D2.2
Workshop Report "Automation of Lab Workflows & Collaboration"

Status: DRAFT

Dissemination Level: Public

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Funded by the European Union

SCIANCE is funded by the European Union Grant Agreement Number 101293570

Abstract	
Key words	Lab automation; lab workflows; collaboration; LIMS; collaborative robots (cobots); Lights-Out operations; RFID sample tracking; interoperability; open protocols; reference architectures; cross-vendor integration; multi-criteria decision analysis (MCDA); co-creation; RAISE; SRIA

This report documents the findings and co-creation outcomes of the European SCIANCE workshop titled **"Automation of Lab Workflows & Collaboration,"** which aimed to define strategic research and innovation priorities for Europe's upcoming AI-in-Science infrastructure roadmap. Organized by DFKI, the event brought together key scientific experts who utilized a combination of initial quantitative surveys, active Miro-board brainstorming, and lightweight Multi-Criteria Decision Analysis (MCDA) to establish a portfolio of long-term priorities. The expert panel actively challenged conventional, standalone mechanical baseline assumptions, shifting focus from routine single-purpose hardware execution toward advanced European software orchestration layers and cross-vendor interoperability frameworks. A key finding from the consensus session indicates a strong prioritization of open standards, algorithm adaptation, and specialized human capital training over traditional commercial automation commodities. Ultimately, these validated community insights will be integrated into the SCIANCE co-creation track to systematically shape the broader Strategic Research and Innovation Agenda (SRIA) and implementation roadmaps for the Resource for AI Science in Europe (RAISE) initiative.

Revision History			
Version	Date	Description	Author/Reviewer
V 0.1	29/10/2026	First draft	Dr. Andrea Lösch, Jessica Otto
V0.2		First draft review	
V1.0		Submitted Version	

Document Description			
Work Package 6	AI in Science Working Groups Terms of Reference		
Document Type	Deliverable		
Document Status	Draft	Version	0.1
Dissemination Level	Public		
Copyright Status	This material by Parties of the SCIANCE Consortium is licensed under a Creative Commons Attribution 4.0 International License.		
Lead partner	DFKI		
Document Link			
DOI			
Author(s)	Dr. Andrea Lösch, Jessica Otto		
Reviewer(s)	To be added based on feedback provided		
Approved by	SCIANCE Management Committee		

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SCIANCE project

The SCIANCE project is a European coordination initiative establishing the foundations for the Resource for AI Science in Europe (RAISE). The project promotes interdisciplinary collaboration to integrate AI into scientific research by enabling streamlined access to trustworthy data repositories, computing resources, and research infrastructures across Europe. Bringing together leading research infrastructures, scientific organisations, and AI centres of excellence, SCIANCE develops a Strategic Research and Innovation Agenda (SRIA) through an iterative co-creation process.

Building on a comprehensive AI-in-science landscape analysis, the SRIA identifies long-term research challenges where AI can accelerate discovery and defines cross-domain AI research and innovation priorities, focusing on open, trustworthy, and frugal AI methods for science. A roadmap for infrastructure upgrades and cooperation mechanisms supports its implementation, translating scientific research and innovation priorities into coordinated action. To consolidate the European AI-in-science ecosystem, SCIANCE pilots the RAISE Secretariat, supported by the RAISE Digital Hub, community-building events at annual AIS Summits, and the RAISE Academy, providing a continuous framework for engagement, capacity building, knowledge sharing, and cross-domain collaborations.

By combining scientific domain expertise with AI research and infrastructure knowledge, SCIANCE delivers robust, evidence-based guidance that is scientifically credible and strategically aligned with European Commission objectives, laying the foundations for future collaborative, AI-enabled science in Europe.

Executive Summary

Context and Purpose
The workshop **"Automation of Lab Workflows & Collaboration"** was organized under the European Commission-funded SCIANCE initiative, which establishes foundations for the Resource for AI Science in Europe (RAISE). By convening leading domain experts, the workshop aimed to identify and prioritize long-term European research and innovation tracks. The ultimate objective is to address critical bottlenecks across Europe's research landscape - including data fragmentation, technician shortages, and proprietary vendor lock-in—and integrate these community-validated priorities into the upcoming AI-in-Science Strategic Research and Innovation Agenda (SRIA).

Methodological Workflow
Managed by DFKI experts, the session utilized a bottom-up co-creation workflow combining qualitative brainstorming with quantitative verification across four connected blocks:

1. **Evidence-Based Preparation:** Desk research pre-mapped eight primary laboratory automation pillars to establish a common evidence baseline.
2. **Expert Validation and Extension:** On-site experts evaluated these baseline options on a 5-star Likert scale via an initial online survey.
3. **Interactive Discussion:** Using a digital Miro board, participants proposed new strategic concepts, debated unconventional ideas, and mapped dependencies to transform a technology checklist into complex research targets.
4. **Multi-Criteria Decision Analysis (MCDA):** Top priorities were formally scored via a Formbricks survey based on Scientific Impact (double weight), Economic Impact (double weight), and European Feasibility (single weight).

Key Findings and Definitive Trends
The consensus data revealed a systematic shift away from isolated physical devices toward unified software intelligence and open European architectural layers:

- **Systemic Interoperability Over Commercial Software:** "European support of common open protocols, reference architectures, testbeds and interoperability benchmarks" ranked as the absolute **#1 priority** (Weighted Score: **4.49**). Experts rejected funding proprietary black-box programs, dropping standalone cloud-based LIMS software to **#27**.
- **Algorithmic Adaptability Dominates Mechanical Speed:** Dynamic, self-correcting frameworks like "AI-assisted closed-loop experimentation, AutoML and continual adaptation" claimed **#2** status (**4.14**), outperforming routine "Lights-Out" hardware execution tracks (**#24**).
- **Human Capital as a Core Bottleneck:** Absent from the initial desk baseline, the expert-contributed priority "Training of staff for hybrid labs" claimed the **#3** position, showing that advanced automated facilities are useless without a workforce trained at the intersection of data engineering and physical science.
- **De-prioritisation of Mature Mechanical Commodities:** Traditional mechanical tools, including precision liquid handling systems (**#30**) and RFID asset tracking (**#38**), finished near the bottom. Experts classified routine hardware execution as a commercial commodity that does not warrant future European research funding.

The Top 15 Strategic Priorities Architecture
The final portfolio groups the workshop outputs into 15 distinct innovation vectors across four tiers:

- **Tier I: Core Infrastructure, Open Standards & Harmonisation (Items 1–4):** Targets common open protocols, cross-platform semantic data models, infrastructure AI-readiness grading, and cross-cloud federated computing layers.
- **Tier II: Autonomous Experimentation & Algorithmic Orchestration (Items 5–8):** Focuses on adaptive closed-loop AutoML, near-instrument edge AI, end-to-end twin simulation engines, and machine-actionable knowledge graphs.
- **Tier III: Socio-Technical Capabilities & Human-Centric Governance (Items 9–12):** Prioritizes specialized hybrid lab curriculums, human-in-the-loop explainability dashboards, background metadata telemetry logs, and literature-trained virtual copilots.
- **Tier IV: Defensive Engineering, Trust & Physical Infrastructure (Items 13–15):** Concentrates on deep cybersecurity access permissions, multi-modal computer vision safety streams, and scalable Robotics-as-a-Service (RaaS) procurement models.

Immediate Next Steps
The report will be published via the RAISE Forum for public review. The feedback will be used to inform and develop the final expert survey for identifying the strategic research and innovation priorities across all SCIANCE areas.

1 Introduction

1.1 Focus of the workshop

The workshop **"Automation of Lab Workflows & Collaboration"** focused on identifying and ranking key AI research and innovation priorities to overcome physical bottlenecks in modern laboratory execution.

Organized under the SCIANCE co-creation process for developing the Strategic Research and Innovation Agenda (SRIA), the event addressed critical challenges like research technician shortages, safety mandates, and data fragmentation across Europe. Participants explored the strategic convergence of agentic AI, robotics, cloud computing, and laboratory informatics.

Key technological areas highlighted included, among others, AI-powered cloud-based Laboratory Information Management Systems (LIMS), collaborative robots (cobots) for overnight "lights-out" operations, and RFID-based sample tracking for automated audit trails. Special emphasis was placed on cross-vendor interoperability to avoid closed vendor lock-ins and connect isolated automation islands.

Through interactive discussions and a multi-criteria decision analysis managed by DFKI moderators, the session evaluated research priorities based on their scientific impact, economic benefit, and feasibility. Ultimately, the workshop aimed to consolidate these community-validated priorities into a formal report to help shape Europe's shared, interoperable AI-in-Science infrastructure roadmap.

1.2 Workshop methodology

The SCIANCE WP2 workshops follow a **bottom-up, expert-driven co-creation approach** to identify and prioritise strategic AI research and innovation (R&I) needs across selected scientific domains and cross-cutting areas. The methodology combines **evidence-based preparation, structured expert elicitation, interactive discussion, and multi-criteria prioritisation**. Its purpose is not simply to identify existing AI solutions, but to determine where future research and innovation efforts could have the greatest potential to advance AI-enabled science at European level. Overall, the methodology consists of the following blocks:

1. **Evidence-based preparation of the workshops and initial mapping:** Prior to the workshops, SCIANCE consolidated relevant evidence from state-of-the-art reviews, landscape analyses and good practices. Based on this evidence, a preliminary collection of relevant AI research and innovations — including tools, applications, models — was prepared for each workshop topic. This provided a common evidence base while keeping the process open to contributions from the participating experts. In the corresponding preparatory session preceeding the actual workshop, experts were asked to prepare individually by identifying the **five AI research and innovations they consider most important** for the respective topic and to assess their perceived relevance. They were explicitly encouraged to identify emerging developments and "outliers" that may not yet be mainstream.
2. **Expert validation and extension:** The workshop started with a plenary review of the evidence and the preliminary collection of AI research and innovations. Participants then were asked to assess the relevance of the identified items using a five-point relevance scale. The assessment took place in form of an initial online survey that was analyzed on the spot. Most importantly, the initial list provided to participants was deliberately kept open: experts could also add missing research and innovations. This allowed the methodology to combine a structured starting point with bottom-up expert input used to extend the original findings while at the same time reducing the risk of the initial evidence base determining the outcome in advance. The result was a **complete, expert-validated collection of relevant AI research and innovations**, accompanied by an initial assessment of their perceived relevance.
3. **Interactive co-creation and consolidation of priorities:** The initial collection then formed the basis for an interactive plenary discussion. Experts jointly examined the identified items, clustered them thematically along related topics, refined them, addressed open questions and differences in interpretation or relevance, and discussed particularly novel or unconventional ideas in greater depth. The explicit inclusion of such "outliers" or "crazy ideas" was intended to ensure that the process does not merely reproduce established technologies and research directions, but also captures potentially important future developments. Through this discussion, the broad collection was consolidated into a **final set of thematic AI research & innovation priorities** for the respective scientific or cross-cutting area.
4. **Multi-criteria prioritisation and consensus:** The final set of priorities were subsequently ranked by experts using a **lightweight multi-criteria decision analysis (MCDA)** in the form of an online survey based on Formbricks. Specifically, three criteria were applied:
    - **Scientific impact** – the extent to which addressing the R&I need could unlock or significantly accelerate AI-enabled research.

- **Economic impact** – the potential effect on the economic performance of European companies and organisations, including productivity, cost reduction, value creation, competitiveness and revenues.
- **Feasibility/accountability** – the extent to which there is both a realistic pathway and a need to address the R&I need at European scale, for example through research, policy, infrastructure or coordination.

In the analysis, scientific impact and economic impact received **double weighting**, while feasibility/accountability receives a **single weighting**. The weighting is therefore designed to balance scientific significance and potential economic relevance with the practical question of whether there is a credible rationale and pathway for European-level action. The outcome of this consensus session was a **jointly validated and ranked portfolio of 42 AI research and innovation priorities**.

1.3 Workshop attendance

Overall, seven experts attended the workshop on-site:

- Dr. Hartmut Schlenz - Forschungszentrum Juelich GmbH, Institute of Energy Materials and Devices (IMD), Materials Synthesis and processing (IMD-2)
- Dr. phil. nat. Sebastian Lobentanzer – Computational Health Center, Helmholtz Munich
- Dr. Pablo Lopez-Tarifa - Netherlands eScience Center
- Prof. Victorita Dolean - Eindhoven University of Technology
- Dr. Georgia Gkioka - Institute of Communication and Computer Systems (ICCS), National Technical University of Athens (NTUA)
- Prof. Marco Aldinucci - Università di Torino
- Prof. Ricardo da Silva Torres – Wageningen University & Research

1.4 Data analysis

In the context of the **initial survey**, we used a structured 5-star Likert relevance scale, where 5 denoted "Extremely Relevant" and 1 denoted "Extremely Irrelevant". The objective of this initial quantitative tracking was to validate whether the key topics from the desk research reflect the perspective of experts and researchers, identify potentially irrelevant items (relevance rating 2 or below) and give experts a chance to add additional relevant items before initiating open co-creation tracks in the interactive discussion round.

For the analysis of the final **Miro board**, we first extracted every individual text element (sticky notes) and analyzed the text cards using semantic proximity mapping (affinity grouping) looking at underlying systemic requirements, shared operational goals, dependencies etc. For instance, cards addressing "data governance", "access control", "secure sharing", and "automated audit trails" were mapped together because they all represent systemic requirements for building trust in multi-site digital collaborations. Once items were sorted into loose groups, we synthesized these groups into corresponding thematic clusters, capturing the strategic innovation and research priorities established during the live session. Finally, we verified the clusters by cross-referencing them with the formal results of the multi-criteria decision analysis survey.

In the final **multi-criteria decision analysis survey**, experts ranked all research and innovation priorities identified previously in terms of three criteria (scientific impact – rated double, economic impact – ranted double, feasibility/accountability – rated single) based on a 5-point Likert scale.

2 Workshop contents

2.1 Workshop agenda

Figure 1 below provides the details of the workshop agenda and sequence of the different sessions:

13:00 – 14:00	***Lunch***
14:00 - 14:15	**Welcome & introduction** by SCIANCE
14:15 – 15:00	**Review of relevant AI research and innovations** (i.e. tools, applications, models, infrastructures) (plenary session)
15:00 – 15:15	**Initial survey** for checking relevance and enabling extension (plenary session)
15:15 – 15:45	***Coffee Break***
15:45 – 16:30	**Interactive discussion**: Identification of AI research & innovation priorities for enabling and/or improving lab automation & collaboration
16:30 – 17:00	**Consensus session**: Ranked list of thematic AI for Science research priority areas for lab automation & collaboration
17:00 – 17:30	**Summary and closing statements** by SCIANCE

Figure 1 - Agenda for the Workshop "Automation of Lab Workflows & Collaboration"

2.2 Welcome & introduction

The workshop opened with a welcome and introduction by Dr. Andrea Lösch representing the SCIANCE team. This initial session set the stage by introducing DFKI's workshop team, outlining the day's agenda, and explaining the SCIANCE co-creation process used to develop the Strategic Research and Innovation Agenda (SRIA). All workshop slides are provided below.

SCIANCE

DFKI's Workshop Team



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Senior Researcher
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SCIANCE Team Lead



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Senior Researcher
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SCIANCE

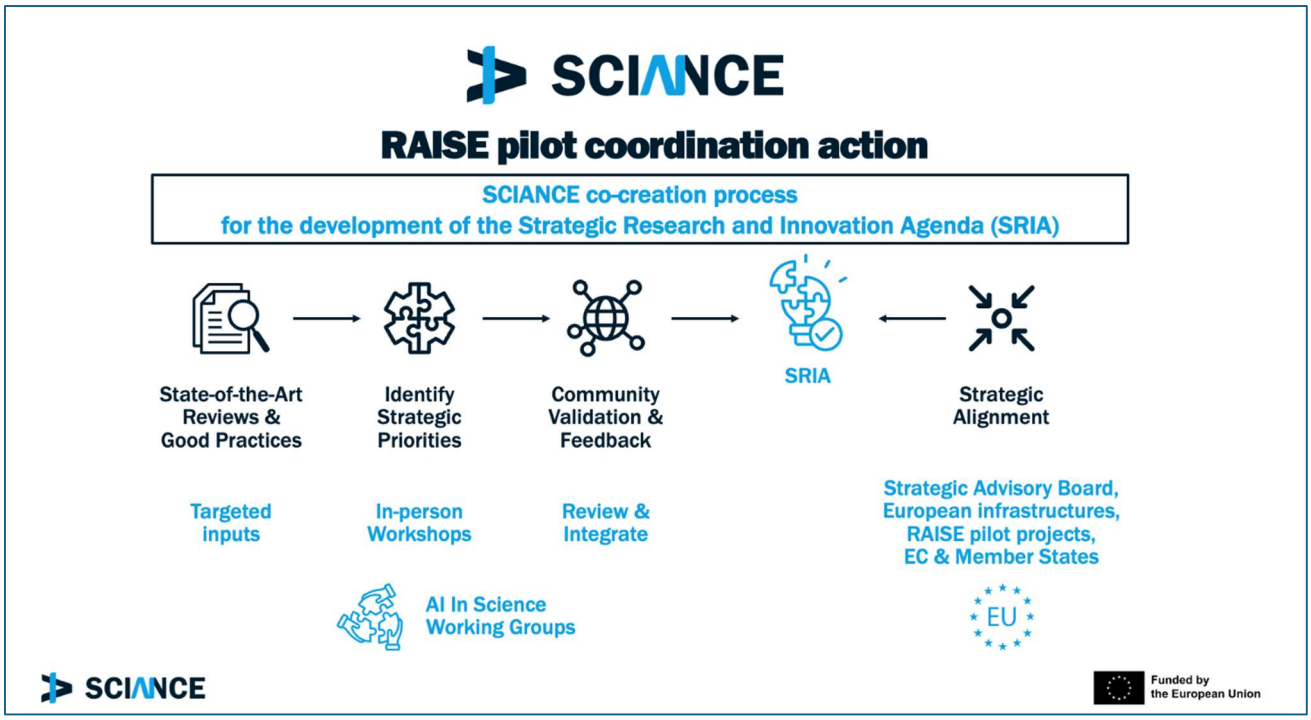
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RAISE – Resource for AI in Science in Europe



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2.3 Review of relevant AI research & innovations

Dr. Tilman Becker led a comprehensive review explaining why laboratory automation has become highly strategic due to physical bottlenecks, technician shortages, and changing methodologies. The presentation highlighted the convergence of agentic AI, robotics, cloud computing, and advanced laboratory informatics as key drivers for modern research. Particular emphasis was placed on the emerging role of AI-powered Laboratory Information Management Systems (LIMS) for seamless orchestration, alongside smart instruments that enable bidirectional automated data communication. Furthermore, the review covered precision liquid handling, collaborative robots (cobots), and "lights-out" unattended overnight lab operations. Finally, the session addressed critical integration challenges, such as overcoming heterogeneous legacy systems and vendor lock-in, while emphasizing the European strategic need for shared, interoperable automation infrastructures. All workshop slides are provided below.

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Why lab automation is becoming strategic

- Laboratory execution remains a physical bottleneck: sample handling, pipetting, instrument runs, measurement and coordination of people and protocols.
- Research technician shortages and safety requirements increase the need for automation.
- Large capital investments in single-purpose instruments can become bottlenecks as methods evolve.
- The review therefore emphasizes integration and flexibility — not simply higher performance of individual devices.
- European Testing and Experimentation Facilities (TEFs) can support access to shared automation and validation infrastructure.



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1. Convergence of AI, robotics and laboratory informatics

AI & agentic layer

- Agentic AI, robotics, cloud computing and advanced informatics are converging.
- AI/ML supports analysis, pattern recognition and predictive scheduling.
- AI-powered LIMS are emerging as orchestration and information layers.
- AI can connect planning, execution, monitoring and analysis.

Connectivity layer

- Cloud-based LIMS reduce local data silos.
- Smart instruments enable bidirectional automated data communication.
- Cross-vendor integration is a major demand.
- RFID-based sample tracking can create automatic provenance and audit trails.

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2. Robotics, cobots and "lights-out" operation

- Precision liquid handling remains a core automation capability for high-throughput laboratories.
- Collaborative robots increasingly work alongside human technicians for sample handling, liquid handling and quality control.
- Labs are moving toward unattended or end-to-end operation for higher throughput and more consistent repeatability.
- AI-powered instrumentation adds real-time sensing and pre-analytical quality control.
- Integrated imaging and AI analysis can bring characterisation and quality assessment directly into the overall lab workflow.



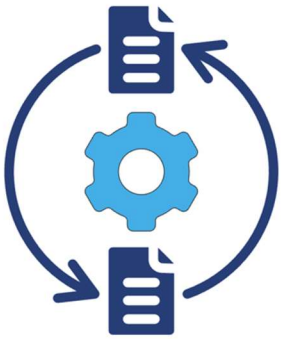
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3. Collaboration is more than data sharing

- Modern research increasingly depends on distributed teams, shared sample/reagent libraries and multi-site workflows.
- Connected laboratory information management systems (LIMS) can allow collaborators, instruments and protocols to share data in real time.
- Cross-vendor interoperability is essential to avoid closed ecosystems and enable flexible research workflows.
- Physical sample tracking, digital provenance and instrument connectivity link the digital and physical layers of collaboration.
- Robotics-as-a-Service and modular integration packages are emerging as alternatives to large, inflexible capital investments.



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4. Lab automation: key research & innovation challenges

Technology / infrastructure

- Heterogeneous legacy instruments and vendor-specific software make integration difficult.
- Interoperability without expensive middleware or vendor lock-in remains unresolved.
- Automation requires specialist expertise that is itself scarce.
- Secure, standardised data management is essential for connected labs.

Trust / access

- Cloud-based collaboration raises data governance and security questions.
- Semi-autonomous and lights-out operation requires robust validation and anomaly detection.
- False alarms can erode trust; missed anomalies can create safety and scientific risks.
- High capital costs risk widening the gap between well-funded and smaller laboratories.

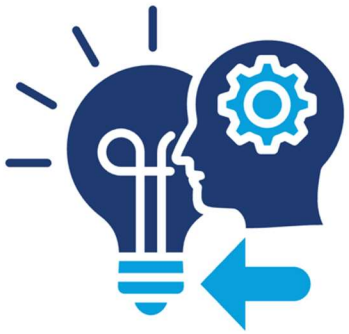
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5. European strategic relevance: shared, interoperable automation

- In the review provided by our colleagues from SZTAKI, AI-powered automated laboratory systems and pilot networks of laboratories are described as explicit European funding priorities.
- The strategic rationale is not only productivity: automation can increase reproducibility and create shared standards and benchmarks.
- Europe's fragmented research landscape makes collaboration and interoperability particularly important.
- Shared infrastructures, TEFs and flexible procurement/deployment models can broaden access to advanced automation.
- Strategic question: how can Europe build an interoperable 'intelligence layer' across existing laboratories rather than creating isolated automation islands?



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Our initial AI research and innovations at a glance

- AI-powered cloud-based laboratory information management systems (LIMS)
- AI/ML for data analysis, pattern recognition, and predictive scheduling
- Smart instrument connectivity for bidirectional, automated data communication
- Precision liquid handling systems (automated pipetting, dispensing)
- Collaborative robots (cobots)
- "Lights-Out" or End-to-End (E2E) operation – Labs running unattended overnight using robots/cobots
- RFID-based sample tracking (including retrofit kits for existing freezers) to enable automatic audit trails & easier compliance
- Robotics-as-a-Service and modular integration packages – flexible, scalable models instead of big capital purchases



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2.4 Initial survey

Following the review, Jessica Otto introduced an online survey designed to extend and validate the initial research findings. Participants were asked to provide direct feedback by rating the relevance of identified technologies across categories like agentic systems, connectivity, and liquid handling. This interactive step ensured that community insights and potential "outlier" innovations were captured to build a complete baseline list. The corresponding workshop slides are provided below.

SCIANCE

Initial survey for extending and validating our findings

Review of relevant AI research and innovations

- Major findings so far and relevant AI research and innovations we have identified so far

Initial survey – your feedback matters now!

- Goal: Extending and validating AI research and innovations we have identified so far
- Tool: Online survey that names all relevant AI research and innovations identified for automation of lab workflows and collaboration
- Survey conduct:
  - Please rate the relevance (5 stars) of each AI research & innovation identified (5* highest relevance)
  - Please add any new AI research and innovations (including "outliers") they feel fit and also indicate perceived relevance
- Result: Complete list of relevant AI research and innovations for automation of lab workflows and collaboration with an indication of their perceived relevance



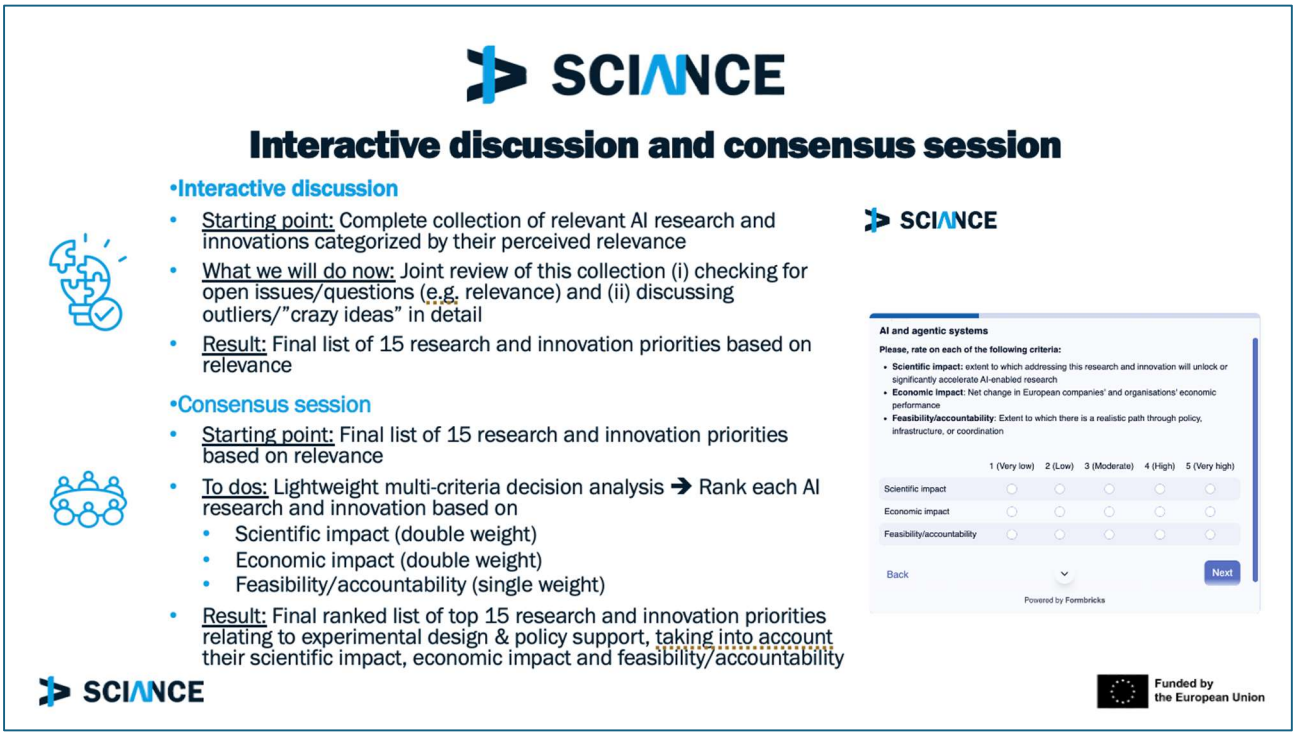
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SCIANCE
Initial survey for extending and validating our findings
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2.5 Interactive discussion

Moderated by Dr. André Meyer-Vitali, the interactive discussion transitioned the workshop from a broad overview to a focused evaluation of priorities. Utilizing a Miro board managed by Jessica Otto and moderated by Dr. Andrea Lösch, participants jointly reviewed the compiled collection of innovations, analyzed and refined them, and discussed "crazy ideas" in detail. This collaborative session successfully extended the initial findings into a complete set of relevant research and innovation priorities. The corresponding workshop slides are provided below.



2.6 Consensus session

In the final consensus session, the top priorities were formally ranked using a lightweight multi-criteria decision analysis managed by Jessica Otto. Participants evaluated each research area through a structured Formbricks survey based on its scientific impact, economic impact, and feasibility at a European scale. The process resulted in a definitive, ranked list of strategic AI for Science priorities to feed directly into the upcoming SRIA and implementation roadmap. The relevant workshop slides are provided below.

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Criteria definition & final survey

1. Scientific impact:
   - Definition: Extent to which addressing this research and innovation will unlock or significantly accelerate AI-enabled research
   - Scores: 1=very low, 2=low, 3=moderate, 4=high, 5=very high
2. Economic impact:
   - Definition: The net change in European companies' and organisations economic performance – measured through productivity gains, cost reductions, value creation, and increases in competitiveness and revenues – resulting from this particular research and innovation
   - Scores: 1=very low, 2=low, 3=moderate, 4=high, 5=very high
3. Feasibility/accountability
   - Definition: Extent to which there is a realistic path and a need – through policy, infrastructure, or coordination – to address this particular research and innovation at European scale (e.g. there is no funding need if corresponding technologies/solutions do already exist)
   - Scores: 1=very low, 2=low, 3=moderate, 4=high, 5=very high

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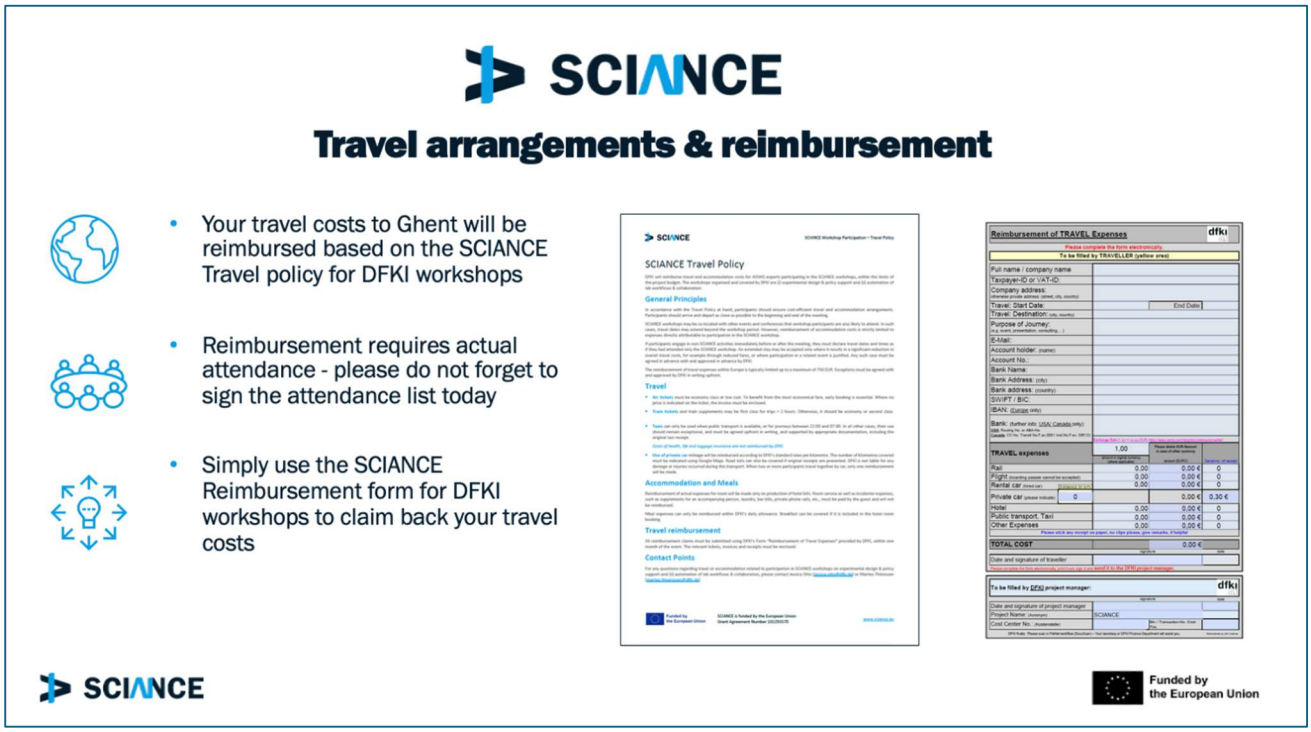
Final survey for ranking research and innovations

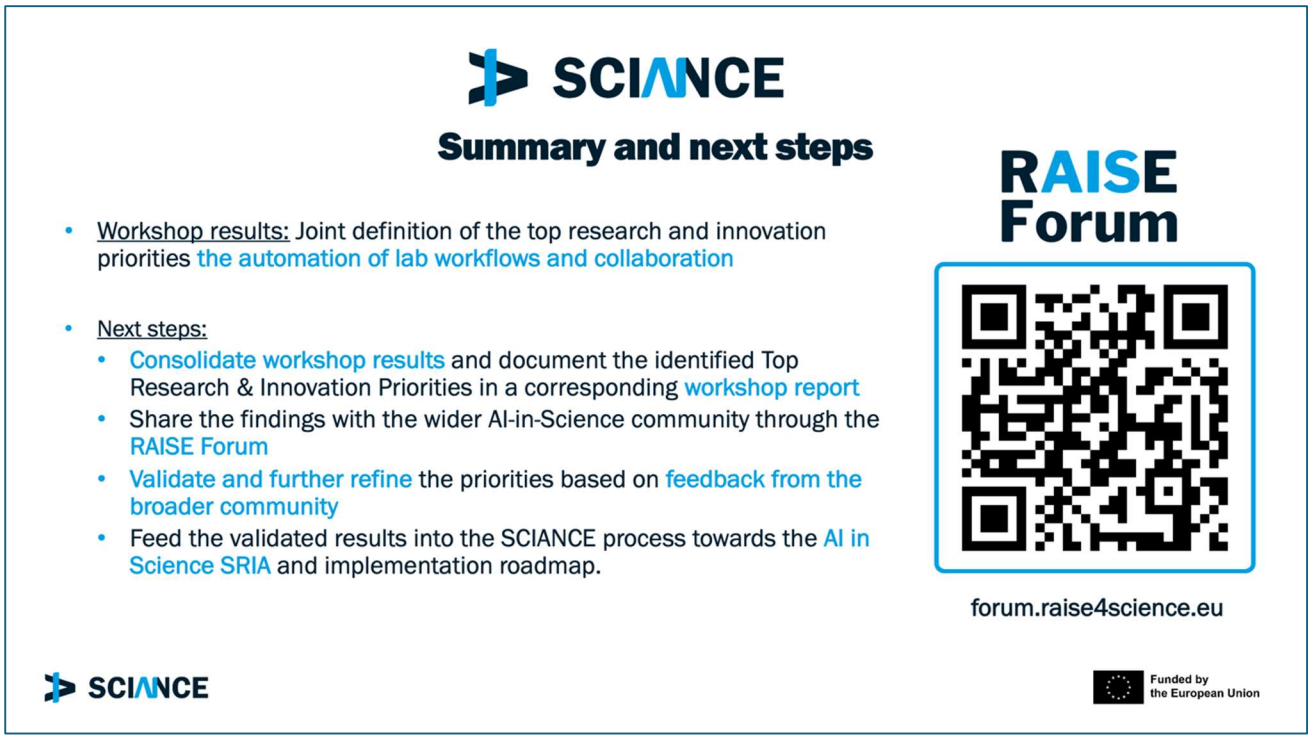
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2.7 Summary & closing statements

The workshop concluded with a final session led by Dr. Andrea Lösch to consolidate the day's findings and outline the immediate next steps. The team detailed plans to document the top 15 identified research and innovation priorities in an official workshop report and share them with the wider community via the RAISE Forum. Ultimately, these validated community insights will be integrated into the broader SCIANCE co-creation process to shape the upcoming AI in Science Strategic Research and Innovation Agenda (SRIA) and implementation roadmap.



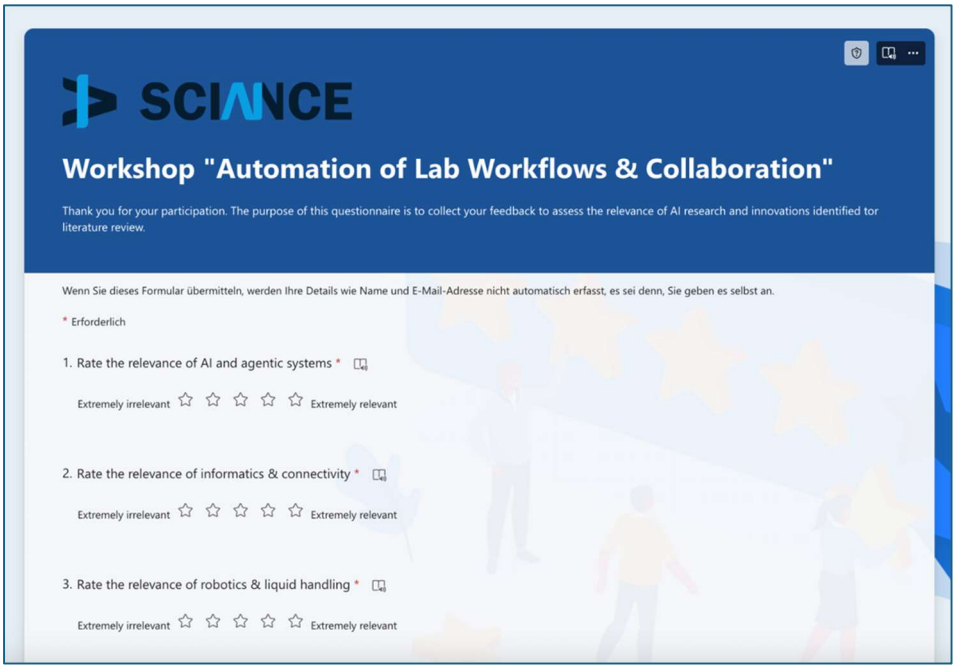


3 Workshop results

3.1 Initial Survey

Figure 1 below provides a screenshot of the initial survey.

Figure 1 – Initial survey extract



As indicated earlier (see 1.2 Workshop methodology) the first part of the expert workshop focused on establishing an analytical baseline by assessing and extending a preliminary collection of artificial intelligence and laboratory automation technologies. Experts were asked to evaluate eight pre-mapped research and innovation priorities that had derived from desk research. For this initial evaluation, experts used a structured 5-star Likert relevance scale, where 5 denoted "Extremely Relevant" and 1 denoted "Extremely Irrelevant". The objective of this initial quantitative tracking was to identify potentially irrelevant items (relevance rating 2 or below) and give experts a chance to add additional relevant items before initiating open co-creation tracks in the interactive discussion round. Table 1 below illustrates the results of the initial survey.

Table 2 - Ranked Results from the initial survey

Rank	Topic & Score
1	AI/ML for data analysis, pattern recognition, and predictive scheduling 4.86 Durchschnittliche Bewertung Ebene 5 6 Ebene 4 1 Ebene 3 Ebene 2 Ebene 1

2 AI-powered cloud-based laboratory information management systems (LIMS)



3 smart instrument connectivity for bidirectional, automated data communication



4 Robotics-as-a-Service and modular integration packages - flexible, scalable models instead of big capital purchases



5 "Lights-Out" or End-to-End (E2E) operation - Labs running unattended overnight using robots/cobots



6 collaborative robots (cobots)



6	RFID-based sample tracking (including retrofit kits for existing freezers) to enable automatic audit trails & easier compliance



8	precision liquid handling systems (automated pipetting, dispensing)



As shown in Table 1 above, while there were no items that had to be removed because of low relevance (2 or below), four core tiers seemed to emerge with regard to the initial research and innovations items proposed, namely:

- **Tier 1: High-Performance Data Orchestration (Rank 1):** The priority **"AI/ML for data analysis, pattern recognition, and predictive scheduling"** stood out as the absolute focal point of the baseline survey, achieving an exceptional average score of **4.86** out of 5.00. A granular review of the vote distribution shows that 6 out of 7 experts classified this domain at the maximum relevance tier (Ebene 5), with the single remaining vote falling at Ebene 4. This strong consensus indicates that Europe's leading scientific minds view analytical intelligence and predictive workflow optimization as foundational components of advanced laboratory operations, rather than secondary software enhancements.
- **Tier 2: Enterprise Middleware and Connectivity (Ranks 2–3):** Enterprise software architectures and data-sharing layers formed the secondary priority tier. **"AI-powered cloud-based laboratory information management systems (LIMS)"** secured the second position with an average score of **4.14**, fueled by 3 max-relevance votes, 2 high-relevance votes, and 2 moderate votes. Directly following this, **"smart instrument connectivity for bidirectional, automated data communication"** averaged **4.00**, balancing evenly with 3 max-relevance votes, 3 high-relevance votes, and a single lower outlier at Ebene 1. These findings show that experts prioritize breaking down local data silos and establishing reliable communication middleware as crucial steps before scaling advanced physical robotics.
- **Tier 3: Modular Deployment Models (Ranks 4–5):** Financial flexibility and unattended automation concepts sat in the middle of the spectrum. **"Robotics-as-a-Service (RaaS) and modular integration packages"** scored an average of **3.71**, reflecting a growing interest in scalable service procurement over inflexible capital investments. Similarly, end-to-end **"Lights-Out" unattended overnight lab operations** reached an average of **3.57**. While

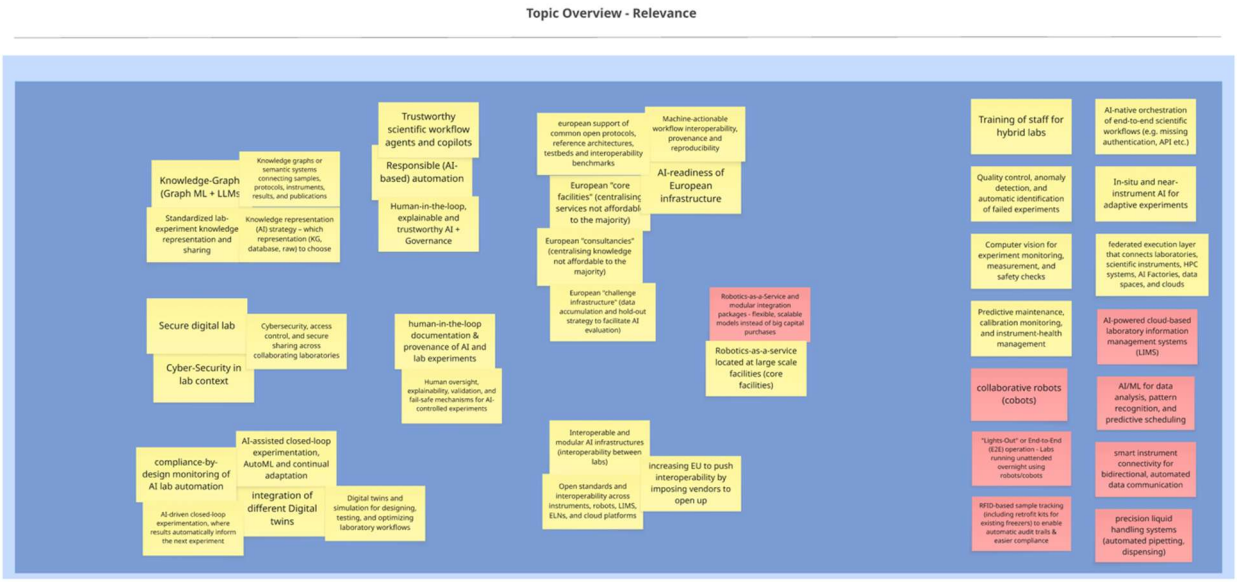
recognized for their potential to scale up throughout, these applications were viewed by experts as complex milestones requiring sophisticated pre-analytical verification frameworks to implement safely.

- **Tier 4: Single-Purpose Hardware Execution (Ranks 6–8):** Traditional mechanical automation tools scored the lowest in initial relevance. Both **"collaborative robots (cobots)"** and **"RFID-based sample tracking"** tied at an average score of **3.43**, each receiving heavily fragmented vote spreads. **"Precision liquid handling systems"** sat at the bottom of the baseline survey, averaging a modest **3.00**. The expert commentary noted that standard mechanical liquid handling, automated pipetting, and dispensing solutions are already mature commercial commodities. Consequently, they do not require new European research funding unless integrated with real-time AI perception or active closed-loop feedback mechanisms.

3.2 Interactive discussion

As explained earlier (see 1.2 Workshop methodology), the interactive discussion was designed to expand the scope of the preliminary findings by allowing the seven experts to propose new concepts, identify structural challenges, and debate unconventional ideas that were all collected, tracked and jointly evaluated using a digital Miro board. Figure 2 below provides the outcomes of the interactive discussion with the yellow sticky notes representing the new items brought forward by the experts and the red sticky notes representing the initial research and innovations presented above (see 3.1 Initial survey).

Figure 2 – Miro board results of the interactive discussion



As becomes apparent from Figure 2, this interactive review process successfully transformed the initial technology checklist into a structured framework of complex research challenges. There is a clear structural divergence between the workshop's pre-mapped baseline technologies (represented by red/pink sticky notes) and the new strategic demands introduced by the expert panel (represented by yellow sticky notes). Rather than adopting the pre-mapped baseline as an immutable framework, the on-site experts utilized the yellow notes to actively challenge, recontextualize, and subordinate the initial technological assumptions, shifting the workshop's focus from localized hardware execution to large-scale infrastructure orchestration.

The physical clustering of the notes on the board revealed a systematic subordination of routine automated hardware tasks under comprehensive semantic and governance layers. Mechanical baseline elements, such as red notes for *precision liquid handling* and *collaborative robots (cobots)*, were moved to the periphery of the board or grouped directly beneath new yellow notes detailing *"AI-assisted closed-loop experimentation"* and *"AI-native orchestration of end-to-end scientific workflows"*. The panel explicitly noted that standalone hardware devices are mature commercial commodities that do not require strategic European research funding unless they are natively integrated with real-time AI perception or adaptive closed-loop feedback loops.

The yellow notes also introduced critical socio-technical, political, and infrastructural considerations that were entirely missing from the initial literature baseline. Experts used yellow notes to target vendor monopolies, demanding that the European Union actively *"impose vendors to open up"* to ensure that baseline *AI-powered LIMS platforms* (red note) do not lead to proprietary vendor lock-in. Furthermore, entirely new domains were established via yellow cards focusing on the human and defensive foundations of automated science, including specialized *"Training of staff for*

hybrid labs," "Cyber-Security in lab contexts," and creating localized "*Knowledge-Graphs*" to guarantee structural data provenance. This dual-color mapping successfully evolved a generic technology checklist into a highly defensive, open-source infrastructure roadmap for European science.

3.3 Consensus session (MCDA)

Figure 3 below provides a part of the survey used for a multi-criteria decision analysis to conclude the final ranking of the research and innovation priorities.

Figure 3 – Extract from final survey used for multi-criteria decision analysis

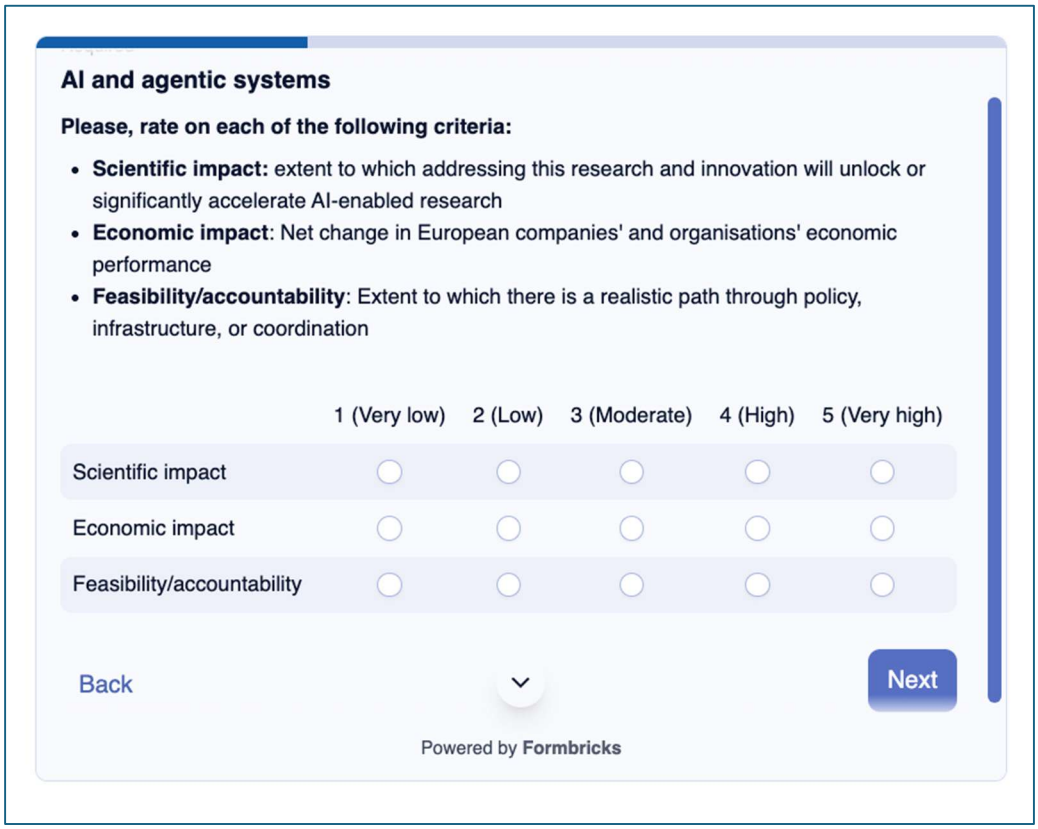


Table 2 below summarizes the outcomes of the final survey that was conducted as part of the consensus session, focussing on the final ranking of the research and innovation priorities identified in the context of the preceding interactive discussion.

Table 3 - Ranked results from the multi-criteria analysis survey

Rank	Topic	Responses (n)	Avg Scientific	Avg Economic	Avg Feasibility	Weighted score
1	European support of common open protocols, reference architectures, testbeds and interoperability benchmarks	7	4.71	4.57	3.86	4.49
2	AI-assisted closed-loop experimentation, AutoML and continual adaptation	7	4.71	4.00	3.29	4.14
3	Training of staff for hybrid labs	7	4.14	4.14	4.00	4.11

4	AI/ML for data analysis, pattern recognition, and predictive scheduling	7	4.00	4.14	4.14	4.09
4	Open standards and interoperability across instruments, robots, LIMS, ELNs, and cloud platforms	7	4.43	4.14	3.29	4.09
6	AI-readiness of European infrastructure	7	4.43	4.00	3.43	4.06
7	In-situ and near-instrument AI for adaptive experiments	7	4.00	4.14	3.43	3.94
8	AI-driven closed-loop experimentation, where results automatically inform the next experiment	7	4.29	4.00	3.00	3.91
8	Federated execution layer that connects laboratories, scientific instruments, HPC systems, AI Factories, data spaces, and clouds	7	4.29	4.00	3.00	3.91
10	AI-native orchestration of end-to-end scientific workflows (e.g. missing authentication, API etc.)	7	4.29	3.86	3.14	3.89
11	Standardized lab-experiment knowledge representation and sharing	7	4.00	3.86	3.43	3.83
11	Cybersecurity, access control, and secure sharing across collaborating laboratories	7	3.57	4.14	3.71	3.83
11	Machine-actionable workflow interoperability, provenance and reproducibility	7	3.71	3.86	4.00	3.83
14	Robotics-as-a-service located at large scale facilities (core facilities)	7	3.86	3.86	3.57	3.80
14	European "core facilities" (centralising services not affordable to the majority)	7	4.00	3.57	3.86	3.80
14	European "consultancies" (centralising knowledge not affordable to the majority)	6	3.83	3.83	3.67	3.80
17	Increasing EU to push interoperability by imposing vendors to open up	7	3.86	4.14	2.86	3.77
17	Human oversight, explainability, validation, and fail-safe mechanisms for AI-controlled experiments	7	4.14	3.57	3.43	3.77
17	Trustworthy scientific workflow agents and copilots	7	4.00	3.71	3.43	3.77

20	Human-in-the-loop documentation & provenance of AI and lab experiments	7	4.29	3.29	3.57	3.74
21	Interoperable and modular AI infrastructures (interoperability between labs)	7	4.14	3.86	2.57	3.71
22	Robotics-as-a-Service and modular integration packages - flexible, scalable models instead of big capital purchases	7	3.57	4.00	3.29	3.69
22	Quality control, anomaly detection, and automatic identification of failed experiments	7	3.86	3.71	3.29	3.69
24	"Lights-Out" or End-to-End (E2E) operation - Labs running unattended overnight using robots/cobots	7	4.00	3.86	2.57	3.66
24	Digital twins and simulation for designing, testing, and optimizing laboratory workflows	7	3.86	3.86	2.86	3.66
26	Collaborative robots (cobots)	7	3.71	3.86	3.00	3.63
27	AI-powered cloud-based laboratory information management systems (LIMS)	7	3.86	3.14	4.00	3.60
27	Computer vision for experiment monitoring, measurement, and safety checks	7	3.57	3.71	3.43	3.60
29	Human-in-the-loop, explainable and trustworthy AI + Governance	7	3.86	3.29	3.57	3.57
30	Precision liquid handling systems (automated pipetting, dispensing)	7	3.43	3.71	3.43	3.54
30	Responsible (AI-based) automation	7	3.71	3.43	3.43	3.54
30	Predictive maintenance, calibration monitoring, and instrument-health management	7	3.57	3.57	3.43	3.54
33	Smart instrument connectivity for bidirectional, automated data communication	7	3.86	3.29	3.14	3.49
33	Secure digital lab	7	3.00	4.00	3.43	3.49
33	Integration of different Digital twins	7	3.86	3.43	2.86	3.49

36	European "challenge infrastructure" (data accumulation and hold-out strategy to facilitate AI evaluation)	6	4.17	2.83	3.00	3.40
37	Knowledge graphs or semantic systems connecting samples, protocols, instruments, results, and publications	7	3.43	3.14	3.71	3.37
38	RFID-based sample tracking (including retrofit kits for existing freezers) to enable automatic audit trails & easier compliance	7	3.14	3.14	4.14	3.34

As becomes apparent from Table 2 above, the mathematical results of the consensus session confirm a greater importance of the dynamically introduced expert concepts over the initial literature baseline: **top-ranked spots were captured exclusively by new, bottom-up expert priorities (originally yellow sticky notes), while the literature baseline's mechanical tasks (originally red sticky notes) dropped to the bottom of the portfolio.** In addition to this general pattern, several other important patterns emerged from the survey results:

- **The priority on systemic interoperability rather than on standalone software:** The expert panel's insistence on decoupling European science from closed proprietary systems could be validated by the top ranking (Rank 1!) of **"European support of common open protocols, reference architectures, testbeds and interoperability benchmarks"** (Weighted Score: 4.49). This priority (which originated entirely from a live yellow sticky note) outperformed the literature review's standalone baseline item for "AI-powered cloud-based LIMS" (only Rank 27 overall with a weighted score of 3.60). As such, it appears that experts reject spending public funds on commercial software layers unless the EU first enforces open reference architectures to break vendor monopolies.
- **Active Algorithm Adaptation outranking Standalone Automation Frameworks:** The yellow expert note for **"AI-assisted closed-loop experimentation, AutoML and continual adaptation"** claimed Rank 2 with an overall score of 4.14 and a maximum Scientific Impact rating of 4.71. In contrast, the original red baseline item for end-to-end "Lights-Out" overnight lab operations dropped to Rank 24 overall (3.66 weighted score). This ranking divergence illustrates that experts may view local mechanical runtime routines only as secondary implementation targets. The strategic funding priority must instead focus on the algorithmic "intelligence layer" that allows instruments to actively learn from data and autonomously modify their own experimental parameters in real time.
- **Human Capital as a Systemic Bottleneck:** Natively absent from the original literature baseline, the yellow note highlighting **"Training of staff for hybrid labs"** successfully ranked 3rd in the final portfolio with a weighted score of 4.11. Backed by a high feasibility rating of 4.00, this selection highlights that sophisticated software pipelines and robotics networks are useless without a specialized workforce trained at the intersection of data engineering and physical science.
- **The De-prioritisation of Mature Mechanical Commodities:** The final survey results also show a thorough de-prioritisation of the original red mechanical items, now occupying very low ranks, namely "Collaborative robots (cobots)" (Rank 26, Weighted Score: 3.63), "Precision liquid handling systems" (Rank 30, Weighted Score: 3.54), and "RFID-based sample tracking" (Rank 38, Weighted Score: 3.34). While these baseline items scored high marks for technical Feasibility (>3.43), their low weighted scores reflect their relatively low Scientific Impact ratings (~3.14). As such, standard hardware automation appears to be a commercial commodity, with the need for future funding tracks to strictly target the cross-platform open standards and adaptive artificial intelligence systems that connect them (see above).

4 Conclusions and recommendations

Based on the above results (3 Workshop results), for the automation of lab workflows and collaboration, the following top 15 research and innovation priorities can be defined and grouped in four tiers:

Tier 1: Core Infrastructure, Open Standards & Harmonisation (Number 1-4)	**1: European Common Open Protocols and Interoperability Benchmarks for Lab automation & collaboration**
	Strategic focus: Establishing unified reference architectures, open-source communication protocols, shared hardware/software testbeds, and standardized performance benchmarks to eliminate closed vendor ecosystems. MCDA Grounding: Ranked 1 overall (Weighted Score: 4.49); driven by an exceptional Scientific Impact score of 4.71 and a strong Economic Impact score of 4.57.
	2: Cross-Platform Semantic Interoperability and Unified Data Standards for Lab automation & collaboration
	Strategic focus: Developing native, open standard interfaces to bridge the data gap across heterogeneous multi-vendor laboratory instruments, robotics, LIMS, Electronic Lab Notebooks (ELNs), and cloud platforms. MCDA Grounding: Synthesized from the raw ranks 4 and 11; maps directly to the urgent demand to combine data analysis tools with cross-vendor instrument abstraction layers.
	3: AI-Readiness and Equalisation of Lab Infrastructures and Facilities
	Strategic focus: Auditing, evaluating, and upgrading existing European research infrastructures to handle AI workflows, while creating shared core facilities to prevent a funding gap between large and small laboratories. MCDA Grounding: Combines raw ranks 6 and 14 (Weighted Scores: 4.06 and 3.80); balances scientific acceleration with political and infrastructural equity at a European scale.
	4: Federated Scientific Computing and Cross-Cloud Execution Layers for lab automation & collaboration
	Strategic focus: Building a unified, secure federated broker layer that dynamically connects local physical laboratories with scientific instruments, High-Performance Computing (HPC) nodes, AI Factories, and decentralized data spaces. MCDA grounding: Positioned at raw rank 8 (Weighted Score: 3.91); addresses the strategic question of building a continent-spanning "intelligence layer" instead of isolated automation islands
Tier II: AI-Driven Experimentation, Data Analytics & Workflow Orchestration (Number 5–8)	**5: Adaptive Closed-Loop Experimentation and Autonomous AutoML Pipelines**
	Strategic Focus: Engineering advanced AI-driven closed-loop orchestration engines that run machine learning pipelines (AutoML) to dynamically adjust experimental parameters in real time without human intervention. MCDA Grounding: Maintained at raw rank 2 due to its massive scientific potential (Weighted Score: 4.14; Scientific Impact: 4.71).
	6: In-Situ and Near-Instrument AI for Real-Time Experimental Control
	Strategic Focus: Deploying edge-computing AI models directly onto lab instruments to perform real-time data interpretation, feature extraction, and instantaneous adaptation during active testing runs. MCDA Grounding: Ranked at raw rank 7 (Weighted Score: 3.94); highlights the shift from post-experimental processing to active, live runtime intervention.
	7: AI-based End-to-End Workflow Orchestration and Digital Twins for Automated Labs
	Strategic Focus: Developing comprehensive multi-modal workflow engines and integrated digital twins to simulate, design, authenticate, and safely execute entire scientific workflows across remote laboratories. MCDA Grounding: Regroups raw ranks 10, 24, and 33; shifts the focus from standalone "Lights-Out" hardware execution toward a software-orchestrated virtual-to-physical management tier.
	8: Standardized Machine-Actionable Knowledge Graphs for Protocol Sharing for Labs
	Strategic Focus: Formulating semantic networks and machine-readable data models that bind physical samples, biological protocols, instrument parameters, and final publications into a clear graph structure to ensure absolute reproducibility. MCDA Grounding: Combines raw ranks 11 and 37 (Weighted Scores: 3.83 and 3.37); provides the data layer required to make multi-site collaboration truly reproducible.
Tier III: Socio-Technical Capabilities & Human-Centric	**9: Human Capacity and Skills Development for Advanced Hybrid Laboratories**
	Strategic Focus: Creating cross-domain training programs, educational tracks, and university curriculums to prepare a new generation of scientists skilled in both physical domain disciplines and AI/robotics engineering. MCDA Grounding: Secured the third position in the final ranking (Weighted Score: 4.11); backed by a maximum Feasibility rating of 4.00, indicating immediate actionable readiness.
	10: Human-in-the-Loop Explainability, Validation, and Fail-Safe Governance for Automated Labs
	Strategic Focus: Engineering intuitive, explainable AI (XAI) models alongside real-time human verification dashboards to maintain absolute scientific control, validate autonomous anomalies, and prevent physical lab hazards.

	MCDA Grounding: Consolidates raw ranks 17 and 29; addresses safety, trust, and validation concerns within semi-autonomous laboratory spaces.
	11: Automated Data Provenance, Metadata Tracking, and Provenance Trails in Labs
	Strategic Focus: Formulating automated background software modules that passively track the lineage, execution state, calibration history, and data provenance of every machine-driven experiment. MCDA Grounding: Ranked at raw rank 20 (Weighted Score: 3.74); guarantees that autonomous outputs remain auditable and compliant with European open science mandates.
	12: Trustworthy Scientific Workflow Agents and Virtual Research Copilots for Automated Labs & Collaboration
	Strategic Focus: Developing specialized Large Language Model (LLM) agents and multi-agent systems optimized to understand lab protocols, write instrument APIs, query literature databases, and assist human technicians in experimental setup. MCDA Grounding: Maintained at raw rank 17 (Weighted Score: 3.77); shifts generative AI from a generic writing tool to a functional lab partner.
Tier IV: Defensive Engineering, Trust & Physical Infrastructure (Number 13–15)	**13: Advanced Cybersecurity and Decentralized Cryptographic Access Control for Automated Labs & Lab Collaboration**
	Strategic Focus: Designing defense-in-depth cybersecurity models, end-to-end encryption frameworks, and granular access permissions to secure remote instrument control and protect collaborative intellectual property from network intrusion. MCDA Grounding: Positioned at raw rank 11 (Weighted Score: 3.83); driven by high industrial and economic safety relevance (Economic Impact: 4.14).
	14: Computer Vision and Multi-Modal Sensor Fusion for Real-Time Safety and Asset Health in Automated Labs
	Strategic Focus: Implementing multi-camera spatial tracking and sensor fusion pipelines to monitor physical labs, automatically flag broken experiments, perform predictive instrument maintenance, and maintain environmental safety protocols. MCDA Grounding: Groups raw ranks 22, 27, and 30; refocuses computer vision from simple observation to proactive, predictive lab asset protection.
	15: Decentralized Robotics-as-a-Service (RaaS) Procurement Models for Automated Labs
	Strategic Focus: Designing modular, cloud-connected automation packages and open-source retrofit automation kits to allow dynamic service-based access to advanced robotic infrastructure. MCDA Grounding: Formed by raw ranks 14 and 22; emphasizes scalable deployment options to widen automation access for smaller European institutions

As shown above, the tiers as identified from the multi-criteria decision analysis in 3.3 differ from the original tiers that emerged from the literature analysis (see 3.1) and so do the corresponding research and innovation priorities. It is important to note though that the numbering provided for the top 15 research and innovation priorities does not constitute a final ranking yet as the research and innovation priorities deriving from the MCDA were partially merged and/or re-designed. As such, the validation of these results by the larger community including a final ranking are still to be done.

5 Glossary of abbreviations

AI: Artificial Intelligence

AIS: AI in Science

AISWG: AI in Science Working Groups

API: Application Programming Interface

AutoML: Automated Machine Learning

DFKI: German Research Centre for Artificial Intelligence (*Deutsches Forschungszentrum für Künstliche Intelligenz*)

E2E: End-to-End

EC: European Commission

EGI: European Grid Infrastructure

ELN: Electronic Lab Notebook

EOSC: European Open Science Cloud

EU: European Union

HPC: High-Performance Computing

LIMS: Laboratory Information Management System

MCDA: Multi-Criteria Decision Analysis

ML: Machine Learning

RAISE: Resource for AI Science in Europe

RaaS: Robotics-as-a-Service

RICAIP: Research and Innovation Centre on Advanced Industrial Production

RFID: Radio-Frequency Identification

SOTA: State-of-the-Art

SRIA: Strategic Research and Innovation Agenda

TEF: Testing and Experimentation Facility