

ERCIM



NEWS

Special theme:

Advancing Open Science

Federated Infrastructures
and Trustworthy
Ecosystems

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tational workflows, the Catalogue-Based Publishing Platform enables researchers to publish these artefacts at different stages of maturity, supporting a genuine “publishing beyond the paper” approach. Each catalogue entry is assigned a persistent identifier and enriched with structured metadata and clear licensing information. This ensures proper attribution, facilitates discovery, and enables reuse. Publication increases visibility within the VRE while also supporting interoperability with external systems through standard interfaces. Publishing is therefore no longer treated as the final step of the research process. Intermediate results, updated versions, and evolving artefacts can be shared early, fostering iterative refinement, transparency, and collaborative improvement.

Recent developments extend these environments with AI-based assistance, as described in the following article by Dell’Amico et al. in this issue.

Interoperability and Sustainability

Sustainable Open Science infrastructures require interoperability across platforms and disciplines. D4Science services expose standard interfaces and APIs, enabling integration with external repositories, analytics tools, and research infrastructures. This federated approach reflects the broader EOSC vision of interconnected services operating across institutional and national boundaries. No single platform can serve all scientific domains. Interoperability ensures modular growth and long-term sustainability.

The D4Science experience demonstrates that effective Open Science depends on cohesive ecosystems rather than isolated tools. By reducing fragmentation and lowering the cost of sharing, VREs make openness a natural outcome of daily research activity. Currently, thousands of users [L1] operate across more than two hundred active VREs spanning biodiversity, environmental science, marine research, social sciences, and computational biology. These environments combine domain-specific datasets and services with shared infrastructure components designed to promote FAIR data management and reproducibility. The D4Science model aligns closely with the vision of the European Open Science Cloud (EOSC) [L2], contributing to a federated ecosystem of interoperable services that supports cross-disciplinary collaboration and sustainable digital research infrastructures across Europe.

This alignment is not merely conceptual but already operational. D4Science also forms the technological foundation of the Digital Twin of the Ocean (DTO) EOSC Node [L3], a flagship Thematic Node within the emerging EOSC Federation. Building on the legacy of the Blue-Cloud initiative [3], the DTO Node adopts a ‘System of Systems’ approach to federate mature marine data infrastructures and modelling services. In this context, D4Science provides the core VRE technology, the federated AAI, and Catalogue interfaces required for seamless integration with the EOSC EU Node. This enables the execution of advanced, cross-domain analytics workflows and the publication of FAIR research artefacts, ensuring that the European marine community is at the forefront of the European digital research landscape.

Links:

[L1] <https://www.d4science.org/>

[L2] <https://kwz.me/hIo>

[L3] <https://kwz.me/hIO>

References:

- [1] M. Assante et al., “Enacting Open Science by D4Science,” *Future Generation Computer Systems*, vol. 101, pp. 555–563, 2019, doi: 10.1016/j.future.2019.05.063.
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Supporting Open Science in Virtual Research Environments: The DAVE Experience

by Andrea Dell’Amico, Alfredo Oliviero, Giancarlo Panichi, Biagio Peccerillo (CNR-ISTI) and Marco Procaccini (CNR-IGG)

DAVE, a conversational assistant integrated into D4Science Virtual Research Environments, simplifies access to services and supports Open Science workflows through natural language interaction.

Virtual Research Environments (VREs) provide integrated access to data, services, and collaboration tools for open and data-intensive research [3].

Building on the D4Science Virtual Research Environments, which support over 230 VREs and around 28,000 users worldwide, our work on conversational agents has led to the development of DAVE (D4Science Assistant for Virtual Research Environments), a system designed to assist researchers directly within their workflows. The D4Science infrastructure and its VREs are described in detail in the article by Assante et al. on page 38 in this issue.

The development of DAVE followed an iterative, user-centered approach that was guided by four key requirements: (a) flexibility and extensibility, as DAVE adopts a highly modular architecture that enables components to be selected, replaced, and extended as needed, ensuring adaptability to an evolving infrastructure; (b) context-awareness, as it relies on a rich and extensible knowledge base that supports heterogeneous research domains and aligns with Open Science ecosystems; (c)

openness and explainability, embodied by the system's transparency in both its behaviour and the knowledge sources behind its responses, which supports trust, reproducibility, and responsible reuse in line with Open Science values; (d) security and trustworthiness, ensuring that privacy and data protection meet the standards of the underlying infrastructure, while also supporting Open Science practices that balance accessibility with the safeguarding of sensitive research data.

Our journey leading to DAVE involved three successive prototypes [1]. The early modular agent, Janet (early 2023), which was based on a pipeline of fine-tuned components, proved to be limited in terms of flexibility and robustness, as well as having a high development and maintenance cost. The second attempt, the D4Science AI Agent (late 2024), adopted the Cheshire Cat framework, moving to a single-agent, multi-tool model. While improving modularity, this architecture proved less suitable for VREs, where diverse services and communities require numerous specialised capabilities. Concentrating all functionalities into one agent led to complex prompt engineering, which increased operational costs and diluted contextual relevance.

DAVE represents a paradigm shift. It adopts a highly modular multi-tool multi-agent system based on the Google Agent Development Kit (ADK) framework. The architecture, shown in Figure 1, features a VRE Assistant acting as a central orchestrator that interprets user requests, plans the sequence of actions, and delegates specific tasks to specialised sub-agents. These specialised agents are tightly integrated with D4Science services within VREs:

1. The Workspace Agent allows users to browse, discover, and summarize scientific documents stored in shared folders;
2. The Catalogue Agent facilitates the discovery and exploitation of research artifacts (datasets, software, publications);
3. The Social Agent summarizes community activities and interactions;
4. The CCP Agent interfaces with the D4Science Cloud Computing Platform, managing the execution of analytics and ensuring the repeatability and reproducibility of research methods.

DAVE simplifies the application of FAIR principles by supporting the discovery and reuse of research artefacts across the scholarly lifecycle. Through natural language interaction, researchers can explore the VRE Catalogue, aggregating datasets, software, and publications, and obtain coherent overviews without navigating complex metadata or multiple interfaces. DAVE also strengthens the collaborative and methodological dimensions of research. By interfacing with

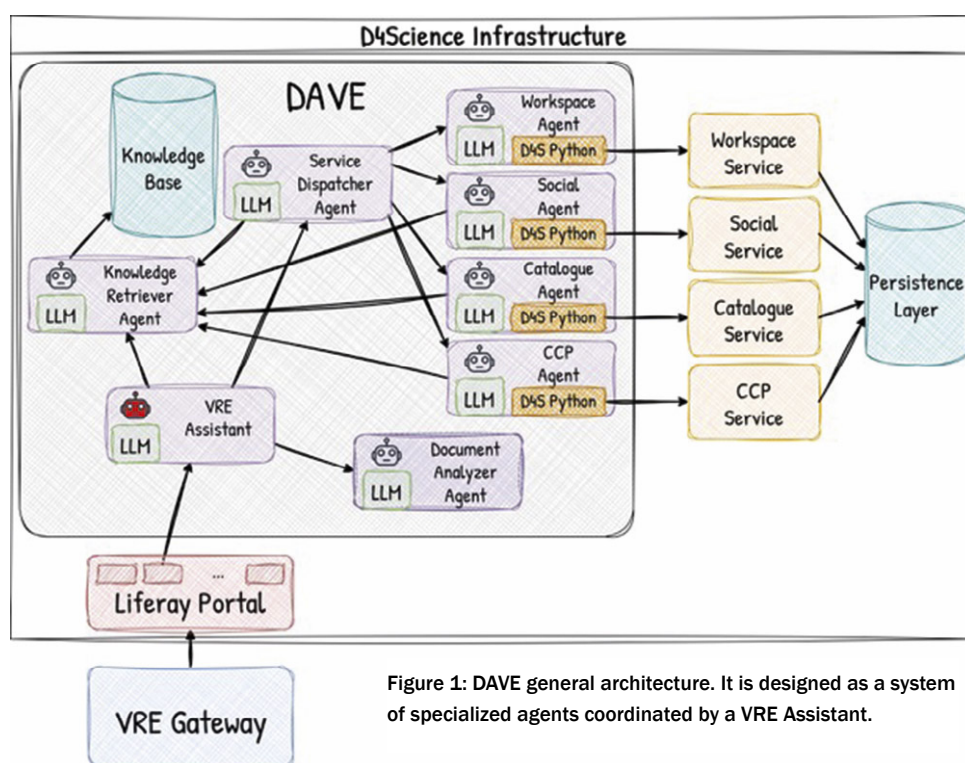


Figure 1: DAVE general architecture. It is designed as a system of specialized agents coordinated by a VRE Assistant.

the VRE social networking services, it provides contextual summaries of community activities and interactions, linking data with ongoing scientific discussion. At the same time, it supports transparency and reproducibility by guiding researchers in preparing, executing, and documenting analytical methods within the Cloud Computing Platform, making algorithms more accessible, executable, and reusable.

In conclusion, DAVE demonstrates how conversational agents can advance Open Science by making VREs more accessible, transparent, and reusable. By supporting the discovery, sharing, and reuse of research artifacts and enabling reproducible methods, DAVE embeds FAIR principles and transparency directly into researchers' workflows, fostering open, trustworthy, and collaborative science.

Links:

- [L1] <https://www.d4science.org>
 [L2] <https://services.d4science.org/web/collab/>

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