres a structured framework to embed DIGITAfrica training within their existing academic and continuing education offers. This supports the type of institutional ownership and curriculum embedding highlighted in initiatives such as CARTA<sup>22</sup> and in UNESCO's work on micro-credentials<sup>27</sup>. They also contribute to the development of communities of practice by creating a shared credential landscape that connects practitioners across countries and institutions, reinforcing collaboration and knowledge exchange over time. Finally, they support policy alignment by offering a recognisable and structured mechanism that can interface with national and regional qualifications frameworks, including the African Continental Qualifications Framework<sup>3</sup>.

Taken together, these roles position micro-credentials not simply as a project output, but as a long-term enabling component of the ecosystem one that gains value as it becomes more widely adopted, better recognised, and more deeply embedded across institutions and countries.

## 8.6 Expected Sustainability Outcomes

The sustainability model proposed for DIGITAfrica, centred on micro-credentials and curricula, is expected to produce interconnected outcomes that gradually shift the initiative from a time-bound project to a more enduring digital skills ecosystem.

In the short term, the framework will establish a structured and institutionally anchored micro-credentials offer covering key DIGITAfrica competency areas, together with modular curricula integrated into selected university programmes across partner countries. These outputs are expected to contribute to strengthening institutional capacity for designing, delivering, and quality-assuring training in digital research infrastructures, with effects that can persist beyond the project duration.

Over the medium term, the progressive use of shared curricula and credential frameworks is expected to support the emergence of communities of practice in digital sciences, connected through common learning pathways and training resources. At the same time, increased availability of trained and credentialed practitioners should facilitate the broader adoption and scaling of DIGITAfrica blueprints and related infrastructure components. Gradual alignment with the African Continental Qualifications Framework<sup>3</sup> and relevant national qualifications systems is also expected to support the recognition and uptake of these credentials within formal education and professional contexts.

In the longer term, the objective is to support a transition from project-based training activities towards a more self-sustaining ecosystem-level training infrastructure. In line with UNESCO's vision of micro-credential ecosystems that contribute to lifelong learning and skills development<sup>27</sup>, DIGITAfrica aims to evolve into a persistent continental training and capacity-building layer that continues to support digital skills development, infrastructure adoption, and research collaboration beyond the project lifecycle.

## 9 Conclusions

The formalization of the DIGITAfrica Competence Framework and its accompanying modular curricula, as detailed in Deliverable D4.2, defines a milestone in establishing a sustainable pan-African human capital ecosystem for digital sciences. By identifying critical gaps in African digital skills and adopting a flexible, "stackable" micro-credential model which complements legacy academic paradigms, this deliverable provides a direct solution to the widening mismatch between university curricula and industry demands. The successful implementation of the Winter School in Kenya (March 2026) serves as a functional proof of concept, proving that blueprint-aligned, practical training can be effectively deployed within the region.

A central contribution of this deliverable is its structural integration with international and regional validation frameworks. By mapping DIGITAfrica competence levels directly to the European Qualifications Framework, the European e-Competence Framework, and the African Continental Qualifications Framework, the project ensures that the qualifications earned by African researchers and technical staff possess cross-border comparability, portability, and trust. Furthermore, by building upon the operational experiences of the SLICES and SoBigData Academies, the framework avoids duplication and maximizes resource efficiency, positioning itself as a robust, localized extension of European research infrastructure excellence.

We'll deepen and execute our approach during the second part of the project. In addition, the role of AI in our education and training process will be considered.

Looking ahead, the long-term impact of this work package depends on institutional anchoring and financial viability. The transition from a consortium-driven incubator to an open, decentralized network of permanent African "Founding Nodes"—supported by a hybrid funding model and secure verification standards like Open Badges—creates a definitive pathway toward self-sufficiency. Ultimately, this strategy directly empowers female and young researchers, retains critical technical expertise within local ecosystems, and secures the human infrastructure necessary to sustain a unified, pan-African digital research network well beyond the project lifecycle.

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# 11 Appendix 1

## Course Name: Network Automation

**Prerequisite:** Computer networking fundamentals, TCP/IP reference model, IPv4 subnetting, NAT, Linux fundamentals, SSH, network technologies e.g. DNS, DHCP, HTTP, SMTP.

**Lecture hours:** 9 hours

### Purpose of the course

To provide students with knowledge and practical skills in the field of network automation.

### Expected Learning Outcomes

At the end of the course, students should be able to:

1. Design and optimise computer networks to support automation,
2. Implement automation of computer network processes.

### Course Content

**Programming languages for Network Automation:** BASH and Python.

**Network Automation Tools:** Ansible, Terraform.

**Automation with BASH ad-hoc scripts:** Mikrotik devices - WLAN AP, switches, routers

**Configuration Management with Ansible:** Linux systems - DNS, DHCP, Web servers, Email servers

**Infrastructure Provisioning with Terraform:** AWS resources - Instances, firewalls, VPC

### Mode of Delivery

Classes will consist of lectures, labs, and group facilitation.

### Instructional Materials and/or Equipment

Audio Visual Equipment, Physical lab equipment, Virtual machines.

### Labs and Practical

Labs will depend on emerging trends and the expertise of the lecturer.

### Useful Materials and Links

1. <https://tldp.org/LDP/Bash-Beginners-Guide/html/>
2. <https://pynet.twb-tech.com/>
3. <https://docs.ansible.com/>
4. <https://developer.hashicorp.com/terraform/docs>
5. <https://help.mikrotik.com/docs/display/ROS/Scripting>

## **Course Name: Cloud Computing**

**Prerequisite:** Computer networking fundamentals, HTTP, Operating systems.

**Lecture hours:** 9 hours

### **Purpose of the course**

To provide students with knowledge and practical skills in the field of cloud computing.

### **Expected Learning Outcomes**

At the end of the course, students should be able to:

1. Implement cloud-ready systems,
2. Implement cloud-native systems.

### **Course Content**

Presentation: Service oriented Architecture / REST

Hands-on: REST API

Presentation: Micro-services / JSON Web Tokens (JWT)

Hands-on: Micro-architecture

Presentation: Virtualization (VM vs Container)

Hands-on: Containerization/Orchestration with Docker & Kubernetes

Presentation: OpenStack

Hands-on: Tutorial how to use OpenStack Web interface (Horizon)

Presentation: serverless

Hands-on: Tutorial how to use OpenFaaS

### **Mode of Delivery**

Classes will consist of lectures, labs, and group facilitation.

### **Instructional Materials and/or Equipment**

Audio Visual Equipment, Physical lab equipment, Virtual machines.

### **Labs and Practical**

Labs will depend on emerging trends and the expertise of the lecturer.

### **Useful Materials and Links**

1. <https://github.com/AdamBelloum/Tutorials/tree/main/Distributed-Systems/cloud-computing-soa>

## **Course Name: Introduction to AI for researchers**

**Prerequisite:** Basic knowledge of Logic.

**Lecture hours:** 4 hours

### **Purpose of the course**

To provide students with an overview of the AI basic concepts and history.

### **Expected Learning Outcomes**

At the end of the course, students should be able to:

1. Understand the basics of AI research.
2. Apply basic Spark and Federated Learning techniques through hands-on exercises.

### **Course Content**

1. AI History
2. Introduction to Agent technologies
3. Lecture: AI and employability

### **Mode of Delivery**

Classes will consist of lectures, labs, and group facilitation.

### **Instructional Materials and/or Equipment**

Audio Visual Equipment, Physical lab equipment, Virtual machines.

### **Labs and Practical**

Labs will depend on emerging trends and the expertise of the lecturer.

### **Useful Materials and Links**

1. <https://aima.cs.berkeley.edu/>
2. <https://turingarchive.kings.cam.ac.uk/publications-lectures-and-talks-amtb/amt-b-5>

## Course Name: Reinforcement Learning (RL)

**Prerequisite:** Probability & Statistics, Linear Algebra, Python Programming, Basic Machine Learning, Basic Deep Learning

**Lecture hours:** 5.5 hours

### Purpose of the Course

To provide students with a basic understanding of methods that can be used to train agents so that they can make sequential decisions using tabular or complex data, collected through interaction with an environment.

### Expected Learning Outcomes

At the end of the course, students should be able to:

1. Model complex decision problems using the Markov Decision Process (MDP) formalism.
2. Understand the theory behind basic fundamental RL algorithms such as Q-Learning and REINFORCE.
3. Use these algorithms in practice using standard libraries and interfaces

### Course Content

1. Agents and environments
2. Guiding decision making using utility functions: the reward hypothesis
3. Markov Decision Processes: policy estimation and value iteration
4. Multi-armed bandits
5. Properties of reinforcement learning methods
6. Temporal Difference methods: SARSA and Q-learning
7. Gradient policy methods: REINFORCE
8. Hybrid methods: actor-critic, PPO
9. Brief introduction to multi-agent reinforcement learning

### Mode of Delivery

Classes will consist of lectures, labs, and group facilitation.

### Instructional Materials and/or Equipment

- Audio visual materials (slides, videos).
- Physical lab equipment: notebooks, virtual machines, simulation environments (gymnasium).

### Labs and Practical

Labs will focus on training agents to solve classic RL problems (e.g., FrozenLake, CartPole).

### Useful Materials and Links

1. Reinforcement Learning: An Introduction (Sutton & Barto):  
<http://incompleteideas.net/book/the-book-2nd.html>

2. Multi-Agent Reinforcement Learning: <https://www.marl-book.com>
3. Gymnasium: <https://gymnasium.farama.org>

## Course Name: Deep Learning

**Prerequisites:** Python programming skills, basic Algebra

**Lecture Hours:** 10 hours

### Purpose of the Course

Provide students with a clear overview of deep learning concepts, key architectures, and historical developments, while building practical intuition about how models behave.

### Expected Learning Outcomes

By the end of the course, students will be able to:

1. Understand the fundamentals of deep learning and neural networks
2. Develop intuition about model behavior and decision-making
3. Apply deep learning techniques to solve basic problems
4. Recognize the role of different architectures, from CNNs and RNNs to Transformers and LLMs
5. Understand model evaluation and responsible AI practices

### Course Content

**Foundations of Neural Networks and Training:** Perceptrons, feedforward networks, activation functions, backpropagation

**Convolutional Neural Networks (CNNs):** convolution, pooling, feature extraction, computer vision applications

**Recurrent Neural Networks (RNNs):** sequence modeling, LSTM, GRU, and training challenges

**Transformers and Attention:** self-attention, encoder-decoder architecture, comparison with RNNs

**Introduction to Large Language Models (LLMs):** tokenization, embeddings, pretraining and fine-tuning

**Model Cards:** Evaluation metrics, documentation, ethical considerations

### Mode of Delivery

Classes will consist of lectures, labs, and group facilitation.

### Instructional Materials and/or Equipment

Audio Visual Equipment, Physical lab equipment, Virtual machines.

### Labs and Practical

Labs will depend on emerging trends and the expertise of the lecturer.

### Useful Materials and Links

1. <https://bit.ly/4bLEWHx>
2. <https://teachablemachine.withgoogle.com/train>
3. <https://animatedai.github.io/>

## **Course Name: Big Data and AI**

**Prerequisite:** Basic knowledge of Python, ML fundamentals, Basic of data analysis.

**Lecture hours:** 9 hours

### **Purpose of the course**

To provide students with knowledge and practical skills in the field of Big Data.

### **Expected Learning Outcomes**

At the end of the course, students should be able to:

1. Explain the core concepts of Big Data, Spark, and Federated Learning in modern AI.
2. Apply basic Spark and Federated Learning techniques through hands-on exercises.

### **Course Content**

Presentation: Introduction to BiGData (Spark) and AI

Hands-on: Spark

Presentation: Introduction to Federated Learning

Hands-on: Federated learning

Guest lecture from industry (Pegasystems)<sup>29</sup>: Agentic AI or GenAI

### **Mode of Delivery**

Classes will consist of lectures, labs, and group facilitation.

### **Instructional Materials and/or Equipment**

Audio Visual Equipment, Physical lab equipment, Virtual machines.

### **Labs and Practical**

Labs will depend on emerging trends and the expertise of the lecturer.

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<sup>29</sup> Depends on available time

## 12 Appendix 2

### Course Name: RESTful API Development with Flask (URL Shortener)

#### *Prerequisite:*

Basic Python programming (dictionaries, functions), Linux fundamentals (Command Line/Terminal), and an understanding of basic HTTP concepts (client-server model).

#### *Lecture Hours:*

3 Hours (1 Hour Lecture, 2 Hours Hands-on Lab)

#### *Purpose of the Course:*

To provide students with practical skills in building, testing, and deploying RESTful web services using the Flask framework, focusing on the relationship between HTTP methods and data persistence.

#### *Expected Learning Outcomes:*

At the end of the course, students should be able to:

1. **Apply RESTful Principles:** Map CRUD operations (Create, Read, Update, Delete) to appropriate HTTP methods (POST, GET, PUT, DELETE).
2. **Develop with Flask:** Set up a web server, define dynamic routes, and handle JSON request/response bodies.
3. **Implement Data Validation:** Create helper functions to validate input data (URLs) and handle errors with appropriate HTTP status codes (201, 301, 400, 404).

#### *Course Content:*

- **Introduction to Flask:** Lightweight framework setup and "Hello World" routing.
- **Architecture of a URL Shortener:** Mapping Short IDs to Long URLs using in-memory data structures.
- **Testing/Debugging:** Using curl to simulate client requests and verify API behavior.

#### *Mode of Delivery:*

- **Interactive Lecture:** Brief overview of REST and Flask.
- **Live Coding:** Step-by-step implementation from a "skeleton" code version.
- **Lab:** Guided session to pass a set of automated test cases.

#### *Instructional Materials and/or Equipment:*

- Python 3.x environment with Flask installed.
- Code editor (VS Code, PyCharm, or similar).
- Terminal/Command Line for curl testing.
- Provided "Skeleton" app script.

#### *Labs and Practical:*

- **Task 1:** Implement the `is_it_an_url` validation logic.
- **Task 2:** Create the POST endpoint to generate 6-character MD5 hashes for URLs.
- **Task 3:** Successfully update and delete records via curl commands.

#### *Course Material:*

<https://github.com/AdamBelloum/Tutorials/tree/main/Distributed-Systems/cloud-computing-soa>

## Course Name: Microservices Architecture & Secure Authentication (JWT)

### *Prerequisite:*

Completion of the "RESTful API Development with Flask" module. Proficiency in Python, basic understanding of hashing (SHA-256/MD5), and familiarity with the Linux CLI (Command Line Interface).

### *Lecture Hours:*

6 Hours (2 Hours Lecture, 4 Hours Hands-on Lab)

### *Purpose of the Course:*

To transition students from a single-user REST API to a secure, multi-user microservices ecosystem. Students will learn to decouple services, manage user identities, and implement secure, decentralized authentication using JSON Web Tokens (JWT) signed with RSA-256.

### *Expected Learning Outcomes:*

At the end of the course, students should be able to:

1. **Architect Microservices:** Split a system into distinct functional units (Authentication vs. Application services).
2. **Implement Asymmetric Cryptography:** Generate and manage RSA key pairs (private/public) to sign and verify data.
3. **Master JWT Mechanics:** Manually construct, sign, and verify base64url-encoded JWTs without high-level libraries to understand the protocol's internal security.
4. **Enforce Multi-User Ownership:** Modify data structures to support user-specific access control and resource management.

### *Course Content:*

1. **Microservices 101:** Communication between the Auth Service and the Shortener Service.
2. **Identity Management:** Password hashing with SHA-256 and secure user registration/login workflows.
3. **JWT Protocol Deep-Dive:** \* Structure: Header, Payload (sub, iat, exp), and Signature.
4. **Security:** RS256 signing (Private Key) and local verification (Public Key).
5. **Secure Routing:** Extracting tokens from Authorization: Bearer headers and validating "sub" claims for ownership.
6. **User-Centric CRUD:** Updating API endpoints to filter and manage resources based on the authenticated user's identity.

### *Instructional Materials and/or Equipment:*

- Python 3.x with flask and cryptography libraries installed.
- RSA Key generation tools (integrated via Python cryptography primitives).
- Multi-service project skeleton with auth\_service/ and shortener\_service/ directories.

### *Course Materials:*

<https://github.com/AdamBelloum/Tutorials/tree/main/Distributed-Systems/cloud-computing-soa>

## Course Name: Cloud-Native Orchestration with Kubernetes

### *Prerequisite:*

Completion of the "Microservices Architecture & JWT" module. Working knowledge of Docker/Containerization, Linux System Administration (NFS, SSH, Sysctl), and basic YAML syntax

### *Lecture Hours:*

2 Hours (4 Hours Lecture, 8 Hours Hands-on Lab)

### *Purpose of the Course:*

To provide students with the expertise to deploy, manage, and scale federated microservices across a multi-node Kubernetes cluster. Students will implement persistent storage solutions and expose services to the Pan-African research network.

### *Expected Learning Outcomes:*

At the end of the course, students should be able to:

1. **Provision a K8s Cluster:** Initialize a control plane and join multiple worker nodes using kubeadm.
2. **Implement Persistent Storage:** Configure NFS-backed Persistent Volumes (PV) and Claims (PVC) to ensure data persistence across container restarts (RWX mode).
3. **Manage Secure Secrets:** Deploy Kubernetes Secrets and ConfigMaps to securely distribute RSA keys and public certificates across a distributed system.
4. **Scale and Expose Services:** Utilize Deployments for service redundancy (e.g., 3 replicas for the shortener) and NodePort Services for external reachability.
5. **Debug Distributed Systems:** Diagnose common orchestration failures, including CNI plugin issues, image platform mismatches (linux/amd64), and NFS mount errors.

### *Course Content:*

1. **Cluster Bootstrap:** Configuring containerd, CNI (Flannel), and the Kubernetes Control Plane.
2. **Kubernetes Resource Manifests:** Creating Namespaces, Deployments, and Services via YAML.
3. **Shared Storage Architecture:** Setting up an NFS kernel server and mapping it to Kubernetes PVs for ReadWriteMany access.
4. **Multi-Arch Container Strategy:** Building and pushing cross-platform Docker images explicitly for linux/amd64 architectures.
5. **Verified CI/CD Workflows:** Running end-to-end unittests against a live Kubernetes environment using port-forwarding.

### *Instructional Materials and/or Equipment:*

- Three Ubuntu 22.04+ VMs (AMD64) with network connectivity.
- Project skeleton including k8s/ manifests and commands/ bootstrap scripts.
- Docker Hub account for image registry.

### *Useful Materials and Links:*

<https://github.com/AdamBelloum/Tutorials/tree/main/Distributed-Systems/cloud-computing-soa>

## Course Name: Scalable Big Data Processing with Apache Spark

### *Prerequisite:*

Completion of the "Microservices Architecture" and "Kubernetes Orchestration" modules. Basic knowledge of Scala or Python and familiarity with Docker Compose.

### *Lecture Hours:*

8 Hours (3 Hours Lecture, 5 Hours Hands-on Lab)

### *Purpose of the Course:*

To introduce students to the architecture and operation of distributed data processing clusters. This course demonstrates how to leverage containerization to deploy, scale, and utilize an Apache Spark environment for large-scale data analytics.

### *Expected Learning Outcomes:*

At the end of the course, students should be able to:

1. **Manage Containerized Clusters:** Use Docker Compose to orchestrate a multi-node Spark environment (Master and Workers).
2. **Execute Distributed Analytics:** Perform interactive data manipulation using the Spark-Shell and DataFrame API.
3. **Implement Data Persistence:** Configure Docker Bind Mounts to provide containers access to external research datasets.
4. **Scale Computational Resources:** Dynamically adjust the number of active Spark workers to meet data processing demands.
5. **Deploy Production Jobs:** Utilize the spark-submit utility to deploy standalone applications to a remote cluster.

### *Course Content:*

1. **Spark Architecture:** Understanding the roles of the central Master coordinator and the task-executing Workers.
2. **Virtualization with Docker:** Utilizing the apache/spark image and configuring services, environments, and port mapping in YAML.
3. **Interactive Data Engineering:** \* Loading CSV datasets into Spark DataFrames.
4. **Schema inspection and data filtering (e.g., age-based user filtering).**
5. **Dynamic Scaling:** Scaling workers from a single instance to a multi-node cluster using --scale.
6. **Job Orchestration:** Submitting computational tasks (e.g., SparkPi) to the cluster via CLI.

### *Instructional Materials and/or Equipment:*

- Docker & Docker Compose environment.
- Apache Spark 3.5.0 distribution.
- Kaggle Bank Personal Loan dataset.

### *Useful Materials and Links:*

[https://github.com/AdamBelloum/Tutorials/tree/main/Big-Data/bigdata-ai/spark/spark\\_cluster](https://github.com/AdamBelloum/Tutorials/tree/main/Big-Data/bigdata-ai/spark/spark_cluster)

## Course Name: Federated Learning: Collaborative AI without Data Sharing

### *Prerequisite:*

Completion of the "RESTful Microservices" and "Big Data Processing" modules. Basic Python proficiency and a foundational understanding of Machine Learning (Training vs. Testing).

### *Lecture Hours:*

6 Hours (2 Hours Lecture, 4 Hours Hands-on Lab)

### *Purpose of the Course:*

To provide students with an understanding of how to train AI models across decentralized data silos. Students will learn the "Model moves, data stays" paradigm, where a global model is improved through local weight updates rather than raw data collection.

### *Expected Learning Outcomes:*

At the end of the course, students should be able to:

1. **Contrast AI Architectures:** Explain the differences and risks between Centralized AI and Federated Learning.
2. **Conduct Local Model Training:** Use Python to train a local AI model on private, institution-specific datasets.
3. **Manage Federated Rounds:** Participate in the orchestration of global model aggregation across multiple client nodes.
4. **Implement Flower (flwr):** Deploy a federated server and clients to facilitate collaborative model weight updates.
5. **Analyze Model Performance:** Evaluate the improvement of a global model through successive rounds of federated training.

### *Course Content:*

- **The Problem of Data Silos:** Why centralized AI is risky and how FL solves privacy concerns in sensitive fields like healthcare or finance.
- **Components of FL:** Clients: Local nodes where training occurs on private data.
- **Server/Aggregator:** central node combines model weights without seeing raw data.
- **FL Workflow with Flower:** Setting up the server environment
- **Configuring client-side training logic and data paths.**
- **Aggregation Strategies:** Understanding how mathematical parameters (model weights) are merged to create a superior global model.

### *Instructional Materials and/or Equipment:*

- Python 3.10+ with the flwr (Flower) and pandas libraries.
- JupyterHub access or individual VMs (student123, 124, 125).
- Pre-partitioned training data (e.g., train.csv for Group A and Group B).

### *Course Materials:*

<https://github.com/AdamBelloum/Tutorials/tree/main/Distributed-Systems/federated-learning>