

Deliverable D2.1

Report on best-practices and indicators available and used by selected Communities

Project Title (Grant agreement no.):	ELIXIR-STEERS: enable federated data visits and large-scale, cross-border analysis in the life sciences by users across the whole European Research Area (101131096)		
Project Acronym (EC Call):	ELIXIR-STEERS (HORIZON-INFRA-2023-DEV-01)		
WP No & Title:	WP2 - Implementation of research software best practices through ELIXIR Communities		
WP leader(s):	Silvio Tosatto, John Hancock, Fotis Psomopoulos		
Deliverable Beneficiary:	Lead	27. UL	
Contractual delivery date:	31/07/2025	Actual delivery date:	31/07/2025
Delayed:	No		
Partner(s) contributing to this deliverable:	20.UNIPD 5.UOCHB		
Authors: John Hancock (27.UL), Federica Quaglia (20.UNIPD), Karel Berka (5.UOCHB)			
Contributors:			
Acknowledgments (not grant participants):			
Reviewers:	Mijke Jetten (Health-RI), Marek Suchánek (IOCB), ELIXIR-STEERS Management Board (MB) members.		

Log of changes

DATE	Mvm	Who	Description
16/06/2025	0v1	John Hancock (UL), Federica Quaglia (UNIPD)	Initial version
23/06/2025	0v2	John Hancock (UL), Federica Quaglia (UNIPD)	Sent to PMO after incorporating internal WP feedback
25/07/2025	0v3	Mado Fernandez	Circulated to the MB for final review before

		(ELIXIR Hub)	submission
31/07/2025	1v0	Mado Fernandez (ELIXIR Hub)	Final version to be uploaded into EC Portal



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1. Executive Summary

ELIXIR STEERS Deliverable D2.1, *Report on best-practices and indicators available and used by selected Communities*, outlines the work and progress of STEERS WP2 during the first half of the project in evaluating infrastructure components use and Research Software Quality (RSQ) indicators awareness and adoption across ELIXIR Communities.

The work accomplished by WP2 involved engaging the ELIXIR Communities through a structured Community Engagement Scoreboard (M2.1: *Community Engagement Scoreboard created*) and a collaborative workshop, followed by a hackathon (M2.3: *Delivery of a Hackathon engaging three or more nominated ELIXIR Communities*). The M2.1 *Community Engagement Scoreboard* captured the uptake of RSQ indicators and key ELIXIR infrastructure components through the ELIXIR Communities and aims to provide snapshots of changes in awareness and adoption levels through the three years of the project. The scoreboard revealed strong initial engagement among several ELIXIR Communities, including 3D-Bioinfo, Single Cell Omics, IDP, Biodiversity, and Systems Biology, and highlighted widespread awareness of best practices in research software. However, adoption of more advanced RSQ indicators and specific infrastructure components remains uneven, presenting an opportunity for targeted support. Broader engagement across the ELIXIR Community will be essential as this work evolves.

The M2.3 *Delivery of a Hackathon engaging three or more nominated ELIXIR Communities*, included two in-person events - a workshop and a hackathon held in Thessaloniki in June 2025 - focused on evaluating, selecting and implementing RSQ indicators using real-world use cases from a subset of ELIXIR Communities. These events provided concrete opportunities to assess the relevance of RSQ indicators through hands-on activities and provided concrete feedback on implementation feasibility within software management plans (SMPs). Moreover, the hackathon also identified priority training needs - including FAIR principles, testing, monitoring and sustainability - to guide future capacity-building initiatives.

Deliverable D2.1 contributes to advancing STEERS WP2 objectives by strengthening community engagement, benchmarking current practices and laying a solid foundation for D2.2 *Research software and workflows best-practice toolkit*. The insights gained will directly inform and shape the future actions of WP2: updating the Community Engagement Scoreboard (M2.4 *Community engagement scoreboard updated*), expanding outreach, awareness and adoption of RSQ indicators through an additional hackathon involving ELIXIR Communities (M2.5 *Delivery of a Hackathon engaging additional Communities for outreach*), and developing training aligned with community needs. These efforts aim to increase the adoption of robust, reproducible and sustainable research software practices across the ELIXIR ecosystem.

2. Contribution toward project objectives

With this deliverable, the project has reached or the deliverable has contributed to the following objectives/key results:

Objective no. / Key Result no. Description	Contributed
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	to:
Objective 1: Partner with user communities to create a toolkit for robust, reproducible, and green software and workflows that allow life-scientists to benefit from open science practices in the emerging European federated data landscape. (WP2, WP3, WP4, WP5)	
Key Result 1.1: Established partnerships with user communities that capture experiences and embed these in good practices for robust, reproducible, and green software and workflows (WP2)	Yes
Key Result 1.2: A toolkit developed consisting of guidelines, best practices and services that supports software development and recognition of individuals involved in software development (WP2, WP3)	Yes
Key Result 1.3: Community-wide agreement on key indicators for technical, scientific, and environmental benchmarking (WP2) embedded into established software and workflow benchmarking systems (WP3)	Yes
Key Result 1.4: Practices for robust, reproducible, and green software and workflows (WP2, WP3) are adopted and embedded in ELIXIR Nodes (WP4), supporting the European federated data landscape and Horizon Europe projects	Yes
Key Result 1.5: Demonstration of the greening potential and reduced carbon footprint of software best practice by applying toolkit and indicators in community-driven activities (WP2)	Yes
Key Result 1.6: Stimulate engagement and uptake by users via European and national communication and outreach programmes (WP5)	No
Objective 2: Enable the landscape for cross-border data analysis in the life sciences by embedding common practice across the whole European Research Area via effective national ELIXIR Nodes. (WP4, WP5)	
Key Result 2.1: Build a common toolkit to enhance the operational and managerial capacity of ELIXIR Nodes that comprise all aspects of sustainability (operational excellence, business planning, interactions with industry and impact assessment) (WP4, WP5)	No
Key Result 2.2: Expand the ELIXIR's Membership by transitioning candidate countries into fully operational national Nodes using capacity building actions (WP4, WP5)	No
Key Result 2.3: Strengthen excellence in RI management with an ELIXIR training programme that complements established Europe-wide offerings with the infrastructure specific needs (WP4)	No
Key Result 2.4: Strengthen the capacity of national training programmes (WP4) to scale the dissemination, training, and uptake of the ELIXIR software development	No

toolkit for robust, reproducible, and green software and workflows (WP5)	
Key Result 2.5: Work with funders to embed the practice in data and software management plans in guidelines to grantees (WP5)	No
Objective 3: Partner in Europe and internationally for global competitiveness and sustainability. (WP5)	
Key Result 3.1: Development of national SME and industry partnerships to support the European innovation ecosystem (WP5)	No
Key Result 3.2: Partnerships with other ESFRI RIs to strengthen the wider RI landscape (WP5) and support adoption of robust, reproducible, and green workflows across RI facilities.	Yes
Key Result 3.3: Foster global knowledge-exchange to drive good international practices and embed international partnerships in Node activities (WP5)	No
Key Result 3.4: Deliver a Node dissemination and communications toolkit that enables ELIXIR Nodes to amplify engagement with scientists and other stakeholders (WP5)	No

3. Introduction

The core ambition of ELIXIR-STEERS is to enable wide participation in advanced computational life science research by delivering a common toolkit of guidelines and services for distributed analytics and supporting software management (WP2, WP3); building national capacity for organising, deploying, and training national communities (WP4); widening the participation of ERA countries in ELIXIR (WP5) and supporting collaborations with industry across Europe (WP5).

This deliverable represents a key stage in achieving the ambition of WP2 to “provide a collection of best-practices and indicators for research software and workflows, implemented across a range of ELIXIR Communities” and specifically supports Task 2.3, which aims to encourage adoption of best practices through Community engagement. It also connects to work within WP3 Task 3.3 *Identify fit-for-purpose reproducible workflows through technical and scientific benchmarking*, and Task 3.4 *Integrating optimisation criteria for environmental impact in commonly used workflow management systems*. The deliverable describes the efforts and outcomes to date in engaging with ELIXIR Communities to a) gain an understanding of adherence to software development best practices and usage of ELIXIR infrastructure components that support those best practices in the [M2.1 Community Engagement Scoreboard](#) (link to live version [here](#)), and b) refine two sets of best-practice indicators, one developed by WP2 ([M2.2 “Collection of existing best-practices and indicators for research software”](#)) and a second developed by WP3 for workflows as part of M3.3 ([“Low and High Level Technical Metrics”](#)).

Importantly, these activities have already led to a clearer understanding of disparities across Communities in terms of RSQ indicators adoption and infrastructure components use. For example, strong performers, such as the 3D-Bioinfo, Galaxy and Systems Biology Communities, demonstrate consistent use of best practices, while other Communities remain at the awareness stage. This insight informs strategic direction for targeted support, outreach, and capacity building, serving as a foundation for the next WP2 steps and for planning the future hackathon (M2.5).

The outcomes also support the alignment of recommendations from WP2 with WP3’s infrastructure development roadmap, and will directly feed into the creation of a best-practice toolkit for research software and workflows (WP2 D2.2). By laying this groundwork, WP2 is actively helping shape a more consistent and higher-quality software ecosystem across ELIXIR, with tangible benefits for sustainability, reproducibility, and cross-Community collaboration.

Interactions with other work packages. The work of WP2 and Task 2.3 ties in closely with the work of WP3, whose aim is to develop additional features to extend existing infrastructure components to implement the best practices and indicators for research software developed in WP2 and workflows developed in WP3. WP2 and WP3 are working closely together throughout the project. The outputs of WP2 provide input to WP3’s efforts and to ensure good integration, the WP2 Community Engagement Scoreboard includes infrastructure components prioritised by WP3 while also providing the opportunity to Communities to suggest their own prioritised infrastructure components. WP2 also interacts with WP4 because its outputs, along with those of WP3, will provide the raw material for training within the ELIXIR Nodes supported by WP4. WP2 and WP3 hold frequent joint meetings both virtually and F2F at the STEERS General Assembly and at dedicated WP meetings. Members of

WP4 are invited to join these meetings as well and engagement is likely to increase as the recommendations from WP2 become more mature.

3.1 Methodology applied

3.1.1 Community Engagement Scoreboard

The [Community Engagement Scoreboard](#) tracks the evolution of uptake by ELIXIR Communities in two areas of relevance to the aims of ELIXIR-STEERS:

1. Indicators Reflecting Community Usage Of Infrastructure Components (from [WP3 Flashcards of resources](#)): [APICURON](#), [BIP! Scholar](#), [Galaxy](#), [DOME Registry](#), [Software Management Wizard](#), [bio.tools](#), [proTES](#), [WorkflowHub](#), [RO-Crate](#), [OpenEBench](#), [Bioschemas](#), and
2. Indicators Adhering To Research Software Best Practices: documentation, standard input/output formats, version control system, persistent global unique identifier, license, citation information, domain-specific registry, Software Management Plan. These indicators have been derived from "[ELIXIR Software Management Plan for Life Sciences](#)" (Alves et al. (2021) BioHackrXiv.org) and were used to define the third set of indicators in STEERS [M2.1: Community Engagement Scoreboard](#).

Communities were asked to complete the columns of the scoreboard by selecting one of the following options describing the overall uptake of either the corresponding Best Practice or Usage of Infrastructure:

- Used consistently by the Community
- Used sporadically by the Community
- Community is aware but does not use
- Community is not aware

ELIXIR Communities (<https://elixir-europe.org/communities>) were initially contacted to identify one or more contacts from each Community who would facilitate the collection of Community input into the Scoreboard. These initial contacts were then followed up firstly by a general cross-Community call on 26/8/24 to explain the aims of the Scoreboard and how to complete it. This meeting was attended by representatives from in total eight ELIXIR communities, i.e., the Plant, Biodiversity, Galaxy, 3DBioinfo, IDP, Systems Biology, Microbial Biotechnology, and Proteomics Communities.

The collection of scores was carried out either by the contacts within their Communities or during meetings with the Communities (typically during their regular, monthly virtual meetings) to collect the scores directly. The following meetings were held:

- Rare Diseases: 2/9/24
- Federated Human Data: 25/9/24
- Intrinsically Disordered Proteins: 6/11/24
- Metabolomics, Food & Nutrition: 12/11/24
- Human Copy Number Variation: 13/11/24
- Toxicology: 4/12/24

In each case the aims of the STEERS project, WP2, and the Community Engagement Scoreboard were explained and Communities were encouraged to complete the scoreboard themselves. In some cases the scoreboard was completed during the meeting.



A final coordination meeting was held by way of a Presentation and discussion at the joint WP2/3 F2F meeting in Padova on 2-3 October 2024 (attended by representatives of eleven Communities, i.e., Systems Biology, Research Data Management, Human Copy Number Variation, Food & Nutrition, Biodiversity, Plant Sciences, IDP, Galaxy, Single Cell Omics, Proteomics and Federated Human Data) [[Agenda](#)].

3.1.2 Engagement with the Community to evaluate indicators of software best practices by way of a hackathon M2.3

This milestone was met by two workshops: one held during the 2025 ELIXIR All-Hands Meeting (AHM) in Thessaloniki on 4/6/25 and a second hackathon held immediately afterwards on 6/6/25 at CERTH, Thessaloniki. The workshops were designed to obtain feedback on the sets of indicators developed by WPs 2 and 3. Using Community use cases identified by ELIXIR Communities, the goal was to assess which indicators are applicable and useful within their specific software ecosystems, and to identify those that are less relevant or effective.

STEERS WP2 Workshop on Research Software Management Quality Indicators

The first workshop entitled “Evaluation of RSQ Indicators” [[Agenda](#)] fulfilled the original requirement for M2.3, namely “presentation of the initial conclusions from Tasks 2.1 & 2.2 to ELIXIR Communities and allowing feedback on those conclusions and what is needed to develop Tasks 2.1 and 2.2 further.” The workshop included short presentations on the collected best practices and indicators for research software quality, followed by an introduction to the milestones that feed into these indicators (M2.1 and M2.2). Software management planning, utilizing the Data Stewardship Wizard (DSW), was introduced in the context of WP3 Task 3.2, “Contributing towards sustainable research software through Software Management Plans”. This work builds on developments in WP2, which focuses on integrating Community-based approaches to improve the quality and sustainability of research software, including aligning with established best practices from ELIXIR. Participants then joined a hands-on working session to provide feedback. They worked together in small groups to rank indicators within individual categories (e.g. FAIRness) by importance, while brainstorming examples of successful implementation from high-performing ELIXIR Communities. This activity was instrumental in identifying which RSQ indicators are seen as most relevant and actionable by the Communities, offering a bottom-up prioritisation that reflects their needs and constraints. The workshop confirmed that research software practices such as documentation, licensing and persistent identifiers are broadly understood and included, while also highlighting areas that require further support or clarification. These insights help WP2 shape future development and support the next activities to be more targeted, relevant, and Community-oriented.

STEERS M2.3 RSQ Indicators Implementation Hackathon

The subsequent hackathon, entitled “RSQ Indicators Implementation Hackathon” [[Agenda](#)], aimed to carry out a hands-on evaluation of the RSQ Indicators prioritised during the preceding workshop, providing feedback on their utility and ease of implementation, as well as concrete examples of implementation. The Hackathon opened with a summary of the previous AHM workshop outcomes. Short talks showcasing ELIXIR STEERS Core communities (those Communities that participated in the original grant submission: 3D-Bioinfo, Single Cell Omics, IDP, Biodiversity and Systems Biology) included use cases from [Scipion](#), [Mol*](#), [biotoolsSchema](#), and [Wombat-p workflow](#), as well as pipelines. An introduction to the STEERS WP3 technical matrix set the stage for a working session focused on implementing selected RSQ indicators. The workshop continued with a session on preparing a survey for software development training, followed by further group work. The event concluded with

feedback from the working session and a discussion aimed at identifying the next steps and areas of work for WP2. The hackathon provided concrete insights into how RSQ indicators are applied across the ELIXIR Communities and their specific contexts, highlighting both enablers and barriers to their implementations. The outcomes will inform the design of future activities, and updates to the Community Engagement Scoreboard, ensuring that WP2 activities build capacity across all ELIXIR Communities and remain aligned with their needs.

4. Results

4.1 Community Engagement Scoreboard

The M2.1 Community Engagement Scoreboard summarizes how participating Communities engage with research software quality practices and infrastructure components use. This milestone focuses on assessing the level of awareness and adoption of research software best practices within ELIXIR Communities at the beginning of the STEERS project. It plays a central role in establishing the baseline of community awareness, engagement, use of infrastructure components and adoption of RSQ indicators. The following analysis highlights overall patterns, key strengths as well as areas for improvement, drawing on detailed data from the accompanying tables.

Table 1: Level of engagements by Communities

Community	RSQI		Infrastructure use	
	No of responses	% response	No of responses	% response
3D-BioInfo	8	100	11	100
Biodiversity	8	100	11	100
Intrinsically Disordered Proteins	8	100	11	100
Single-Cell Omics	8	100	11	100
Systems Biology	8	100	11	100
Federated Human Data	8	100	11	100
Food and Nutrition	8	100	11	100
Galaxy	8	100	11	100
Human Copy Number Variation	0	0	4	36
Metabolomics	8	100	11	100
Microbial Biotechnology	0	0	0	0

Microbiome	8	100	11	100
Plant Sciences	7	88	11	100
Proteomics	8	100	11	100
Rare Diseases	8	100	11	100
Research Data Management	8	100	11	100
Toxicology	0	0	0	0
Core (ave)		80		91
Non-core (ave)		74		78

Table 1 summarises the number and percentage of responses from participating Communities regarding their engagement with Research Software Quality Indicators (RSQI) and the use of infrastructure components. The numbers presented correspond to the numbers of columns completed by each Community in the Community Engagement Scoreboard under the two categories. Overall, the data show high engagement among the majority of core Communities, with most reporting 100% response rates. Non-core Communities show a slightly lower but still substantial participation. Indeed, 14 of 17 Communities engaged returned scores (82%), and 12 Communities (71%) returned scores for all indicators, highlighting the Communities' commitment to both software quality and infrastructure integration. While a few Communities reported limited or no data, overall we see strong involvement across the Communities. Although not comprehensive, this forms a solid basis for assessing changes in uptake and awareness when the scoreboard is updated while reflecting on the variability across domains, which could inform future targeted Community support and capacity building.

Table 2a: RSQI Indicators by Community

Community	RSQI Response (number)			
	Consistently	Sporadically	Aware	Not Aware
3D-BioInfo	5	1	1	1
Biodiversity	5	1	0	2
Intrinsically Disordered Proteins	5	2	0	1
Single-Cell Omics	4	0	4	0
Systems Biology	0	0	8	0

Federated Human Data	4	0	4	0
Food and Nutrition	7	0	1	0
Galaxy	6	1	0	1
Human Copy Number Variation				
Metabolomics	4	3	1	0
Microbial Biotechnology				
Microbiome	3	4	1	0
Plant Sciences	4	2	1	0
Proteomics	6	0	0	2
Rare Diseases	5	2	1	0
Research Data Management	5	2	1	0
Toxicology				
Core (%)	44	9	41	6
Non-core (%)	62	20	14	4

Table 2a breaks down RSQ engagement by Community, showing whether responses reflect consistent, sporadic, or just awareness-level practice. Overall there is strong usage of RSQ indicators across the Communities. Core Communities awarded more “Aware” scores proportionately than non-core Communities but this primarily reflected the response from the Systems Biology Community. The data reveal a diverse landscape: some Communities show strong consistent application of RSQ practices, with others demonstrating broad awareness but limited implementation. Although a few Communities did not provide RSQI responses, the available data highlight the heterogeneity across Communities, with a need to move from awareness toward adoption in certain areas.

Table 2b: Infrastructure components usage by Community

Community	Infrastructure component usage Response (number)			
	Consistently	Sporadically	Aware	Not Aware

3D-BioInfo	4	1	2	4
Biodiversity	3	0	3	5
Intrinsically Disordered Proteins	1	3	5	2
Single-Cell Omics	2	3	4	2
Systems Biology	0	3	6	2
Federated Human Data	0	4	3	4
Food and Nutrition	0	3	5	3
Galaxy	4	1	4	2
Human Copy Number Variation	2*	0	2*	0
Metabolomics	2	3	2	4
Microbial Biotechnology				
Microbiome	4	1	3	3
Plant Sciences	1	4	4	2
Proteomics	0	1	1	9
Rare Diseases	2	4	4	1
Research Data Management	1	1	7	2
Toxicology				
Core (%)	20	20	40	20
Non-core (%)	16	21	34	29

Table 2b details how Communities interact with infrastructure components, distinguishing consistent users, sporadic users, those aware but not using, and those unaware. Different Communities show different reliance on the identified infrastructure components, but the general pattern is broadly similar for core and non-core Communities. As a general trend, there tends to be more awareness than use, although some Communities stand out as stronger users, notably 3DBioinfo, Galaxy and Microbiome, reflecting robust, consistent engagement. Importantly, these findings highlight both a strong foundation of active infrastructure use and clear opportunities for enhancing uptake across

the Communities. Efforts to improve uptake should particularly focus on those Communities where most improvement is possible, such as Proteomics, offering valuable direction for targeted outreach and capacity-building initiatives without overemphasising individual Community response levels.

Table 3a: RSQ Indicators by Indicator

Indicator	Response (number)			
	Consistently	Sporadically	Aware	Not Aware
Contains documentation in an accessible and structured format	11	2	1	0
Uses standard input/output formats, supported by the respective community/communities	11	2	1	0
Uses a version control system	12	1	1	0
Releases have a persistent global unique identifier	8	2	4	0
Software has a license (ideally a permissive one)	13	0	1	0
Software includes citation information in a structured format (ideally also containing the authors' ORCIDs)	3	6	3	2
Software is registered in a domain-specific registry	5	4	3	1
Software is accompanied by a respective Software Management Plan	0	1	9	4

Table 3a shifts focus from Communities to the specific RSQ indicators, showing how well these best practices are integrated in the responding Communities. Most indicators already show a strong

pattern of usage. Core software practices - such as documentation, version control, licensing, and the use of standard input/output formats - show strong, consistent adoption across Communities. More advanced practices, e.g. persistent identifiers, structured citation metadata, and Software Management Plans, show lower levels of consistent use, though awareness is generally high. Provision of citations in software tends to be sporadic, highlighting an area where both awareness and application could be further strengthened. Similarly, while domain-specific registries (as opposed to e.g. GitHub) are recognized, their use could benefit from more consistent integration. Software Management Plans are still a relatively new concept although there is already considerable awareness, largely driven by discussions in ELIXIR. This makes them a prime area for future focus, suggesting that upcoming efforts should prioritize converting existing awareness into concrete implementation, especially for advanced and emerging practices, rather than focusing on Community-specific gaps.

Table 3b: Infrastructure components by component

Infrastructure component	Response (number)			
	Consistently	Sporadically	Aware	Not Aware
APICURON	1	2	5	6
BIP! Scholar	0	0	0	13
Galaxy	6	5	4	0
DOME Registry	0	1	6	6
Software Management Wizard (based on DSW)	0	2	10	2
bio.tools	9	6	0	0
proTES	0	0	5	8
WorkflowHub	6	1	6	1
RO-Crate	2	4	7	1
OpenEBench	1	2	9	2
Bioschemas	1	9	3	1

Table 3b details how Communities interact with infrastructure components, distinguishing consistent users, sporadic users, those aware but not using, and those unaware. While overall patterns are broadly similar between core and non-core Communities, there is generally more awareness than

active use. Only a few infrastructure components - notably bio.Tools, Galaxy, and WorkflowHub show a strong, consistent uptake, reflecting their established roles within ELIXIR. Bioschemas shows largely sporadic usage despite its high profile, likely reflecting its role in summarising web-based content. Other infrastructures, such as the DOME Registry (restricted to AI/ML applications so not always relevant), Software Management Wizard, RO-Crate and OpenEBench, show more awareness than practical implementation, indicating future growth potential. Low awareness of APICURON, BIP!Scholar and proTES should be addressed, suggesting a need for improved communication and outreach. Finally, these findings point to both a solid foundation of infrastructure use and clear opportunities to improve uptake, where focused efforts could yield more progress.

CE Scoreboard results

Level of engagement

The data show strong engagement across most core Communities, with high response rates and widespread adoption of research software quality best practices such as documentation, licensing, and version control. Non-core Communities show more variability to some extent, while still demonstrating substantial awareness and sporadic uptake. Notably, infrastructure use lags behind awareness in several areas, indicating room for improvement and consistent application.

Matrix of results

The scoreboard highlights a heterogeneous landscape, where some Communities (e.g. 3D-Bioinfo, Galaxy) and tools (e.g. WorkflowHub, bio.tools) emerge as leading examples, while others show a still limited level of engagement or are currently positioned at the awareness stage. The following matrix view helps identify where targeted interventions - by Community, by tool or by practice - could have the greatest impact. In the matrix, high engagement refers to consistent use of both RSQI best practices and infrastructure components, moderate engagement indicates partial or sporadic use, with notable awareness but gaps in consistent application and low engagement reflects little to no reported use or responses, marking key areas for targeted outreach or support.

Table 4: ELIXIR Communities engagement matrix highlighting levels of RSQ indicators adoption and infrastructure components use

Community	High Engagement (Consistent Use)	Moderate Engagement (Sporadic / Awareness)	Low Engagement (No Use / No Response)
3D-BioInfo	Strong RSQI; consistent use of infrastructure (Galaxy, WorkflowHub)	Awareness of additional components; minor gaps	Some unawareness of advanced infrastructure components
Biodiversity	Some infrastructure components use (bio.tools)	Moderate awareness; some domain-specific component awareness	No consistent practice
Intrinsically Disordered Proteins	Strong RSQI practices, partial use of standard infrastructure components	Sporadic infrastructure component use; partial awareness of advanced components	Gaps in SMPs
Single-Cell Omics	Strong RSQI, consistent	Consistent/sporadic	Gaps in advanced

	use of infrastructure components (Galaxy, WorkflowHub)	infrastructure component use	practices
Systems Biology	High awareness of RSQI best practices	Sporadic infrastructure component use, some awareness of domain-specific components	No consistent application of practices
Federated Human Data	Mixed RSQI; consistent use of bio.tools, WorkflowHub	Awareness of multiple components, limited consistent uptake	Low consistent uptake; limited SMP use
Food and Nutrition	Strong RSQI, consistent use of Galaxy, bio.tools	Awareness of infrastructure components; limited consistent use	Low adoption of advanced infrastructure components
Galaxy	Strong consistent use of infrastructure components (Galaxy, WorkflowHub, bio.tools)	Sporadic use in some advanced RSQI indicators	-
Human Copy Number Variation	Some consistent infrastructure component use (Galaxy, WorkflowHub)	Low RSQI responses; partial awareness	Sparse overall engagement
Metabolomics	Strong RSQI, sporadic use of Galaxy, WorkflowHub	Sporadic infrastructure component application; moderate awareness	Awareness-only for several advanced practices
Microbial Biotechnology	-	-	No responses reported
Microbiome	Strong RSQI; consistent use of infrastructure components (Galaxy, WorkflowHub)	Awareness of additional infrastructure components	Some unaware of advanced infrastructure components
Plant Sciences	Strong RSQI; consistent use of Galaxy, WorkflowHub, bio.tools	Sporadic infrastructure component use; moderate awareness	Low consistent application of advanced practices
Proteomics	Strong RSQI core practices	Low infrastructure component use; awareness but minimal uptake	Priority area for infrastructure components adoption
Rare Diseases	Strong RSQI; consistent use of Galaxy, bio.tools	Awareness of multiple infrastructure components; sporadic	Low consistent uptake of advanced infrastructure components

		advanced tool application	
Research Data Management	Strong RSQI; consistent use of multiple components (e.g., WorkflowHub, RO-Crate)	Awareness of domain-specific components; sporadic adoption of advanced RSQI practices	Gaps in advanced infrastructure component application
Toxicology	-	-	No responses reported

Strengths and weaknesses

Key strengths include the high adoption of core software practices and the successful integration of several widely used infrastructure components. Weaknesses can be identified in the uneven adoption of advanced practices (e.g. Software Management Plans) and - to date - the low visibility or usage of newer or specialized infrastructures to do so. Addressing the identified gaps will offer opportunities to strengthen overall Community capacity and alignment with ELIXIR goals.

4.2 M2.3 Workshop and Hackathon

Two M2.3-related events - a workshop and a hackathon - were conducted in person in Thessaloniki. The workshop took place on 4th June 2025 during [ELIXIR All Hands Meeting 2025](#), and the hackathon was held on 6th June 2025 at CERTH. Slides from the events are available [here](#).

Workshop: “ELIXIR-STEERS WP2 Workshop on Research Software Management Quality Indicators”

The workshop provided a structured forum for introducing key concepts and fostering community engagement around research software quality (RSQ) indicators. The programme included short presentations on the following topics: an introduction to STEERS WP2 and WP3; RSQ indicators specifically targeting workflows (WP3); and an overview of Software Management Plans (SMPs).

The second half of the workshop was dedicated to a hands-on activity aimed at gathering participants’ perspectives - both in-person and online - on the relative importance of RSQ indicators.

Hands-on Activity: Research Software Quality Indicators (RSQI) “Game”

Participants engaged in an interactive card-based activity (guidelines available [here](#)) designed to facilitate the selection, ranking, and evaluation of RSQ indicators across defined dimensions. Each card represented a specific RSQ indicator, sourced from existing guidelines and categorised by dimension. Through structured rounds of play, participants collaboratively constructed prioritised lists of indicators and explicitly identified indicators deemed less or more relevant. Two sets of RSQ indicators were used during the workshop: [one set](#) derived from the Zenodo collection developed during the BioHackathon, comprising 186 indicators, and the [other set](#) from the technical matrix developed by WP3. Scoring was based on group consensus and individual assessments, with results

systematically recorded in a shared [RSQI spreadsheet](#). This activity promoted critical discussion, collective learning, and the refinement of RSQI sets to inform ongoing project work.

Hackathon: RSQ Indicators Implementation

Building on the outcomes of the workshop, the hackathon focused on the practical implementation of prioritised RSQ indicators. The event included a series of flash talks showcasing use cases from ELIXIR Core Communities, including:

- 3D-BioInfo: [Mol*](#) and [Scipion](#)
- Proteomics: Nextflow-based workflows
- Biodiversity Community pipelines ([ERGA HiFi-only Assembly+QC Hifiasm v2409 \(WF2\) Version 1](#) and [ERGA-BGE Genome Report ANNOT analyses version 2](#))
- Intrinsically Disordered Proteins: [CAID](#)
- Single Cell Omics: [Seurat](#) and [Scanpy](#) pipelines

Participants conducted hands-on evaluations of the prioritised RSQ indicators, providing feedback on their utility, applicability, and ease of implementation (available [here](#)). Concrete examples of indicator application were also documented to inform best practices. In addition, the hackathon included contributions from WP4 (Task 4.3), featuring a dedicated training session on survey design for software development training activities. Finally, the RSQ indicators were mapped to the actual developmental version of the Software management planning questionnaire in the Data Stewardship Wizard with the goal of using SMP in DSW to ease the fulfilment of the RSQ indicators for the research software.

Outcomes of the Workshop on Research Software Quality (RSQ) Indicators

The ELIXIR-STEERS WP2 workshop on research software management quality indicators, held on June 4 2025 at the ELIXIR AHM 2025, featured a hands-on activity designed to collect, assess and prioritise community perspectives on software quality indicators relevant to research software workflows and tools. This activity directly supported milestone M2.3 and the broader objectives of WP2 to refine and validate indicators that are meaningful and actionable for research software stakeholders across ELIXIR communities. The hands-on activity consisted of a structured, interactive exercise aimed at assessing the relevance of individual Research Software Quality indicators. Participants worked in groups, both in person and online, focusing on one or more dimensions of RSQ indicators. Participants received a deck of indicator cards, representing distinct RSQ indicators, and were asked to select the most relevant indicators for their dimension and rank them, discard indicators perceived as irrelevant or unclear and record their group's selection. The following table summarises the indicators prioritised through the hands-on activity (a full list is available [here](#)).

Table 5a: ELIXIR Core Communities use cases and focus areas for RSQI assessment

Indicator	Dimensions	Description
Project Description	Documentation	The project website MUST succinctly describe what the software does (what problem does it solve?).
Functional correctness	Source code	Degree to which a product or system provides accurate results when used by intended users

Basic Documentation	Documentation	The project MUST provide reference documentation that describes the external interface (both input and output) of the software produced by the project.
Listed in registries	Findability	Register software projects in a disciplinary or community registry (e.g. ascl.net, bio.tools, swMath, RRID portal, RSD, WikiData, DataCite) to ensure that software can be found and accessed.
Functional completeness	Source code	Degree to which the set of functions covers all the specified tasks and intended users' objectives
Safe integration	Interoperability	Degree to which a product can maintain safety during and after integration with one or more components.
Support	Issue tracking	Existence of an issue tracking system or helpdesk, facilitates structured software development. Leveraging issues to track down both new enhancements and defects (bugs, documentation typos). Applies as well to services to report operational and user issues
Functional appropriateness	Source code	Degree to which the functions facilitate the accomplishment of specified tasks and objectives
Test Coverage of Code+Function	Testing	It is SUGGESTED that the test suite cover most (or ideally all) the code branches, input fields, and functionality
Adoption of community standards	Community	Follow community standards when developing software: An example can be language-specific standards and best practices (e.g. DESCRIPTION file in R, see also https://swcarpentry.github.io/r-novice-inflammation/08-making-packages-R.html).
Monitoring service public endpoints	Monitoring	The Service public endpoints are monitored, such as probes measuring the http or https response time
Versioning	Versioning	(0) No software versioning applied. (1) There is some kind of versioning for the software. (2) The software uses structured (e.g. semantic) versioning. (3) A description of the versioning scheme is available. (4) There is a documentation on release cycles for the software.

Maintainability	Fundability	Measured by the resources spent in terms of time and cost in keeping a system up and running over a period of time
Publication Repository	Findability	<p>Open Publication Repository</p> <p>(0) There is no information available on where to find the software.</p> <p>(1) The software is contained in an online repository.</p> <p>(2) Some kind of description is available giving further information on the software in this repository (e.g. readme file).</p> <p>(3) A structured meta data description (e.g. following DataCite) given for software is in this repository.</p> <p>(4) The repository is listed in some overarching meta-repository (e.g. Helmholtz Research Software Directory (RSD)).</p> <p>(5) The meta-repository is performing quality checks (e.g. re3data) for the used publication repository.</p>
Licensing & Reusability	Licensing	<p>(0) Not clear.</p> <p>(1) The software uses a custom license allowing reuse. (i.e. ask your lawyer before you use it)</p> <p>(2) The software uses a FOSS/OSI approved license including that license dependencies are at least being checked manually.</p> <p>(3) The software uses an appropriate license for different file types (code, text, images etc.) following e.g. the REUSE specification.</p> <p>(4) There is a process available for automatically checking e.g. the REUSE specification.</p>
Intellectual Property	Licensing	<p>There are multiple statements embedded into the software product describing unrestricted rights and any conditions for use, including commercial and non-commercial use, and the recommended citation. The list of developers is embedded in the source code of the product, in the documentation, and in the expression of the software upon execution. The intellectual property rights statements are expressed in legal language, machine-readable code, and in concise statements in language that can be understood by laypersons, such as a pre-written, recognisable licence.</p>
Infrastructure monitoring	Monitoring	The Service is monitored for infrastructure-related criteria

Out of 186 indicators analysed, the following top 10 indicators were selected in 13 rounds of the RSQ indicators group activity: 1) Functional correctness, 2) Project Description, 3) Listed in



registries, 4) Maintainability, 5) Safe integration, 6) Support, 7) Publicly Accessible Repository, 8) Adoption of community standards, 9) Monitoring service public endpoints and 10) Versioning.

The prioritisation outcomes of the RSQ indicators activity revealed a community focus on indicators that reflect core functional quality, documentation, findability and operational robustness of research software. Indicators such as project description, functional correctness, basic documentation, and listed in the registry, were consistently prioritised. Other valued indicators included those addressing completeness, testing coverage, versioning, and operational stability (monitoring, support), which reflect the communities' emphasis on robust engineering and maintainability. The selection of community standards, licensing, and intellectual property indicators highlights the importance of legal clarity and best practices for reuse. Conversely, indicators on advanced security, code metrics, and user interaction were more often discarded, suggesting a need for refinement or clearer guidance on their relevance.

The workshop outcomes provide a validated prioritisation of RSQ indicators based on community feedback and input, through an engaging and effective mechanism for building consensus and collecting actionable feedback from the participant groups.

Outcomes of the Hackathon on Research Software Quality (RSQ) Indicators

The ELIXIR-STEERS WP2 Hackathon on RSQI Implementation took place on 6th June 2025 at CERTH, and it built directly on the outcomes of the preceding workshop and focused on two main goals:

- I. testing the applicability of prioritised RSQ indicators through real-world use cases from ELIXIR Core Communities
- II. collaborating with WP4 (Task 4.3) to identify training needs and priorities for software development training skills across ELIXIR.

Four out of five ELIXIR Core Communities (3D-BioInfo, Biodiversity, Intrinsically Disordered Proteins, Single Cell Omics) provided use cases to test RSQ indicators applicability, as did the Proteomics Community.

Table 5b: Priority research software quality training topics identified in the WP4 training needs survey

Community	Use Cases / Tools	Focus of RSQ indicators assessment
3D Bioinfo	Mol*, Scipion	Documentation, interoperability, monitoring
Biodiversity	Community pipelines	FAIRness, documentation, adoption of community standards
IDP (Intrinsically Disordered Proteins)	CAID	Testing, monitoring, sustainability
Single Cell Omics	Seurat pipeline, Scanpy pipeline	Licensing, packaging, usability, versioning

Proteomics	Nextflow workflows	Versioning, reproducibility, testing, licensing
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The participating Communities are able to apply many of the core RSQ indicators (e.g. documentation, licensing, or testing) effectively to their use cases. Indicators related to monitoring, FAIRness, and adoption of community standards showed considerable variation across communities, underlining the need to take into account flexible and above all context-specific implementation guidelines. More advanced indicators, such as those addressing monitoring of infrastructure and public endpoints were identified as challenging to implement consistently and provide examples of needs of a targeted approach and additional guidance to reach expected levels of awareness and implementation. Overall, the activity demonstrated that the structured application of RSQI can play a valuable role in advancing research software quality and sustainability across ELIXIR Communities.

Following the RSQ indicators session, WP4 led a focused activity to identify training needs for software development skills across ELIXIR Nodes, through a collaborative survey and group discussion designed to inform the development of targeted training offerings within Task 4.3 of WP4. This activity aligned with the project's objective of supporting skills development in research software, enabling the adoption of best practices represented in the RSQ indicators framework. The session also aimed to map existing training provision and demand among Nodes and to define key competencies required of instructors.

Table 5c:

Topic	Training Type	Rank (Importance)
(Re)Usability (containerisation, reproducibility)	Fundamental	5
Testing (types of tests, how to set up)	Fundamental & Advanced	-
Versioning & Issue Tracking (Git basics, standards)	Fundamental	-
Licensing (overview, reuse focus)	Fundamental	-
Packaging / Interoperability (standards, interfaces)	Fundamental	4
FAIRness (Findability, Accessibility, Interoperability, Reusability)	Advanced	2-4
Monitoring (service monitoring basics)	Advanced	1
Security (secure coding, testing for security)	Fundamental & Advanced	-
Documentation (standards, best practices)	Fundamental	-
Sustainability (code and product perspectives)	Fundamental & Advanced	-

High priority topics included version control, licensing, interoperability, testing, sustainability and practical application of FAIR principles. The session emphasised the importance of a modular training approach, related to RSQ indicators dimensions, and the need for instructors to combine technical expertise and software quality practices. These insights will directly inform the design of WP4 (Task 4.3) training modules.



5. Conclusions

The M2.1 and M2.3 activities under WP2 provided valuable insights into the current landscape of Research Software Quality indicators as well as infrastructure components awareness and use, and community engagement across ELIXIR, and identified actionable priorities for further development.

The M2.1 Community Engagement Scoreboard highlighted a heterogeneous engagement profile among ELIXIR Communities. While several communities and tools, e.g., 3D-Bioinfo, Galaxy, WorkflowHub, and bio.tools, demonstrated strong and consistent RSQI adoption and infrastructure use, others exhibited more limited or awareness-level engagement. Importantly, higher-level RSQ indicators (e.g. persistent identifiers, structured citation metadata, and Software Management Plans) are widely recognised but are not yet consistently implemented, highlighting a key opportunity to translate awareness into sustained practice and adoption. Similarly, while awareness of core infrastructure components (e.g. Bioschemas, Software Management Wizard, RO-Crate, OpenEBench) is growing, actual uptake remains uneven. Several specialised tools (e.g. APICURON, BIP!Scholar, proTES) remain underutilised, suggesting the need for improved outreach and dissemination mechanisms. The overall findings provide a valuable basis for targeting future support efforts, with particular attention to lifting under-engaged communities alongside supporting the already existing high performers.

The M2.3 activities, comprising the ELIXIR-STEERS WP2 workshop and Hackathon, further advanced the community's collective understanding of RSQ indicators, awareness, and implementation. The workshop's prioritisation activity successfully captured community consensus on RSQ indicators of highest relevance to research software quality workflows and tools. RSQ indicators relating to core functional quality, documentation, and findability were consistently prioritised. In contrast, indicators addressing advanced security, code metrics and user interaction were identified as areas requiring further clarification and targeted support. The outcomes provide a prioritisation of RSQ indicators that will guide the future work of WP2 in promoting awareness and adoption of research software quality best practices. The subsequent hackathon demonstrated how RSQ indicators are concretely applied to use cases provided by core ELIXIR Communities, while accommodating Community-specific needs. The hackathon also successfully identified priority training topics through a collaborative joint session with WP4 Task 4.3. High-priority areas included version control, licensing, interoperability, testing, sustainability and the application of FAIR principles. The discussion that took place highlighted the relevance of aligning training skills development with RSQ indicators awareness and adoption.

Overall, the outcomes of M2.1 *Community engagement scoreboard created* and M2.3 *Delivery of a Hackathon engaging three or more nominated ELIXIR Communities* will directly feed into the next phase of work in WP2, specifically the update of the Community engagement scoreboard (M2.4) to track the progress of the Communities related to the uptake of RSQ indicators and another hackathon that will involve additional ELIXIR Communities beyond the core ones (M2.5). Indeed, the next steps of the project will focus on increasing the awareness and adoption of RSQ indicators by the ELIXIR Communities, providing targeted support towards an increased Community engagement, delivering training that bridges the current skills gaps. In doing so, the work of STEERS WP2 will help drive the adoption of high quality, sustainable research software quality practices across the ELIXIR ecosystem and will feed into WP2 D2.2, the creation of a research software and workflows best-practice toolkit.



6. Impact

In the context of WP2, M2.1 and M2.3 contributed to strengthening awareness and adoption of Research Software Quality (RSQ) indicators and key ELIXIR infrastructure components across the ELIXIR Communities, while driving Communities engagement.

RSQ indicator awareness was raised among the ELIXIR Communities through the Community Engagement Scoreboard and the RSQ indicators workshop and hackathon of M2.3, demonstrating consistent adoption of core practices such as documentation, licensing, version control, and standard input/output formats. Awareness has increased for advanced RSQ indicators, including persistent identifiers, structured citation metadata, and Software Management Plans, but their adoption lags behind awareness. This is a clear opportunity for turning awareness into adoption, promoting consistent use through support and training.

Similarly, the visibility and uptake of infrastructure components shows a pattern of broad awareness but uneven use. There is indeed an opportunity to push for stronger uptake of components such as Bioschemas, Software Management Wizard, RO-Crate, and OpenEBench, tools that are well known but not yet widely adopted by the Communities. Specific platforms like APICURON, BIP! Scholar and proTES, instead, currently have low visibility across most ELIXIR Communities and, in the next phase of the project, could benefit from increased outreach and improved communication strategies.

Moreover, targeting uneven Community engagement will be one of the main focus of WP2 in the second half of the project. Indeed, the results of M2.1 highlight uneven levels of Community engagement. The Scoreboard highlights the presence of leading communities that are already consistently applying RSQ indicators and using infrastructure components, such as 3D-Bioinfo, Galaxy, Single Cell Omics, Systems Biology. Other Communities (such as Proteomics, Biodiversity, or Human Copy Number Variation), show a strong potential for improvement and are currently positioned at awareness stage or with limited uptake and should be now actively targeted in the next phase. Capacity building will therefore play a key role now, to ensure that STEERS WP2 not only reinforces existing high-performing Communities but helps lift the baseline across the currently under-engaged Communities.

These impacts directly support the original goals of WP2 and specifically Task 2.3, which set out to assess and promote the adoption of research software best practices and indicators through structured Community engagement. The use of the Community Engagement Scoreboard (M2.1) and the delivery of the workshop and hackathon (M2.3) provided concrete mechanisms to gather Community feedback, test real-world use cases, and iteratively refine the proposed indicators and tools. In line with the project plan, this work has leveraged the width of ELIXIR Communities and their diverse software ecosystem to not only raise awareness but also encourage uptake of best practices, indicators and infrastructure components. As foreseen in the grant agreement, this also establishes the groundwork for the forthcoming best-practice toolkit (D2.2) and positions WP2 as a key driver of improved software quality, sustainability, and interoperability across the ELIXIR research infrastructure.



7. Next Steps

Building on the strong foundation of M2.1 and M2.3, the future work of WP2 will focus on the following strategic activities to deepen community impact, broaden adoption, and contribute to the sustainability of research software practices across ELIXIR:

- Leveraging RSQ indicators awareness and adoption through targeted Community-specific support, outreach and communication strategies and training opportunities. This will help translate the awareness built in the first project phase into tangible improvements in RSQ indicators adoption practices, while also addressing specific gaps identified during the workshops and hackathon.
- Promoting stronger uptake of infrastructure components, particularly those with current low visibility, by acting as a liaison between Communities and tools to address specific Community needs. By bridging this gap, WP2 will help ensure that the infrastructure components are effectively used, ultimately contributing to greater interoperability, standardisation, and reusability of research software across Communities.
- Updating the Community Engagement Scoreboard (M2.4 *Community engagement scoreboard updated*, due M24) to track progress and provide snapshots of changes in the awareness and uptake of RSQ indicators and infrastructure components use, thereby supporting targeted Community-specific interventions.
- Supporting Communities in moving from the awareness stage to adoption for both RSQ indicators and infrastructure components use. This work will focus on building capacity, offering tailored support to Communities based on their specific profiles, and ensuring inclusivity across different levels of maturity and engagement within ELIXIR.
- Organizing a joint WP2 & WP3 workshop later in 2025, that builds on the previous F2F workshop held in Padova in 2024, with hands-on activities
- Planning for M2.5: *Delivery of a Hackathon engaging additional Communities for outreach* (due M30); the event will build on the outcomes of the delivered milestones and M2.3 events, and will involve a broader range of Communities.
- Further engagement with WP3 to determine how the recommendations from WP2 can be incorporated into the knowledge model for software development plans. This step will help ensure that WP2 outputs feed directly into technical developments, ensuring their long-term integration and sustainability within the ELIXIR ecosystem.

8. Deviation from Description of Action

Not applicable

