

Skills 4 EOSC

D4.3 Open Science Essentials for undergraduate programmes and Doctoral Schools

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Deliverable Abstract

Deliverable D4.3 outlines a strategic proposal to embed Open Science (OS) skills and competencies in undergraduate and doctoral education, aligned with the objectives of the European Open Science Cloud (EOSC) and the reform of research assessment.

The deliverable provides concrete guidance for integrating these skills into curricula through modular, flexible learning pathways, ensuring compatibility with diverse institutional and national contexts. It also highlights how higher education institutions and doctoral schools can lead this transformation by embedding OS in training plans and supervision practices.



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TERMINOLOGY

In the context of developing Open Science (OS) education within Skills4EOSC (S4E), it is important to distinguish between these interconnected but distinct concepts that we will use extensively in this deliverable.

Curriculum Development: It often aligns with the official provision of degrees and qualifications at national or institutional level. It defines the structure, scope, progression, and intended outcomes of a complete training offer. In S4E curriculum development is driven by the Minimum Viable Skillsets (MVS) and ensures that the content aligns with national or institutional strategies, policy agendas, and labour market expectations.

Open Science Essentials (OSE): is the translation of MVS into teachable and assessable content. OSE define what is essential to teach to build minimum OS competences for a given target group. OSE are expressed through structured lessons, modules, and learning outcomes, and are the backbone of Skills4EOSC's curricular interventions and of the pilot trainings reflected in this document.

Learning Path / Learning pathway: A learning pathway is the operational expression of a curriculum. It is the sequenced arrangement of modules, lessons, and activities designed to progressively build competences in a coherent manner. Learning pathways reflect the curriculum at a concrete level, in a particular syllabus and may vary depending on the learner profile (e.g. undergraduate, PhD, professional).

Learning Design: The pedagogical planning process that ensures the coherence, engagement, and accessibility of the learner's journey across a given pathway. It includes decisions on the format or delivery modes (e.g. self-paced, online, blended, synchronous, etc.), assessment strategies, and use of educational technologies. The learning design serves as a bridge between curriculum objectives and their implementation in a specific context.

Instructional Design: focuses on the detailed process of creating modules, lessons, and learning materials. It ensures that each learning unit aligns with learning outcomes and quality criteria (e.g. accessibility, open licensing, FAIRness, etc.). Instructional design is applied here through the FAIR-by-Design methodology and is supported by the S4E Quality Assurance Framework (QAF).

Acronym	Definition
CoARA	Coalition for the Advancing Research Assessment

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DORA	(San Francisco) Declaration on Research Assessment
ECR	Early Career Researchers
ECTS	European Credit Transfer System
ELSI	Ethical, Legal and Social Issues
EOSC	European Open Science Cloud/Commons
ERA	European Research Area
FAIR	Findable, Accessible, Interoperable, and Reusable
FbD	FAIR by Design
HE	Higher Education
HEI	Higher Education Institutions
ISCED	International Standard Classification of Education (UNESCO)
LIS	Library and Information Science
LMS	Learning Management System
MVS	Minimum Viable Skillset
O5	Objective 5
OER	Open Educational Resources
OS	Open Science
OSE	Open Science Essentials
QAF	Quality Assurance and Certification Framework
RRA	Responsible Research Assessment
RRI	Responsible Research and Innovation
S4E	Skills4EOSC
SRIA	Strategic Research and Innovation Agenda (EOSC)
SSH	Social Sciences and Humanities
STEM	Science, Technology, Engineering and Mathematics
TAU	Tampere University
TtT	Train the Trainers
UC3M	Universidad Carlos III de Madrid
UC3MT2OS	UC3M Ticket to Open Science
WP	Work Package

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1.Executive summary

Deliverable D4.3 presents a strategic and practical framework for embedding Open Science Essentials (OSE) into undergraduate and doctoral education across European Higher Education Institutions (HEIs). Developed under Work Package 4 (WP4) of the Skills4EOSC (S4E) project, the report builds on the Minimum Viable Skillsets (MVS) defined in WP2 and operationalises them into modular, pedagogically sound learning paths tailored to the needs of bachelor students and PhD candidates.

The deliverable details two parallel learning paths, developed in T4.3 and T4.4, each supported by tailored learning and instructional design, quality assurance, and piloting. Under T4.3, we designed and piloted a modular, self-paced undergraduate course introducing Open Science (OS), Open Access, copyright/licensing, and research data management (RDM), later converted into a Train-the-Trainers (TtT) package for easy institutional reuse. Under T4.4, we created a transversal, discipline-aware OS learning path for PhD candidates, delivered online with weekly sessions, an optional discipline-specific module, recognition via micro-credentials, and a companion TtT course for doctoral schools. Together, these pathways operationalise the Minimum Viable Skillsets (MVS) into concrete, pedagogically robust Open Science Essentials (OSE) that HEIs can adopt as full programmes or à-la-carte modules.

Throughout the development and pilot phases, the FAIR-by-design (FbD) methodology and the Skills4EOSC Quality Assurance Framework (S4E-QAF) ensured that training materials met standards of openness, accessibility, and reusability. Feedback loops with learners and trainers led to continuous improvements and fostered co-creation practices aligned with institutional and national needs.

D4.3 offers transferable models for integrating OS training at different institutional and national contexts. It underscores the importance of early and structured exposure to OS principles, flexible and modular delivery, and harmonisation of curricula across countries, while preserving national idiosyncrasies and disciplinary diversity. It concludes with concrete lessons

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and recommendations for embedding OS sustainably in HEIs, advancing the vision of **Open Science-ready** institutions within the European Open Science Cloud (EOSC) ecosystem.

2. Introduction and Scope

2.1. Shaping Open Science-ready institutions

The transformation of research practices toward openness and reproducibility, along with the demanding EOSC (European Open Science Cloud/Commons) ecosystem, has created an urgent need to embed Open Science (OS) principles across all levels of Higher Education (HE) and professional development. This challenge calls not only for individual competence but also for institutional capacity to support, incentivise, and sustain OS practices systematically and inclusively. In this context, S4E project aims to unify the fragmented OS training landscape in Europe by establishing a trusted and sustainable training ecosystem. Particularly Work Package 4 (WP4), under which this deliverable is framed, focuses on designing harmonised curricula and learning paths that support the emergence of *Open Science-ready institutions*.

In the WP4-Skills4EOSC context, we define **Open Science-ready institutions** as those institutions that integrate Open Science principles into their core missions of education, research, and societal engagement. This includes ensuring that students, researchers, and staff are trained in OS competences, that policies and infrastructures support FAIR data management, open access, and responsible research assessment, and that OS is embedded structurally into curricula, professional development pathways, and institutional strategies. Such institutions should also be proactive in aligning with national and European OS frameworks (including EOSC) and act as enablers of a research culture change.

In parallel, WP4 also addressed the needs of data professionals and support staff in these **OS-ready institutions**, whose roles are increasingly central to the implementation of OS practices across the research lifecycle. These

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aspects were explored in detail in D4.2 *“Learning Paths for Data Professionals”*, which complements the present report in the general endeavour of shaping up Open Science readiness.

2.2. Scope of this deliverable

Deliverable 4.3 specifically addressed Objective **(O5)** of the project, which aims to define *“Open Science and data-intensive science essentials”* for integration into undergraduate and doctoral curricula. The deliverable is founded in the work conducted under **Tasks 4.3** and **4.4**, which respectively focused on the development and piloting of OS learning modules tailored to bachelor's degree programmes (T4.3), and on the alignment of PhD training pathways (T4.4.) with the evolving demands of Open and FAIR research practices.

The contents of this deliverable reflect a dual ambition: to empower students (future professionals or future researchers) with foundational OS competences, and to provide institutions with modular, adaptable teaching resources that can be embedded into existing programmes. For that, we have transformed the Minimum Viable Skillsets (MVS) into Open Science Essentials (OSE). OSE are the translation of the MVS into structured sets of lessons, modules, and learning outcomes that make OS competences teachable and assessable within academic programmes. This pedagogical transformation is informed by a skill-based approach, guided by stakeholder input, both from students (within the pilots) and trainers (within the Train the Trainers' course), and oriented towards flexible integration into diverse educational contexts, in this case, particularly into undergraduate bachelors' education and graduate education at the doctoral level.

- The **undergraduate level** might have two approaches:
 - a) Integrating **Open Science (OS) literacy**, research data management, and data ethics into general curricula, with specific pathways for STEM and SSH fields and professions. This training could be integrated into the generic training in digital competencies in all bachelor's and undergraduate degrees.

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- b) **Generic Open Science training:** offering a dedicated Open Science course or seminar as a formal component of specific disciplinary programmes, such as in Library and Information Science (LIS), within European iSchools¹ or related faculties.
- The **doctoral level** may likewise follow two possible approaches:
 - a) Embedding OS competences within **disciplinary doctoral training**, where OS topics (e.g. FAIR data, open access publishing, responsible metrics) are taught as integral elements of subject-specific research methodologies or thematic modules within the candidates' field of study.
 - b) Implementing a **transversal OS training pathway** coordinated through the university's Doctoral School, applicable across disciplines. This route enables a coherent, progressive acquisition of OS competences throughout the different stages of the doctoral journey, from research design and data management to dissemination and community engagement, sharing differences among disciplines.

This deliverable contributes to the **interoperability of training offers** within EOSC by producing FAIR-by-Design (FbD) educational materials and aligning the proposed modules with the quality assurance and certification framework (QAF) developed in WP2. So, D4.3 supports the recognition and transferability of OS competences across institutions and national contexts, and fosters the **emergence of a pan-European education model** that is responsive to the needs of Open Science.

¹ The iSchools (<https://www.ischools.org>) represent an international organisation of around 130 universities. A common interest in all aspects of research and teaching about information unites them. The scope is deliberately broad and methodologically agnostic, with a strong reliance on the social and behavioural sciences, as well as computing and linguistics. iSchools topics include artificial intelligence, data science, human-computer interaction, information organisation and access, bibliometrics, and information integrity. The iSchools are the natural HE context to teach open science experts and data librarians/stewards. A list of EU iSchools see: <https://www.ischools.org/european-region>. TAU (Tampere University) in Finland and UC3M (Universidad Carlos III de Madrid) co-leads of this deliverable and the tasks involved in it are both iSchools).

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2.3. Alignment with EOSC Strategic Priorities

The educational strategies developed in this deliverable respond to the broader policy objectives outlined in the ***EOSC Strategic Research and Innovation Agenda (SRIA)***, particularly the need to build a new generation of digitally skilled research professionals. By embedding OS Essentials into formal, semi-formal or complementary academic pathways, Skills4EOSC contributes to systemic transformation in research culture and supports the long-term goal of making **OS practices the "new normal"** in European Research Area (ERA) and addresses a critical component of this transformation by the integration of OS competences into formal academic education at both undergraduate and graduate/pHD levels.

D4.3 addresses several key priorities set out in the context of the EOSC partnership, especially:

- Skills development and capacity-building for researchers and research professionals;
- Recognition and certification of OS competences, including those acquired through non-formal or modular learning paths;
- Support to institutional change, by enabling HEI to become OS-ready institutions, structurally including OS into their education and training ecosystems.

3. Underlying work and tasks supporting this deliverable

The creation of the Open Science Essentials for Undergraduates and PhD candidates was founded on the work done in WP4, especially Tasks 4.3 and 4.4. The work undertaken in WP4, and reflected in this deliverable, is directly supported by the outcomes of WP2: the co-creation of the Minimum Viable Skillsets (MVS)², the FAIR-by-Design (FbD) methodology for learning materials³, and the Quality Assurance and Certification Framework (QAF)⁴.

² <https://zenodo.org/records/8101903> [R5]

³ <https://zenodo.org/records/14711525>

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These foundational elements have enabled the translation of abstract competence models into practical, adaptable educational resources now presented as **Open Science Essentials (OSE)** or specific learning paths for two different stages of the research career pipeline (undergraduate and doctoral studies).

3.1. OS essentials at undergraduate level (Task 4.3)

The objective of T4.3 was to introduce foundational OS competences (essentials OSE) at the undergraduate level by producing a flexible self-paced course for students and a companion TtT for educators. The task was led by TAU (Tampere University) and built upon the recognition that foundational OS competences should be introduced early in academic training to ensure that future researchers and professionals are well-prepared to operate in Open and FAIR research environments.

To this end, the task reshaped existing undergraduate courses on information and data skills, identifying essential OS competences based on the Minimum Viable Skillsets (MVS) framework developed in WP2 (T2.1). Particular attention was paid to tailoring content to the distinct needs of students in STEM and SSH disciplines, supporting their potential progression into data stewardship roles or related careers in academia, the public sector, or industry. The main output of the task was the design of a modular course titled *“Introduction to Open Science and Research Data Management for Undergraduate Students”*. The course integrated topics such as Open Access, FAIR data principles, data management planning, and research integrity. It reused and adapted existing high-quality Open Educational Resources (OERs), ensuring pedagogical soundness, adaptability, and alignment with FbD principles (as per T2.3). The course was designed to be flexible enough to be integrated either into general digital skills training across bachelor programmes or as a stand-alone module within domain-specific degrees such as Library and Information Science (LIS) or iSchools. The course was piloted in TAU iSchool, taught in Finnish during Year2 of Skills4EOSC⁵.

⁴ <https://zenodo.org/records/15731878>

⁵ <https://doi.org/10.5281/zenodo.15478446> [R2]

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To facilitate broader implementation and capacity building, the course was subsequently transformed into a Train-the-Trainers (TtT) programme entitled: *“Teaching Open Science and Research Data Management for Undergraduates”*. This TtT programme is intended for instructors, particularly in LIS faculties or iSchools, who are responsible for delivering OS training to undergraduate audiences. It equips educators with the didactic strategies, reusable content, and assessment tools necessary to embed Open Science competences effectively into undergraduate teaching⁶. TtT sessions target master trainers in the S4E Competence Centres and facilitate pilots at partner institutions to test and validate the materials. This approach ensures the sustainability and scalability of undergraduate OS training across European higher education institutions, while supporting the broader goal of transforming them into OS-ready environments.

3.2. OS ready PhD curricula (Task 4.4)

T4.4 focused on developing OS training pathway for doctoral candidates, to integrate OS competences into PhD curricula in a structured, flexible, in a domain-agnostic manner, but highlighting differences among disciplines and engaging students in the comparison. Led by Universidad Carlos III de Madrid (UC3M), this task recognised the need to provide early career researchers (ECR) with the skills and mindset necessary to navigate an increasingly open and data-intensive research landscape, in alignment with the ERA (European Research Area) agenda and the MVS defined in WP2 [R5].

The task explored two complementary models for introducing OS into doctoral education:

- ~ The **transversal approach**, whereby OS training is delivered through Doctoral Schools and applies to all disciplines regardless of field or methodology.
- ~ The **disciplinary approach**, in which OS competences are embedded within subject-specific doctoral training modules or methodological courses, enabling alignment with field-specific needs, norms, and practices.

⁶ <https://doi.org/10.5281/zenodo.15193549> [R3]

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To operationalise these models, UC3M designed and implemented the pilot course *“UC3M Ticket to Open Science”* (UC3MT2OS), a modular training programme delivered online, conducted in English, and offered through the institutional Doctoral School to all doctoral candidates enrolled at UC3M, regardless of their discipline or stage in the PhD process.

The *UC3M Ticket to Open Science* pilot demonstrated the feasibility of embedding OS into doctoral training as a scalable, modular programme that can be adapted by other institutions. It also set the groundwork for the development of a follow-up Train-the-Trainers (TtT) course: *“Shaping Open Science Champions: A Train-the-Trainers Course for Educators of PhD Candidates”*, held in May 2025, reinforcing the sustainability and outreach of the work undertaken in T4.4.

3.3. Interdependencies with other WPs, WP4 and Skills4EOSC generic approach

The development of the OSE for undergraduate and doctoral levels, as presented in this deliverable, was made possible through strong interdependencies with other WPs and activities across the Skills4EOSC project. These interconnections ensured a coherent methodological foundation, alignment with the project’s overall vision, and reusability of outputs across contexts and audiences.

In particular, the work conducted in WP2 was fundamental to the curricular development process:

- ~ Task 2.1: Mapping of Open Science career profiles and the definition of Minimum Viable Skillsets,
- ~ Task 2.3: The FAIR-by-design methodology for training materials,
- ~ Task 2.4: The quality assurance and certification framework for learning materials, and
- ~ Task 2.5: The Skills4EOSC Recognition Framework for competence validation

The outputs of this deliverable are also connected to the community-building and stakeholder consultation processes developed in WP6 (Professional Networks for Lifelong Learning) and WP8. WP6 and WP8 (Synergies,

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stakeholder engagement, advocacy and communications). WP6 enabled feedback from professional and thematic networks, ensuring that the learning paths are meaningful and adaptable across disciplines, countries and institutions. WP8, along with the national Competence Centres, helped align and extend D4.3 outputs with national and European policy agendas and supported engagement, particularly with European University Alliances (EUA) and University networks.

This deliverable shares a common methodological approach⁷ with all other WP4 tasks, particularly those focusing on data professionals (T4.1 and 4.2), whose resulting learning paths are described and analysed in D4.2: *“Learning Paths for Data Professionals”*. The use of a shared design process grounded in MVS profiles, co-creation principles, FAIR-by-design materials, and pilot testing ensures consistency across all training pathways developed in WP4, while allowing for adaptation to different target audiences. D4.3 and D4.2 are different but complementary outputs that collectively contribute to the overarching objective of WP4 of building a modular, scalable, and interoperable training ecosystem for OS-ready institutions.

These interdependencies and integration not only enhanced the technical and pedagogical coherence of the curricula and OS essentials described in this deliverable but also contributed to their co-creation, contextualisation, adaptation and future sustainability. They reflect the project's integrated approach to curriculum development, ensuring that the educational resources created under WP4 are embedded in a broader European effort to strengthen OS skills and competences across the research and education ecosystem, helping to build up the so-called **“OS-ready institutions”**.

⁷ See Section 4 below.

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4. Methodology: Curriculum and Learning Path Design Process

4.1. Common iterative methodology to create OS Essentials in WP4

The design of OSE the different learning paths in WP4 followed a common iterative methodology applied consistently across all tasks (whether focused on undergraduate (T4.3), doctoral (T4.4), or professional (T4.1 and T4.2) learning paths⁸. This shared methodology, illustrated in Figure 1, ensured coherence across the different training pathways and fostered alignment with the broader objectives of the S4E project.

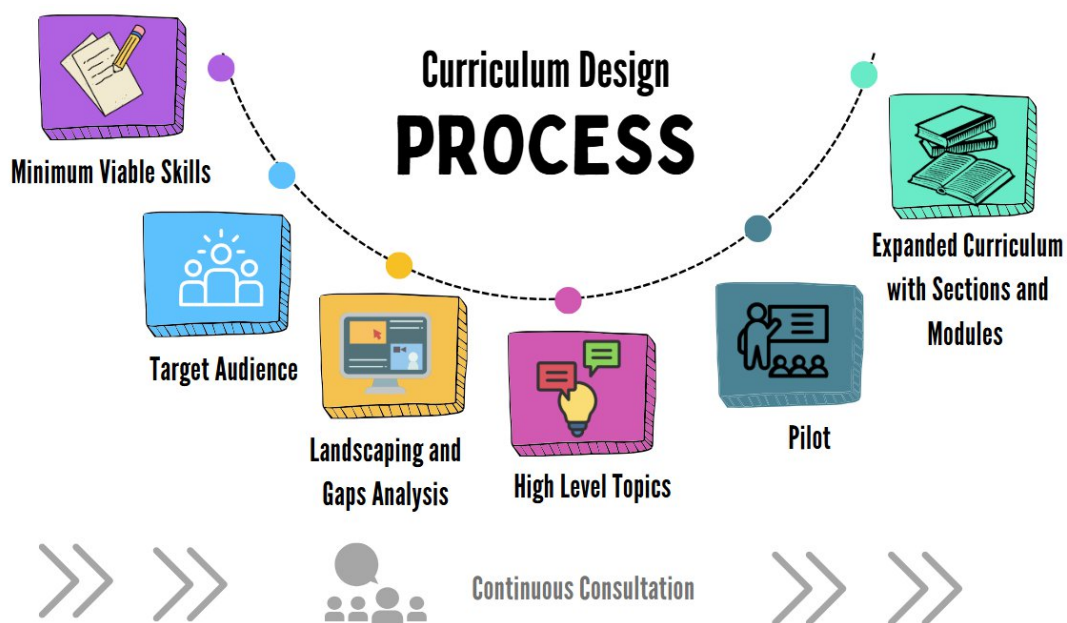


Figure 1: Curriculum Design Process (WP4 – image from T4.1)

In our case (undergraduate and doctoral pathways), the process began with the analysis of MVS for each target group, as developed in WP2⁹. These

⁸ The learning paths for data professionals are described and detailed in D 4.2. <https://doi.org/10.5281/zenodo.15691090> [R4]

⁹ <https://doi.org/10.5281/zenodo.8101903> [R5]

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profiles provided the basic competence framework upon which each curriculum was built. This was followed by an explicit identification of the **target audience**, to tailor the instructional design to educational levels, and assessing also possible disciplinary approaches.

A **landscaping and gap analysis** phase then allowed partners to review existing training materials, practices, and institutional strategies. This step was essential for identifying both content gaps and reusable resources, ensuring that new developments were complementary and not duplicative.

From this base, **high-level topics** were defined for each audience segment, outlining the core content areas, learning outcomes, and pedagogical structure. This conceptual design was then transformed into concrete outputs through the creation of an **expanded curriculum**, structured into thematic **sections and modules**.

The resulting curricula were tested through **pilot implementations** in partner institutions (TAU for undergraduates, UC3M for PhDs), which served both as validation environments and as spaces for gathering feedback from students, trainers, and institutional stakeholders. Throughout the entire process, continuous consultation was maintained with relevant communities, including participants in the pilots, expert trainers, and members of the Skills4EOSC Competence Centres. This participatory and iterative approach was adopted to ensure reusability, adaptation and improvement of the learning paths.

4.2. Principles: Co-creation, Modularity, FAIR-by-Design

The development of “the essentials” (OSE) and the corresponding learning pathways for undergraduate and doctoral education within WP4 was guided by a set of foundational principles designed to ensure consistency, cohesion, relevance and adaptability across diverse institutional and disciplinary contexts. These principles (co-creation, modularity, and FbD) were applied consistently across Tasks 4.3 and 4.4, and are aligned with the overall pedagogical and technical vision of the Skills4EOSC project.

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Co-creation is a central principle of the Skills4EOSC project (reference). Both learning paths were developed in a collaborative environment. Figure 2 shows the example of the shared collection of resources in Zotero. An iterative consultation with Key stakeholders, including educators, institutional support staff, national Competence Centres, doctoral schools, and student participants, were iteratively consulted at different points of the design and piloting phases. Feedback gathered during pilot phases (especially from learners and trainers) was used to refine content, balance workloads, and improve usability. This participatory approach ensured that the resulting curricula are context-sensitive and responsive to the actual needs and constraints of OS teaching and learning, which are usually aligned and depend on national OS strategies as well as national and regional research and education budgets.

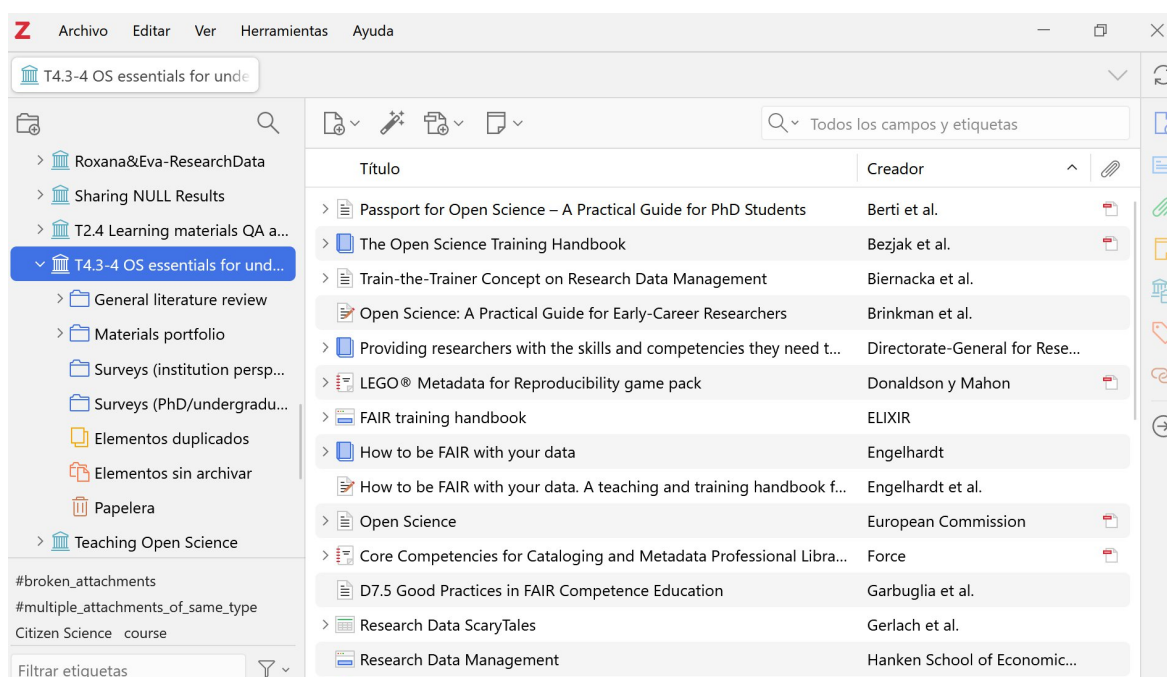


Figure 2: Zotero Shared Collection of bibliography and resources for the OSE for undergraduates and PhD candidates (T4.3, T4.4.)¹⁰

Modularity was adopted as a core instructional design principle to allow institutions to flexibly adapt and adopt or integrate specific components of

¹⁰ Zotero's shared group: T4.3-4 OS essentials for undergraduates & PhD students: https://www.zotero.org/groups/4864717/t4.3-4_os_essentials_for_undergraduates_phd_students

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the courses into existing training structures. Each course was organised into stand-alone modules (6, in the case of undergraduate students and 10 in the case of PhD candidates), with clearly defined learning outcomes and assessments, enabling educators to reuse individual units or reconfigure the sequence according to local requirements, disciplinary relevance, or credit allocation norms. This modularity was tested during the TtT courses, where participants adapted the different modules to their national or institutional realities.

FbD. The **FAIR-by-Design (FbD) methodology** represents one of the core distinguishing features of the Skills4EOSC project. It mirrors the principles of FAIRness originally developed for research data management (RDM) and extends them to the domain of educational resources and learning paths. By applying the FAIR principles (Findability, Accessibility, Interoperability, and Reusability) to training materials from the outset, FbD acts as both a conceptual framework and a practical quality standard for the development of OS educational assets. It guarantees that all learning outputs, materials, OER, etc. are produced with discoverability and reusability in mind.

In accordance with the FbD methodology, our learning paths and pilot courses (both, for targeted audiences and for trainers) use metadata systematically, made licensing terms explicit, design content for openness, multilingual adaptability, and technical interoperability with commonly used Learning Management Systems (LMS). This approach maximises the visibility, reusability, and long-term value of the training materials within and beyond the Skills4EOSC ecosystem.

4.3. From MVS to OSE

Designing learning paths at undergraduate and PhD levels focuses on two entry points of the academic journey and the HE system: undergraduate students and doctoral candidates. These two groups reflect different levels of academic development, competence maturity, and learning needs, and are thus addressed separately in the learning paths presented in this report¹¹.

¹¹ *Vid. Infr.* Section 5 (undergraduate level), Section 6 (PhD candidate's level).

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We started by analysing the MVS¹² for both targeted audiences. The MVS for undergraduate students highlights essential skills related to data management, open licensing, and the FAIR principles, adapted to the competence level typically acquired during bachelor's studies or even master (ISCED 6-7¹³). In contrast, the MVS for Early Career Researchers (ECR) significantly expands the scope of competences, incorporating advanced data management, digital skills, research communication, project management, open publishing and open peer review, and the crucial topic for research career advancement of RRA (Responsible Research Assessment—CoARA, DORA—). However, the ECRs spectrum covers more than PhD candidates. Our specific target audience addresses the earliest stages of the research career, specifically R1 (First Stage Researcher: doctoral candidate), according to the European Commission's Researcher Career Framework (R1–R4¹⁴). Therefore, the training focuses on structured and discipline-aware OS competences such as responsible research planning, open and FAIR data management, research ethics, open publishing, responsible research assessment, and community engagement. This distinction also aligns with the *OECD's Frascati Manual*¹⁵ which recognises doctoral education as the formal beginning of a research career (level D) and bachelor studies as preparatory training that may or may not lead to research activity. While the MVS provide a structured description of the essential competences required for specific learner profiles, they remain at a conceptual level, intended primarily for curriculum planners; OSE, in contrast, represent the pedagogical translation of these skillsets into **teachable and assessable educational components** (lessons, learning outcomes, learning activities, etc.) and are more like a

¹² <https://doi.org/10.5281/zenodo.8101903> [R5]

¹³ ISCED is the UNESCO'S International Standard Classification of Education: [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=International_Standard_Classification_of_Education_\(ISCED\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=International_Standard_Classification_of_Education_(ISCED)). In this classification: ISCED 6 corresponds to Bachelor's or equivalent level; and ISCED 7 to Master's or equivalent level.

¹⁴ <https://euraxess.ec.europa.eu/career-development/researchers>

Towards a European Framework for Research Careers (2011).

https://euraxess.ec.europa.eu/sites/default/files/policy_library/towards_a_european_framework_for_research_careers_final.pdf

¹⁵ <http://dx.doi.org/10.1787/9789264239012-en> [R7]

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syllabus suitable for integration into academic programmes. The transformation from MVS to OSE implied the following steps:

- Competence mapping for each target group.
- Definition of learning outcomes: reformulation of the intended skills into concrete, measurable learning outcomes, adapted to each learner group.
- Module structuring: grouping learning outcomes into thematic modules or specific lessons, considering the logical pedagogical progression (e.g. from ethos to practice).
- Content development: developing learning materials for each unit (texts, multimedia resources, quizzes, and assignments) in order to fulfill module's objectives.
- Validation: both learning paths were validated through pilots and stakeholder feedback, which led to the refinement of both content and instructional approach.

This process ensured that the OSE were not just aligned with MVS in terms of content but also pedagogically meaningful and contextually adaptable (as demonstrated by the adaptation of the undergraduate learning path to the national level in Finland, and the PhD learning path to the institutional context of the UC3M Doctoral School¹⁶). Appendix I shows the transformation from MVS to OSE in the developed pilots.

4.4. Quality Assurance and Certification Alignment

Quality assurance is a core component in the S4E project, and a key element of the methodology applied in the development of both the undergraduate and the doctoral learning path in WP4. The Skills4EOSC Quality Assurance Framework (S4E-QAF) provides structured guidance to ensure that training materials are not only aligned with OS values, but also meet high standards of pedagogical coherence, openness, accessibility, and ethical integrity. The QAF was applied iteratively throughout the design and piloting phases of both Task 4.3 (*Teaching Open Science and Research Data Management for Undergraduates*) and Task 4.4 (*Shaping Open Science Champions*), embedding quality assurance into every step of the process.

¹⁶ *Vid. Infr.* Sections 5 and 6.

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Both the learning paths and the related pilot courses progressed through a staged quality assurance cycle, beginning with the *QAF Checklist & Guide* during early planning (Maturity Levels 1–2), followed by a structured first evaluation round using feedback spreadsheets (Level 2–3), and culminating particularly in the case of the doctoral course with a self-assessment via the QAF Quality Compass App, reaching Maturity Level 4¹⁷. These evaluations, conducted in close dialogue with T2.4, led to concrete improvements in areas such as metadata quality, licensing clarity, accessibility, instructor documentation, and ethical use of resources. The QAF thus acted both as a design support tool and a mechanism for continuous improvement, contributing to the robustness, reusability, and long-term impact of the OSE and curricula developed here.

4.5. Pilot iteration and feedback

The design and refinement of the OSE for both undergraduate and doctoral levels followed an iterative piloting methodology, fully aligned with the co-creation principles of S4E. Each pilot gathered feedback from students and trainers which served not only to test pedagogical content and delivery strategies, but also as a structured feedback loop to improve alignment with the MVS and other methodological pillars of the project, like FAIR-by-design and the Quality Assurance Framework (QAF).

5. Undergraduate Level Learning Path

5.1. Target Audience and Needs

The undergraduate learning path developed in T4.3 targets bachelor-level students, with particular emphasis on students in programmes related to LIS and information studies (iSchools). The course was designed as an introductory-level intervention to equip students with OSE competences early in their academic journey, regardless of whether they pursue research-

¹⁷ See Appendix IV for QAF maturity outcomes (PhD TtT reached Level 4; undergraduate TtT progressed to Level 2–3 with planned improvements), plus concrete metadata/licensing/accessibility actions implemented.

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intensive or professionally oriented paths. This early exposure responds to a growing need across Europe to embed OS principles not only in graduate education but also at the foundational level of Higher Education. It recognises that undergraduates represent a crucial leverage point in cultivating long-term cultural change towards openness, data literacy, and responsible research behaviour.

5.2. Curriculum Design and Learning Objectives

The course content was explicitly aligned with the Minimum Viable Skillset (MVS) for Undergraduate Students, developed in WP2 of Skills4EOSC. The curriculum addressed core areas such as:

- Understanding the principles and goals of Open Science and FAIR data;
- Recognising the research data lifecycle and good data management practices;
- Navigating copyright, open licensing, and intellectual property in research contexts (coming from the ELSI Task 4.5);
- Identifying credible sources of open data and evaluating their quality;
- Appreciating the importance of research visibility and impact.

Additional learning objectives went beyond the initial MVS framework and contributed to its further refinement in coordination with T2.6 (Monitoring and co-creation). These included awareness of impact indicators, visibility strategies for research outputs, and the ethical and legal dimensions (ELSI) of OS practices.

5.3. Course Structure and Modules

The pilot course was structured into six thematic modules:

- ~ Module 1: Introduction to Open Science
- ~ Module 2: Open Access Publishing
- ~ Module 3: Copyright and Licensing
- ~ Module 4: Research Data Management Fundamentals
- ~ Module 5: Research Data Management in Practice
- ~ Module 6: Research Impact and Visibility

Each module combined textual documents, short videos, and different assignments (e.g., reflections, quizzes) and readings, designed for

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asynchronous online delivery. The course was developed in English and translated into Finnish for implementation at Tampere University (TAU).

The instructional design aimed for flexibility, self-paced learning, and the possibility of integration into existing digital skills offerings or domain-specific curricula (e.g. LIS).

5.4. Piloting and Implementation at TAU

The pilot course on Open Science for undergraduate students was conducted at Tampere University, Finland (TAU), in the spring semester 2024¹⁸. The course introduced undergraduate students to Open Science and research data management, providing them with the basic knowledge and skills needed in today's research environment for their studies and future careers.

The course was developed in English, but was translated into Finnish for piloting. It was based on earlier, well-established, open-learning materials, which were adapted and combined for this purpose. The course content was planned to take advantage of the MVS for Undergraduate Students.

The course aligned with the MVS for undergraduates developed in WP2. The course also included learning objectives that extend beyond the MVS. As part of the co-creation process for the MVS, T4.3 also reported to T2.6 (responsible for the co-creation process), on this, and the

5.5. Feedback and Evaluation

A total of 37 undergraduate students participated in the pilot course. Comprehensive feedback was collected throughout the course and at its conclusion. Overall, the course was well received and considered both relevant and useful. Students reported that they had successfully achieved the intended learning outcomes, and they found the course structure clear and accessible. The combination of textual materials, videos, and varied assignments was particularly appreciated, contributing to a positive and engaging learning experience. The course received a high overall rating, and

¹⁸ For a full report on the pilot, See: <https://doi.org/10.5281/zenodo.14381603> [R6]

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the feedback highlighted a clear demand for this type of training at the undergraduate level.

However, several areas for improvement were identified. Some students felt that the course was “too light”. Participants also noted inconsistencies in the length and depth of modules, with some perceived as significantly shorter than others. Additional feedback pointed to the need for clearer definitions of key concepts, more detailed information on specific topics, and greater precision in assignment instructions (e.g. word count requirements). A few practical issues were also reported related to the usability of the Learning Management System (Moodle).

The students were also allowed to suggest ideas for topics they would like to see covered in the course. The students suggested topics like the impact of AI on Open Science and Open Science from the students’ perspective. It is also worth noting that while many liked the opportunity to work independently at their own pace, it is not for everyone, and the possibility to discuss with others could contribute to learning.

5.6. Final Version and Recommendations for Reuse

Based on the feedback, improvements were made to the course. The course content was expanded for more comprehensive coverage, with efforts made to balance module sizes and improve the clarity of concept explanations. New topics were introduced, including content related to artificial intelligence (AI), such as the relationship between AI and Open Science and copyright issues involving AI. Existing content was reorganised to improve thematic flow, and key terms were clarified. Assignments were revised across the course; some were added, others relocated for better alignment, and answer sets were developed.

The course for undergraduates is available as a stand-alone / self-paced course, either in its entirety or in selected parts. The course content and materials are easily accessible and can be used directly or copied to other platforms. As assignment options, there are written exercises and quizzes. Instructions for writing a learning diary are also provided at the end. After the improvements, the course was added to the Learning Platform as

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National Training Pilot (in Finnish): *Johdatus avoimeen tieteeseen ja tutkimusdatanhallintaan*¹⁹.

Building on this, we identify at least three concrete reuse pathways:

- Adopting the course as a transversal digital-skills for bachelor's students by importing the full self-paced version into the institutional LMS with assessment via quizzes plus a short reflective task;
- Embedding selected core modules in existing curricula (e.g., Modules 1–4 for LIS/iSchool programmes) complemented by brief specific reading lists to ensure disciplinary alignment;
- Offering a faculty-led micro-credential covering all modules (1-6), culminating in a capstone deliverable (e.g., an OS plan for a bachelor's thesis) with an institutional digital badge.

All materials are LMS-ready, licensed under CC BY, and designed for localisation (e.g. Finnish translation of the course) thereby facilitating straightforward adoption and multilingual deployment.

5.7. Train-the-Trainers Course

After the improvements based on the feedback from the pilot course, the English version of the course for undergraduates was transformed into the Train-the-Trainers (TtT) format and renamed *Teaching Open Science and Research Data Management for Undergraduates*. A dedicated section for trainers was added, and the content from the student course was repurposed as training material, but otherwise it remained the same as before. As the student course, also the TtT version is a self-paced online course.

The course is designed to prepare trainers for delivering the course "Introduction to Open Science and Research Data Management" to undergraduate students. The TtT version provides trainers with a thorough understanding of the course content, structure, and assignments. By completing the course, trainers will become familiar with both the course content and practicalities, equipping them with the knowledge and

¹⁹ <https://doi.org/10.5281/zenodo.15478446> [R2]

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confidence to offer the course to their students. The course is completed by (1) getting to know the student course, (2) passing the quiz after each module, (3) completing a final quiz after the whole course, and (4) filling out the course feedback survey.

The Train-the-Trainers course *Teaching Open Science and Research Data Management for Undergraduates* was migrated to the learning platform and launched there in April 2025. During the spring and summer, 84 participants enrolled in the course, with 11 completing it in full. However, it is worth noting that a low number of completions does not necessarily mean that few participants engaged with the course. Many may have gone through the material or used it independently without formally completing it, which was also allowed.

The course for undergraduate educators received very positive feedback overall, with participants rating it highly in terms of clarity, relevance, and effectiveness. Most respondents felt they had achieved the intended learning objectives and appreciated the course structure and content. Some noted that the course might be too advanced for undergraduate students and suggested making it more interactive and accessible. Recommendations included incorporating additional videos, improving transitions between modules, and providing more detailed feedback on assignments. Overall, the training was regarded as valuable and impactful.

The course applied the Skills4EOSC Quality Assurance Framework (S4E-QAF) throughout its design and pilot phase, as documented in Appendix IV. The QAF offers a structured, community-informed methodology for designing and evaluating OS learning resources, covering essential aspects such as accessibility, licensing, alignment with FAIR principles, and pedagogical coherence. The undergraduate TtT course reached Maturity Level 2–3, reflecting ongoing refinement and strong alignment with quality criteria.

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6. Doctoral Level: Learning Path

6.1 Target Audience and Needs

The doctoral learning path developed in T4.4 targets early-stage researchers enrolled in PhD programmes across all scientific disciplines. The course was designed as a transversal training intervention to equip doctoral candidates with OSE competences at different stages of their research journey (starting their thesis or publishing several related papers), regardless of their disciplinary background or previous exposure to OS.

Doctoral candidates represent a strategic target group in fostering systemic cultural change within academia. Providing structured, modular OS training at this stage of professional development empowers future researchers to integrate openness into their workflows and to act as catalysts for change across disciplines and institutions.

6.2 Transversal and Disciplinary Approaches

The doctoral-level learning path was designed to be applicable across all disciplines, while also allowing reflect field-specific practices and norms. This dual approach ensures both broad accessibility and disciplinary relevance.

At its core, the learning path adopts a transversal structure and domain-agnostic approach, enabling integration into institutional doctoral schools as a general training offer. It covers foundational topics, such as FAIR principles, ethical and legal aspects, and responsible research assessment, that are essential for all PhD candidates regardless of their doctoral disciplinary programme. These modules provide a shared baseline of OS literacy and promote common understanding across disciplinary boundaries.

In addition, the final module of the course was conceived as discipline-oriented and on-demand, allowing participants to engage with tailored content based on their field of study. This approach acknowledges the diversity of research workflows, data practices, and publishing cultures in STEM and SSH fields, and encourages peer exchange and community building within and across disciplinary cohorts.

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The combination of transversal and disciplinary elements increases the potential for uptake across diverse doctoral programmes and enhances the flexibility of the learning path, facilitating adaptation to institutional and national contexts. The choice between a generic or domain-oriented approach may be shaped by the course demand itself or by the needs and preferences of the learners. For this reason, it is recommended to survey participants at the beginning of the course to better understand their disciplinary backgrounds and specific interests and knowledge in OS topics.

6.3 Curriculum Design and Learning Objectives

The curriculum for the doctoral learning path is structured to provide a comprehensive introduction to Open Science, with particular attention to its relevance for Early Career Researchers. It combines foundational knowledge with applied skills, supporting doctoral candidates in developing both conceptual understanding and practical competences aligned with the principles of Responsible Research and Innovation (RRI). The design follows a modular approach that enables flexibility in delivery formats and adaptation to institutional or disciplinary needs. Each module is associated with specific learning objectives, articulated in terms of knowledge acquisition, skill development, and attitudinal change. These objectives are mapped to the EOSC-related competence frameworks and address both transversal and domain-specific dimensions of OS. The path builds progressively from awareness to practice, supporting doctoral candidates in understanding, adopting, and eventually advocating for Open Science practices within their disciplines and institutions²⁰.

A detailed description of the curriculum structure, including module content, learning outcomes, is detailed in Appendix III.

²⁰ For example, doctoral candidates joining the UC3M pilot were invited to join the Open Science Community Madrid, <https://osc-international.com/oscm-uc3m>, created also within S4E WP6.

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6.4 The UC3M Pilot course for doctoral candidates: Ticket to Open Science (UC3MT2OS)

Inspired by the original, engaging and comprehensive document *Passport for Open Science: A Practical Guide for PhD Students*²¹, the UC3M pilot adopted the metaphor of a journey to introduce doctoral candidates to the principles and practices of OS.

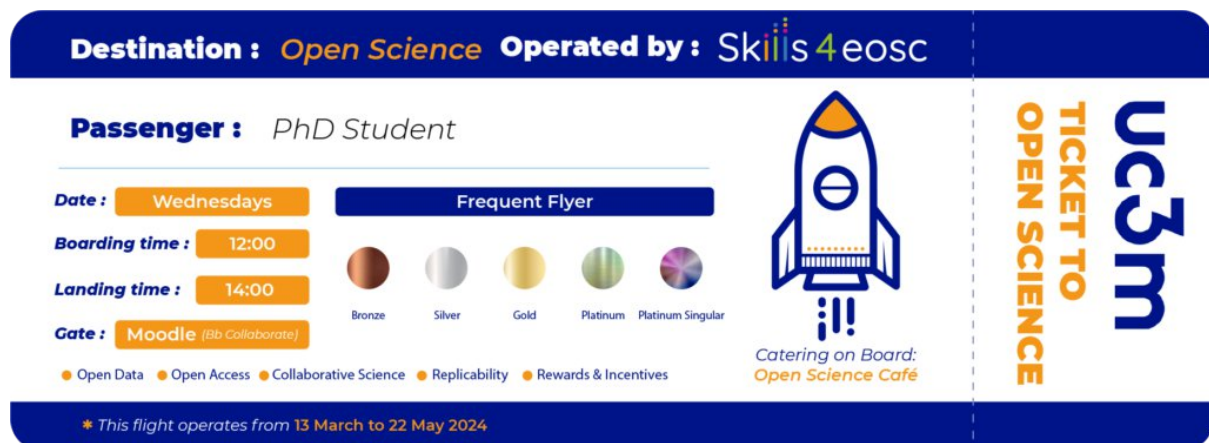


Figure 3: Course announcement: Boarding pass for UC3MT2OS²²

The course used the notion of a "ticket" as a symbolic and practical entry point into a more open, responsible, and FAIR-aligned research culture. This metaphor provided a coherent pedagogical narrative that connected the learning modules and encouraged participants to see themselves as active travelers shaping their own OS pathways.

The “UC3M Ticket to Open Science” (UC3MT2OS²³) was officially offered through UC3M doctoral school²⁴ to all its PhD students and completion

²¹ <https://www.ouvrirlascience.fr/wp-content/uploads/2024/03/24-02-22-PSO-EN-GP.pdf> [R8]

²² Main webpage of the Course: <https://www.curatore.es/uc3m2OpenScience>. Even though the course had a specific course in Moodle at the University's LMS called Aula Global, where all the PhD students are familiar with and access every day, the course had an OPEN webpage disclosing the content and also the course's blog.

²³ A detailed description and analysis of the pilot is available in a report here: <https://doi.org/10.5281/zenodo.16734329> [R9]

²⁴ See here the course advertised as transversal education of the Doctoral School: https://www.uc3m.es/doctorado/media/doctorado/doc/archivo/pdf_uc3m-ticket-to-open-

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implied 3ECTS of the mandatory so-called “transversal education”. The programme consisted of ten sessions from 13 March to 22 May 2024, each Wednesday: 9 sessions addressing the thematic modules covering key OSE for PhD candidates, including openness in publishing, FAIR data, research integrity, citizen science, and responsible evaluation. To address discipline-specific needs, an optional on-demand final module (Session 10) enabled participants to explore OS practices tailored to their fields. This final session was organised in domain-based clusters (e.g., STEM or SSH) and facilitated by UC3M’s Unit for Open Science (UniOS), which provided targeted resources and expert guidance.

The course design combined asynchronous content delivery with interactive elements to foster engagement, reflection, and community building, but it was online synchronous to facilitate the participation of the many international doctoral students involved in UC3M doctoral programmes.

6.5. Modules, Activities and Tools

The modules covered a wide range of topics, including the ethos of Open Science, FAIR data management, Open Access publishing, reproducibility and preregistration, ethical and legal issues (ELSI), citizen science, responsible research assessment, and discipline-specific open practices. The content was delivered via the UC3M Learning Management System (AulaGlobal, Moodle-based platform), incorporating a mix of text, multimedia resources, external readings, and self-assessment quizzes and online participation (Wooclap), along with the weekly synchronous online session for each module taught in BbCollaborate platform.

Each module included clearly defined learning outcomes and a short formative assignment or activity, ranging from multiple-choice quizzes to reflective prompts. The course culminated in a final assignment where students submitted a public blog post describing their reflections on the training and its impact on their research approach.

science/uc3m2os_programme2024_em_final.pdf

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A key innovation in the UC3MT2OS course was the inclusion of *Open Science Cafés* synchronous online sessions designed to bring together students, trainers, and institutional stakeholders. *Open Science Cafés* were complementary sessions each week for informal, discussion-based sessions with key actors in the current OS/EOSC ecosystem²⁵, open to doctoral candidates, supervisors, and research support staff and almost any interested person at UC3M. These online cafés created spaces for dialogue and reflection, helping to bridge gaps between policy, practice, and everyday research experience.

The course blended structured content with open-ended, learner-centred activities, supporting diverse learning styles and fostering the development of knowledge and practice.

6.6. Micro-Credentials and MVS Alignment

To support formal recognition of the acquired skills, the pilot implemented a micro-credential system using a gamified metaphor of “frequent flyer” membership levels (Silver, Gold, Platinum) tied to module completion and engagement. This symbolic system aimed to acknowledge students' active participation and to incentivise progress through the course. These micro-credential/frequent flyer categories include:

- Open Science-Bronze à Registered for the course, invited to be part of the community
- Open Science-Silver à Completed modules 1-2-3
- Open Science-Gold à Completed modules (1-2-3) + 4-5-6
- Open Science-Platinum à Completed modules (1-2-3-4-5-6) + 7-8-9
- Open Science-Platinum Singular à Completed modules 1-2-3-4-5-6-7-8-9- + final post + disciplinary meeting (Module 10)

These badges do not confer formal credit, but they align directly with the MVS for ECR and OSE for PhD candidates to signal competence progression in OS practices. This alignment ensured coherence between the pedagogical

²⁵ <https://www.uc3m.es/pdi/OpenScienceCafe> Speakers included, among others: Maja Dolinar (OpenAire), Javier López Albacete (EC-RTD-Open Science Unit), Joy Davison (DCC, S4E partner), Ezsébet Tóth-Czifra (CoARA), Cameron Neylon (COKI-Australia, Barcelona Declaration). See: <https://www.uc3m.es/pdi/OpenScienceCafe/ponentes>

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structure of the course and the broader professional skill profiles endorsed by Skills4EOSC.

The micro-credential framework also served as a prototype for further institutional adoption of recognition systems tied to OS training, and as a mechanism to encourage self-paced learning and formative assessment in a possible self-paced future edition of the UC3MT2OS.

6.7. Feedback and Evaluation

The evaluation of the UC3MT2OS pilot was based on a combination of quantitative participation data and qualitative reflections provided by the participants. The modular, weekly delivery perfectly fit PhD schedules. The students also appreciated practical tools (FAIR data, licensing, responsible metrics).

Out of the 19 students who enrolled in the course, 13 completed all modules and submitted a public reflective blog post as a final assignment. These blog entries offered deep, personal insights into how the course had influenced their understanding and practice of Open Science²⁶.

Across the cohort's blogposts²⁷, students consistently report a marked attitudinal shift: OS is no longer equated with "just Open Access," but understood as a comprehensive, process-wide approach that foregrounds transparency, FAIR data, reproducibility and responsible assessment. Posts describe concrete behavioural changes (e.g. adopting DMP, depositing in Zenodo, and engaging beyond publications). Participants also appreciated the clarity and modularity of the course content, the balance between theory and practice, and the opportunity to engage in the Open Science Cafés. The flexible structure and sessions once a week were also seen as a strong asset, enabling students to integrate training into demanding PhD schedules.

²⁶ See here all the student's blogposts: <https://www.curatore.es/uc3m2OpenScience/blog/>

²⁷ Figure 4 shows an example of these blogposts.

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Figure 4: Example of one of the doctoral students' blogposts

Feedback highlighted the usefulness of practical tools, especially those related to FAIR data, licensing, and responsible metrics. Several reflections pointed to a shift in attitudes toward open research, greater confidence in applying OS principles, and a more critical perspective on publishing and assessment systems. Participants also expressed interest in further disciplinary deepening, suggesting that the domain-specific final module could be expanded. The feedback, collected from this pilot through the student's blogposts, directly informed the development of the subsequent TtT course and provided strong evidence of the course's relevance and impact in **supporting cultural change at the earliest steps in the academic career**.

A comprehensive analysis of the pilot experience, evaluation and feedback has been submitted for publication to the *Journal of Experimental Education*.

6.8. Follow-up: Train-the-Trainers Programme

To ensure broad uptake and sustainability of the doctoral-level OSE learning path, a dedicated TtT course was also developed as part of T4.4. This course, entitled *A Train-the-Trainers Course for Educators of PhD Candidates*, was

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designed to support doctoral schools' trainers, supervisors, and academic staff in effectively delivering modular OS content to PhD students.

The TtT course was taught in a blended model, including self-paced activities and shared material with 3 online synchronous sessions in May 2025. It followed a modular, competency-based structure, aligned with the learning path and OSE for doctoral candidates, and grounded in the FbD methodology. It includes guidance on curriculum adaptation, delivery strategies, and evaluation, while promoting a flexible approach that allows institutions to implement full programmes or selected modules based on local needs.

Participants were introduced to the structure and rationale of the UC3MT2OS learning path, with practical guidance on how to deliver each module, design assessments, integrate OS Cafés, and adapt content to various academic and disciplinary settings. Facilitation notes are provided to support pre-course planning, in-session engagement, and post-course follow-up. The guide encourages active facilitation, use of real-world examples, and community engagement strategies such as narrative CV building and open blog posts.

Shaping Open Science Champions was chosen by 78 participants from more than 20 different countries, including Macedonia, Uruguay, Argentina and Brasil. 32 of these students followed the course, and 9 of them were completely engaged with a high level of participation and participated in the co-creation activities and community building (Figure 5). These more committed students created their versions of the OSE learning path for their PhD candidates within their national and institutional contexts, and they received the badge as OS instructors for PhD Students.

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Commitment Level	Explanation	Number of people
No commitment	Never entered the course	28
Low	Started the course	32
Medium	Did 1 activity	9
High	Did all the activities	9

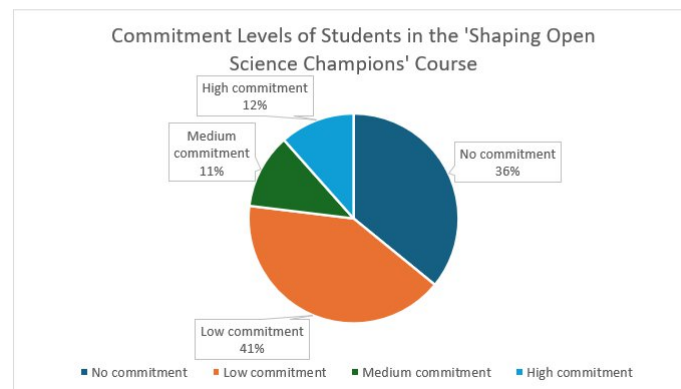


Figure 5: Level of commitment and participation of the students involved in the TtT for Educators of PhD candidates

The Train-the-Trainers course is part of the Skills4EOSC Instructor Kit and, following the completion of its hybrid implementation, it will be made available on the S4E platform as a self-paced course, with all materials and pedagogical tools openly reusable by trainers.

The course underwent a full quality assurance process in alignment with the Skills4EOSC Quality Assurance Framework (S4E-QAF), as detailed in Appendix IV. A final self-assessment using the S4E Quality Compass App confirmed that the course achieved in the second iteration a maturity Level 4, demonstrating that it is not only pedagogically robust, but also fully compliant with FbD principles.

7. Lessons Learnt for Embedding OSE in Higher Education Institutions

The experience gained through the design, implementation, and evaluation of the Open Science Essentials (OSE) learning paths for undergraduate and doctoral levels within S4R has provided valuable insights into how Open Science training can be sustainably embedded in Higher Education Institutions (HEIs). The following lessons and recommendations aim to

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inspire further dialogue among trainers and institutions committed to developing a capabilities-driven “human layer” for EOSC, operationalised via the S4E Competence Centres.

- Introducing OS skills at the undergraduate level is crucial to cultivating openness, transparency, and research integrity as default values for new generations. **Early exposure to OS** reinforces the foundations for responsible research and prepares students for digital and data-intensive academic and professional environments.
- Both the undergraduate and PhD-level learning paths adopted a **modular design**, allowing institutions to adopt entire programmes or select relevant components **based on local needs, academic calendars, or disciplinary approaches**. This flexibility supports integration into both formal curricula and transversal training schemes, including converting the training in micro-credentials.
- The **co-creative methodology** applied throughout WP4 (engaging students, trainers, academic staff, and institutional support services like libraries and OS units) is crucial for ensuring that the content addresses real needs. Feedback gathered through pilots led to meaningful improvements and increased the sense of training identity among learners and educators.
- Transversal OS training ensures a shared literacy across disciplines, but disciplinary examples and tailored content enhance uptake and application. Allowing **room for contextualization** (e.g. SSH and STEM as done in the PhD training pilot) might be important for learners' engagement. Managing a brief survey at the start of a course can help align content with learners' fields and expectations, as well as use the disciplinary diversity to put examples and **promote interdisciplinary debate**.
- **Quality assurance is a continuous and enabling process**. Applying the S4E-QAF throughout design, pilot, and revision phases as part of the instructional design allowed course teams to improve materials iteratively while ensuring compliance with FbD, reusability of the learning objects and compliance of pedagogical standards. The S4E-QAF process (from checklists to Compass App) strengthens both content and delivery.
- The creation of two **TtT programmes** ensured that the developed **courses could be adapted and reused** by other institutions. These programmes not

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only enable wide dissemination of OSE, but also contribute to institutional capacity building and promote a trainers' community.

- The development of the undergraduate and doctoral-level OSE learning paths highlights **the need for harmonised Open Science curricula across Member States and associated countries**, especially under the EOSC framework. Harmonisation enables portability, recognition, and mutual learning across borders, supporting mobility and shared standards in researcher's education. However, harmonisation must not come at the expense of contextual relevance. National and institutional idiosyncrasies (ranging from research traditions and funding landscapes to language and legal frameworks) must be considered. This balance between **consistency and contextualisation** is key to fostering a genuinely inclusive and effective OS learning ecosystem across Europe and beyond.
- Embedding OSE works best when **training is flexible and inclusive**: combine self-paced components for time-constrained learners, fully online sessions to reach international cohorts, modular pathways for disciplinary alignment, and multilingual adaptations (e.g., a Finnish translation of the undergraduate course). For future iterations, we recommend systematise accessibility checks via the QAF, expand language options and enrich discipline-tailored examples for both STEM and SSH.

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8. References

No	Reference/Description/Link ²⁸
R1	<p>iSchools: https://www.ischools.org</p> <p>It represents an international organisation of around 130 universities. A common interest in all aspects of research and teaching about information unites them. The scope is deliberately broad and methodologically agnostic, with a strong reliance on the social and behavioural sciences, as well as computing and linguistics.</p> <p>The iSchools are the natural HE context to teach open science experts and data librarians/stewards. A list of EU iSchools see: https://www.ischools.org/european-region</p>
R2	<p>Alamettälä, T., Kumpulainen, S., Rauste, P., Fuchs, S., Hämäläinen, A.-M., Stork, C., Paschetta, M., Bakas, N., & Schirru, L. (2025, May 21). Johdatus avoimeen tieteseen ja tutkimusdatanhallintaan. Zenodo. https://doi.org/10.5281/zenodo.15478446</p> <p>This is a Finnish version of the introduction course on Open Science and Research Data Management. It focuses on adapting the course materials for a Finnish-speaking audience at TAU (Tampere University).</p>
R3	<p>Alamettälä, T., Kumpulainen, S., Rauste, P., Fuchs, S., Hämäläinen, A.-M., Stork, C., Paschetta, M., Bakas, N., & Schirru, L. (2025, April 11). <i>Teaching Open Science and Research Data Management for Undergraduates</i>. Zenodo. https://doi.org/10.5281/zenodo.15193549</p> <p>This document presents the experience and structure of the self-paced TtT course for educators and trainers in teaching the basics of Open Science and data management to undergraduate students.</p>
R4	<p>Wildgaard, L., Derksen, B., Buss, M., Filiposka, S., Drązewski, K., Musidlowska, M., Hadrossek, C., Jannik, J., Bernier, M., Janicka, A., Alamettälä, T., Kjorvezirski, V., Nordling, J., Hansen, K. K., Antoine, D., Sharma, S., & van Leersum, N. (2025). D4.2: Learning paths for</p>

²⁸ All the electronic resources cited here were last accessed on August, 5 2025.

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No	Reference/Description/Link ²⁸
	<p>data professionals. Zenodo. https://doi.org/10.5281/zenodo.15691090</p> <p>This deliverable presents the outcomes of T4.2 on Learning Paths for Data Professionals. It synthesises the design, piloting, and refinement of three co-created courses and reports instructional strategies, quality checks, alignments and recommendations for broader adoption.</p>
R5	<p>Whyte, A., Green, D., Avançaço, K., Di Giorgio, S., Gingold, A., Horton, L., Koteska, B., Kyprianou, K., Prnjat, O., Rauste, P., Schirru, L., Sowinski, C., Torres Ramos, G., van Leersum, N., Sharma, C., Méndez, E., & Lazzeri, E. (2023). D2.1 Catalogue of Open Science Career Profiles - Minimum Viable Skillsets (v1.2). Zenodo. https://doi.org/10.5281/zenodo.8101903</p> <p>This deliverable presents the catalogue of OS career profiles and their corresponding MVS. It defines key roles, stakeholders and potential trainees and identifies essential OS skills and competences for each and serves as key foundation for curriculum development throughout S4E project.</p>
R6	<p>Alamettälä, T., Kumpulainen, S., Rauste, P., Fuchs, S., Stork, C., Paschetta, M., Bakas, N., & Schirru, L. (2024). Milestone: Pilot Course for Undergraduate Students (1.0). Zenodo. https://doi.org/10.5281/zenodo.14381603</p> <p>This is the original pilot course document delivered in English, describing the full structure and evaluation of the Undergraduate pilot version as piloted at TAU.</p>
R7	<p>OECD (2015), Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264239012-en</p> <p>This manual is a crucial reference in metaresearch, particularly in this deliverable, we used the standard framework for classifying research personnel by level of seniority, where "D" researchers (junior researchers, including PhD students). This classification is widely used for statistical and policy purposes in the monitoring of</p>

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No	Reference/Description/Link ²⁸
	R&D activities across OECD countries.
R8	<p>Ministry of Higher Education and Research (France). (2024). Passport for Open Science: A practical guide for PhD students (2nd ed.). French Committee for Open Science. https://www.ouvri.la.science.fr/wp-content/uploads/2024/03/24-02-22-PSO-EN-GP.pdf</p> <p>One of the key documents supporting France's national Open Science strategy (<i>Ouvrir la science</i>), coordinated by the French Committee for Open Science under the Ministry of Higher Education and Research. Targeted at PhD candidates, provides a structured and accessible introduction to the principles, practices, and resources of OS. Its second edition (2024) strengthens its role as a foundational pedagogical tool to foster a more open, collaborative, and responsible research culture.</p>
R9	<p>Méndez, E., & Sánchez Moreno, M. (2024). Milestone: Pilot learning path for PhD candidates. Zenodo. https://doi.org/10.5281/zenodo.16734329</p> <p>This document is a report on the pilot developed at UC3M titled Ticket to Open Science, targeting doctoral candidates from any discipline, registered at the UC3M doctoral school.</p>

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Appendix I. Mapping between MVS and OSE for undergraduate and PhD curricula

This appendix presents a comparative mapping between the Minimum Viable Skillsets (MVS) and the Open Science Essentials (OSE) as implemented in the pilot learning paths for undergraduate (Table 1) and PhD students (Table 2). It demonstrates how abstract skills definitions were translated into concrete, pedagogically structured modules adapted to different academic levels.

Table 1: Undergraduate's Level Learning Pathway	
MVS	OSE for bachelor students (pilot)
<ul style="list-style-type: none"> Fundamental understanding of Open Science and FAIR principles Basic data literacy: data lifecycle, management, and use within academic assignments Awareness of open licensing and copyright in research Familiarity with open data sources and how to evaluate them Recognition of the value of research impact and visibility Introduction to research integrity and ethical conduct 	<ul style="list-style-type: none"> Introduction to Open Science Research Data Management Fundamentals Open Access Publishing Copyright and Licensing Research Data Management in Practice Research Impact and Visibility

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Table 2: PhD Candidates' Level Learning Pathway

MVS for ECR (PhD and PostDocs)	OSE for PhD students (pilot)
<p>Proactive adoption and promotion of Open Science and research transparency</p> <p>Ability to manage FAIR data in discipline-specific contexts</p> <p>Capacity to assess FAIRness and choose OS-compliant tools and workflows</p> <p>Upgradable digital skills (e.g., version control, RMarkdown, repository use)</p> <p>Research management: designing open research strategies and embedding OS in workflows</p> <p>Communication and collaboration skills across stakeholders</p> <p>Knowledge of ethical, legal, licensing, data protection requirements</p> <p>Ability to disseminate research outputs openly with metadata, data, and code</p> <p>Engagement in open peer review and community-based science practices</p> <p>Awareness of responsible metrics and research assessment</p>	<p>Ethos and Introduction to Open Science</p> <p>Disseminating your research publications: Open Access publications</p> <p>Disseminating your research data: Open and FAIR data</p> <p>Pre-registration and Reproducibility</p> <p>Planning your responsible research in the Open. Resources and tools</p> <p>Ethical, Legal and Social Issues (ELSI) of Open Science</p> <p>Citizen Science and public engagement</p> <p>RRA Responsible Research Assessment: Towards a reform of the Research Evaluation</p> <p>How UC3M will help you to be an Open Scientist: UniOS & Library support</p> <p>Discipline-oriented Open Science (on-demand session)</p>

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Appendix II. Learning path for undergraduate students

This annex presents the structure of the undergraduate-level learning path piloted at Tampere University (TAU) under Task 4.3. The learning path could be offered as a modular, self-paced course integrated into bachelor-level curricula across disciplines, or as part of transversal digital skills training.

This structure laid the groundwork for the development of a Train-the-Trainers programme targeting educators and instructors interested in delivering Open Science content to undergraduate students.

<i>Module</i>	<i>Title</i>	<i>Topics Covered</i>	<i>Learning Outcomes</i>
1	<i>Introduction to Open Science</i>	OS principles, openness, reproducibility, transparency	Understand the rationale and goals of OS
2	<i>Open Access Publishing</i>	OA models, preprints, licenses, repositories	Identify publishing routes and licensing options
3	<i>Copyright and Licensing</i>	CC licenses, copyright basics, reuse and attribution	Apply correct licensing in academic outputs
4	<i>RDM Fundamentals</i>	Data lifecycle, planning, storage, formats	Recognise stages of RDM and related best practices
5	<i>RDM in Practice</i>	File naming, metadata, tools, documentation	Implement basic data management techniques
6	<i>Research Impact and Visibility</i>	Metrics, visibility, scholarly profiles	Use tools to enhance research visibility

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Appendix III. Learning path for PhD candidates

This appendix presents the structure of the doctoral-level learning path piloted at Universidad Carlos III de Madrid (UC3M) under Task 4.4. The learning path could have the title: “[your institution] Ticket to Open Science” and be offered through the institutional Doctoral Schools as a transversal, modular training programme accessible to PhD candidates from all disciplines and at any stage of their doctoral journey.

This structure served as the basis for further development of the Train-the-Trainers programme targeting PhD educators across European institutions and beyond.

<i>Module</i>	<i>Title</i>	<i>Topics Covered</i>	<i>Learning Objectives</i>
1	<i>Ethos and Introduction to Open Science</i>	Openness in science, transparency, OS values, reproducibility	Understand the foundations and rationale of Open Science
2	<i>Planning Your Responsible Research in the Open</i>	Research planning, OS tools, integrity, DMP, and institutional resources	Integrate OS principles into early-stage research planning
3	<i>Disseminating Your Research Publications</i>	Open Access models, preprints, publishing strategies, licenses	Select appropriate OA venues and understand the implications of licensing
4	<i>Disseminating Your Research Data</i>	FAIR data, repositories, metadata, open formats	Apply FAIR principles and use data repositories
5	<i>How [your</i>	Local services: e.g:	Identify institutional

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Module	Title	Topics Covered	Learning Objectives
	<i>institution] Will Help You to Be an Open Scientist</i>	Library support, infrastructures, etc.	support for OS implementation
6	<i>Pre-registration and Reproducibility</i>	Reproducibility crisis, pre-registration practices, tools (e.g. OSF)	Reflect on reproducibility and apply preregistration methods
7	<i>Ethical, Legal and Social Issues (ELSI)</i>	Ethics, IPR, data protection, legal frameworks	Recognise and address ethical and legal responsibilities in OS
8	<i>Citizen Science and Public Engagement</i>	Civic engagement, co-creation, communication strategies	Understand the value of involving non-academic actors in research processes
9	<i>Responsible Research Assessment (RRA)</i>	Metrics reform, CoARA, DORA, narrative CVs	Apply responsible assessment principles and tools
10	<i>Discipline-Oriented Open Science (SSH / STEM split)</i>	Domain-specific practices, tailored examples by discipline	Reflect on and apply OS practices relevant to one's disciplinary field

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Appendix IV. Application of the S4E Quality Assurance Framework to TtT developed in T4.3 and T4.4

This appendix summarises how the Skills4EOSC Quality Assurance Framework (S4E-QAF) was applied to the development and refinement of the two Train-the-Trainers (TtT) courses produced under Tasks 4.3 and 4.4. The table below highlights the quality assurance process followed for each course across key dimensions, including planning, evaluation, maturity levels, alignment with FAIR and MVS, and ethical/legal compliance.

<i>Aspect</i>	T4.3 – Teaching OS & RDM for Undergraduates	T4.4 – Shaping Open Science Champions (PhD)
<i>Initial QA Planning</i>	✓ QAF Checklist & Guide used in early design phase (Level 1–2) ²⁹	✓ QAF Checklist & Guide used in early design phase (Level 1–2)
<i>First Evaluation Round</i>	✓ Evaluation by course team & Task 2.4 reviewers (Level 2–3)	✓ Evaluation by course team & Task 2.4 reviewers (Level 2–3)
<i>Key Improvements Implemented</i>	Metadata clarity, licensing, accessibility, assignment instructions	Metadata completeness, instructor guide, IPR notices, accessibility in slides
<i>Final QA Self-Assessment</i>	✗ Not yet performed with Compass App	✓ Completed using QAF Compass App (Level 4 achieved)

²⁹ Remember that the S4E-QAF defines four (4) maturity levels for quality assurance implementation:

- **Level 1 (Awareness):** Basic awareness of QA principles; use of checklist for guidance.
- **Level 2 (Structured Design):** Initial application of QA indicators; partial alignment with standards.
- **Level 3 (Evaluated):** Formal evaluation conducted; revisions implemented based on feedback.
- **Level 4 (Optimised):** Fully compliant, self-assessed, and openly documented; training materials are FAIR-by-design and ready for reuse.

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<i>Aspect</i>	T4.3 – Teaching OS & RDM for Undergraduates	T4.4 – Shaping Open Science Champions (PhD)
<i>Final Maturity Level Reached</i>	Level 2–3 (iterative improvements in progress)	Level 4 (fully compliant, self-assessed and optimised)
<i>Publication Format</i>	Partially open (PDF on Zenodo), moving toward editable source upload	In progress – full editable source format to be uploaded on Zenodo
<i>Alignment with MVS and FAIR</i>	✓ Modules mapped to MVS for undergraduates; FAIR principles partially applied	✓ Fully mapped to ECR MVS; FAIR-by-design methodology applied
<i>ELSI & Ethical Licensing Compliance</i>	Moderate – CC licenses used; attribution improved post-evaluation	High – CC-BY with explicit IPR statements and attribution refinements