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The Reference Architecture of a National Digital Education Ecosystem

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Abstract

The fragmented IT landscape in education hinders transitions for both individual users (learners/teachers) and administrative bodies. Germany's initiative to create a national digital education space addresses this issue. While some efforts focus on administrative services or specific aspects of digital education, the National Digital Education Ecosystem takes a broader approach. Its prototype features a distributed middleware that connects existing IT systems of educational institutions while preserving their autonomy. Beyond administrative functions, it offers value-added features and access to informal education scenarios via a dedicated portal. This article outlines the prototype's architecture, illustrates it with use cases, introduces key components, and concludes with the rollout's current status and next steps.

Keywords: Enterprise Architecture, Digital Ecosystem, Education, TOGAF, HERM

1 The German National Digital Education Ecosystem

Transitions between different educational institutions – be it along the qualification levels or during exchange programs – always require exchange of information between the IT systems involved. For international mobility, for example, a certain degree of standardization has been achieved by introduction of catalogues and data formats such as EDCI/ELMO. Nevertheless, teachers and learners

continue to transfer educational material, certificates or simply profiles manually from platform to platform. Initiatives such as Npuls (Netherlands), Digivisio (Finland), 'Mein Bildungsraum' (Germany) and the Interoperability Framework try to address this[1]. However, these initiatives have not yet published a norm-compliant reference architecture, which would require arranging all the components in an orderly fashion to allow the solution to be operationalized along the given frameworks. Facing the size and complexity of the German educational system with a federal, multi-tiered supervisory structure (Lassnigg, 2016), the vision of a National Digital Education Ecosystem (NDEE) is ambitious. Unlike the other initiatives, all educational domains are addressed, from schools and vocational training to higher and further education. If a solution can be found here, it could also be of interest beyond national spheres. However, it must seek international compatibility from the very beginning as interoperability in European University Alliances is evolving (Benzinger, 2025). An equally simple and flexible architecture can help to build bridges between existing approaches (like de Jong & Scheers, 2021; Hautakangas & Nordlund, 2023). For example, the Digivisio 2030 system architecture describes a service component model including a common (API) integration platform – not a reference architecture. Addressing national services like *Virta* and *codebase* as well as systems in Higher Education Institutions (HEIs), the model's aim is interoperability in Finland. Although we expect our initiatives to work together, the NDEE requires a more holistic reference architecture including security design.

From the very first architectural description for the NDEE (Knoth et al., 2022; Lucke 2024), great emphasis was placed on the autonomy of the systems to be connected and the sovereignty of the individual users. The approach was able to prove its suitability in the R&D context by connecting several dozen projects across the funding line[2], so that the specification developed could then also be used in an adapted form for the invitation to tender for the resulting productive system. With the current transfer of the first components to the roll-out, a stabilisation of the concept has been achieved, which means that no fundamental changes to the architecture are expected for future extensions.

The article is structured as follows: Chapter 2 introduces the NDEE architecture, followed by five common use cases in Chapter 3. Chapter 4 outlines its key components, and Chapter 5 concludes with a summary and outlook. Our aim in this paper is threefold. First, we would like to discuss the architecture with relevant experts in order to further improve or validate it. Second, we are interested in gaining new collaborations to extend the ecosystem by new features/components. Finally, we would be glad to inspire similar approaches in other regions or application fields.

2 Reference Architecture of the NDEE

An overview of the reference architecture is provided below. It has been developed according to TOGAF and ArchiMate. We are using the terminology defined in the BIRD project, which delivers the NDEE prototype, because it has been worked out in more detail. The NDEE design is based on more than 14 personas and 50 scenarios (Erdmann et al., 2023). A key requirement for the NDEE is to extend the functionality of existing IT solutions and services in the education domain for relevant use cases, while at the same time preserving these components and the autonomy of their providers as well as ensuring a highest level of security. We have therefore derived an architecture model from Schönbächler et al. (2017) as shown in Figure 1 below. Originally designed for micro-service-based architectures, it provides full agility, flexibility, and security aspects. Note that application components such as Learning Management Systems (LMS) are linked to the HERM standard[3] and thus can easily be translated into the institution's IT landscapes.

[1] https://npuls.nl/ || https://digivisio2030.fi/ || https://www.meinbildungsraum.de/ || https://op.europa.eu/s/z7bI
[2] https://www.uni-potsdam.de/fileadmin/projects/multimedia/docs/2021-05-20_Schnittstellen-BIRD_v1.pdf
[3] https://www.caudit.edu.au/communities/caudit-higher-education-reference-models/

Administrative domains are shown vertically, e.g. existing IT landscapes from educational institutions (grey boxes), or newly added NDEE components (blue boxes). For simplicity, existing systems such as Student Information Systems (SIS), are summarized in larger boxes, knowing full well that their internal structure is much more complex. Horizontally, there is a structuring into five security zones, which must only be accessed top-down and zone-by-zone. As an example, users need to identify and authenticate within the *Entry Zone* and may then be authorized to show any content. In order to access web applications within the *Application Zone* and using services hosted in the *Service Zone* below, further authentication and authorization applies. Deeper zones store more sensitive data and therefore provide the highest security levels. Only well-defined services can establish connections and authorize. Design driven, zones cannot be bypassed, and any communication requires agreed standards such as XML or REST. Depending on the level of trust between the NDEE and its partners, middleware components may be connected to the *Integration Zone* or required to use integration services in the zone above. Note that the *Hosting Zone* shall have no other access than authenticated and authorized middleware. However, the current prototypic implementation includes some backends with GUIs and interfaces bypassing middleware, that allow direct access for development purposes. These functions must be separated and provided as appropriate services in the *Service Zone*.

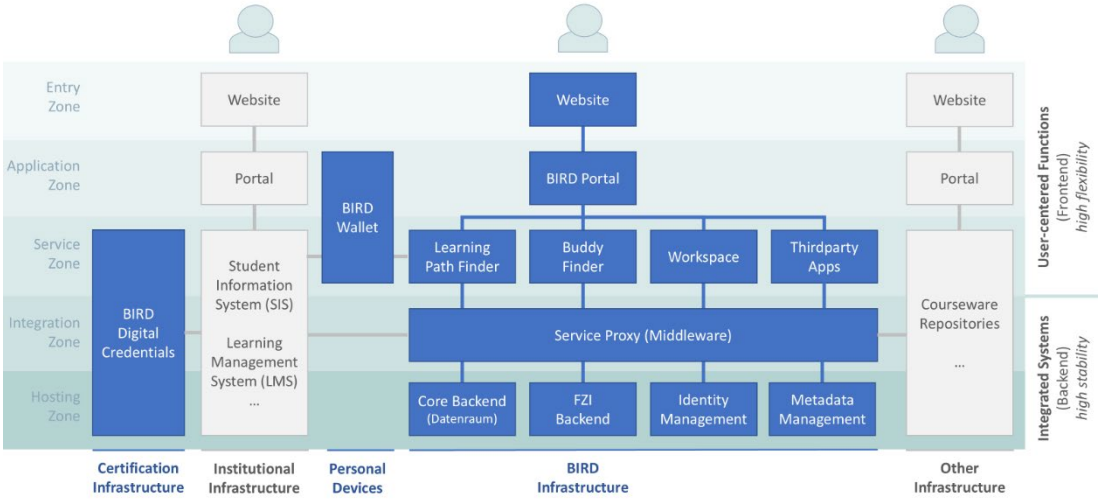

Figure 1: The proposed NDEE architecture[4] connects existing IT solutions (grey boxes) and new components (blue boxes) following a five-layered security scheme.

Future Work applies Zero Trust Architecture, Core Principles & Commandments (Rose et al., 2020; Gosh et al., 2021; Carlson et al. 2021) towards the NDEE architecture. Starting with identity-based access policies, micro segmentation & isolated network segments, and software defined network overlays, any aspects of implicit trust will be minimized. As an example, vertical communication will be controlled not only by zones but known identities which require an authority granting rights. While the architecture draft in the figure assumes trust within a zone, Zero Trust will minimize this as well.

The Digivisio 2030 architecture follows a service component model with national and HEI services, offering a shared API integration platform. Our approach also enables interoperable services across institutions, but stands out through its integrated security design, requiring all participants to follow defined security policies. Vertical and horizontal separation and adding Zero Trust Principles is essential in a highly distributed and autonomously governed IT landscape. Our approach improves the expected level of sovereignty in the administrative domains. Though, our architecture can still be easily

[4] The ArchiMate-Model has been published as https://doi.org/10.5281/zenodo.15732800

connected to other solutions using the given policies. For example, any authorized third-party service may communicate within the *Integration Zone*, if it's trusted.

In this way, an ecosystem of independent players or components is formed that can interact via defined interfaces without being placed under centralized control. This also allows the solution to be deployed across multiple private or public clouds. The prototype was originally deployed to the cloud (Geßner et al., 2025) but has recently been rolled back to the education infrastructure. The basis for this is the existing connectivity via the Internet as well as the offerings of existing and specific new services of the educational sector. The added value to the users stems from the implemented use cases, which are presented below. Users are not forced to switch from their current to the NDEE tools; rather, existing tools are enriched by additional services. The main components of the original NDEE specification (Knoth et al., 2022) can still be found in this architecture, although some aspects have been clarified, and others marginalized in the course of development. The basic principle of service-based middleware (Kiy et al., 2014) is still applied. As most services already exist in this decentralized network, the coupling is a realization of the "bring your own service" approach (von der Heyde, 2014).

3 Use Cases of the NDEE Prototype

In this chapter we describe five use cases, each consisting of several scenarios as specified by Erdmann et al. (2023). All the components mentioned as well as their respective functions are then explained individually in Chapter 4. Those components and functions are marked with *italics*.

3.1 Exchanging Credentials for Transition between Institutions

In the first use case, transitions of learners between different educational institutions (or the transfer of their credentials between the related SISs) are supported. Here, only the three most-left columns of Figure 1 come into play. An example of the transition from secondary to higher education follows:

- Within the local institutional school infrastructure, the diplomas of students are issued.
- A hash of that diploma is sent to the *certification infrastructure*, where it is digitally *signed* to verify the eligibility of the issuer and the content of the certificate.
- This signature is bound to the diploma, which is then transferred to the *wallet* of the student on his/her personal device for *storage* and later use.
- For application to a Bachelor programme, the student may *retrieve* the signed diploma from the *wallet* and send it to the SIS in the institutional infrastructure of the university.
- The SIS can *verify* the diploma using the *certification infrastructure*.
- If necessary (like in case of administrative errors or fraud), signed diplomas can be *revoked* from the *certification infrastructure* and then no longer verified.

A similar approach can be used for other transitions, such as exchanging micro-credentials between LMS or in application processes with employers. The architecture and interfaces remain unchanged.

3.2 Exchanging Courseware between Institutions

In the second use case, only the two lower layers of the BIRD infrastructure and the existing infrastructure of institutions are being looked at. This enables cross-institutional interconnection of educational content, which involves the following interaction between the components:

- Within a local learning management system, teachers of a course may decide to *publish* their created course material to the *data space* of the ecosystem.

- Building on this interconnection, teachers at other institutions can *search* the *data space* system for suitable materials when creating their own courses.
- In the case of single artifacts, those can be *retrieved,* and a copy will be added to the local learning management system.
- In the case of whole learning offers (like open courses), a link from the local to the external learning management system will be set. In this case, learners may use the *identity management* to *authenticate* with the remote system.
- Learning results from offerings can be *stored* in the individual *data wallet* of the learners.

Teachers can integrate third-party materials or services into the metadata management system, including repositories like open educational resources or commercial offerings published in the data space. In such cases, the architecture's right column becomes relevant.

3.3 Finding Individual Learning Pathways

In the third use case, an additional component is introduced to the service zone of the BIRD infrastructure and is thus also accessible via the *BIRD portal*. This enables personalized, cross-institutional access to and recommendation of educational content. Here, the interaction of the components is as follows:

- A learner may *search* for specific offerings fitting to his/her learning goals in the *learning path finder*.
- This will trigger a *search* in defined curated learning pathways as well as in underlying offerings as kept by the *metadata management*.
- In case the user has connected his/her *data wallet* before, additional parameters can be used to *enrich* the search based on *retrieved* pre-knowledge in order to not suggest pathways the user has already completed.
- Once a certain step within a *recommended* pathway has been chosen by the user, the learning path finder will hand over to the respective offering.
- Learning results from offerings can be *stored* in the individual *data wallet* of the learners.

The added value from this use case is to combine a) traditional queries to repositories with b) curated learning pathways and c) enhancing the search parameters by additional information on the users as well as d) by AI-generated keywords and topics.

3.4 Finding Individual Learning Buddies

With the aim of connecting people with people (beyond people with content), a fourth use case can be realized through the *BIRD portal*. The challenge here is that searching catalogues with metadata on all available content is rather a technical matter, while a catalogue of all users of a system would be very sensitive in terms of privacy. For instance, misuse for surveillance or commercial interest should be prevented. That’s why we introduced a pseudonymization of user data for matching:

- An educator or learner *offers* help for specific content and context in the *BuddyFinder*.
- Learners select their individual educational context and add *search* criteria.
- The *match* between offers and searches is performed under the restriction of GDPR on anonymized cryptographic hashes.
- Both parties *confirm* the offered matching relation.
- Learner and educator establish a connection based on the confirmed matching relation.

This concept implements an effective platform to connect people with people, while providing enough privacy mechanisms to prevent misuse.

3.5 Collaborating across Institutional Borders

In the fifth and last use case presented here, users are empowered to collaborate on found content or even jointly create new artifacts with their buddies. This is based on the use case described above and extends the architecture by additional mechanisms to invoke third-party tools for communication and collaboration:

- Communication and collaboration tools can be integrated into the *BIRD portal*.
- Collaboration partners can be invited from any institution within the *single sign-on* federation.
- Learners and educators communicate through the BIRD ecosystem in synchronous and asynchronous patterns.
- The results of the collaboration can be transferred between partners.
- Collaborative editing of documents is key in educational and scientific contexts.

The prototype should be seen as a reference implementation, enabling any learning management system provider to support the educational ecosystem through the provided interfaces.

4 Components of the NDEE Prototype

The components identified in the previous section and their technical realization are explained separately below. We limit the description to the new components introduced by the NDEE prototype and do not consider the well-known existing IT systems of the educational landscape. The presentation is not exhaustive; new use cases and scenarios may also add new functions to the components presented or completely new components.

4.1 Digital Credentials / Certification Infrastructure

The Digital Credentials / Certification Infrastructure (Knoth et al., 2023) securely manages the issuance, verification, and revocation of education certificates (e.g., EDCI and eIDAS). Cryptographic techniques ensure certificate authenticity and integrity. Verification services allow external parties, such as universities or employers, to confirm credentials without accessing personal data. Flexible revocation mechanisms, both centralized and decentralized, prevent misuse of invalid certificates. Private keys are stored securely, and encrypted communication ensures GDPR compliance. Signed certificates are easily verifiable and stable. Based on open-source software and standards like Verifiable Credentials (VC), EDCI/ELMO, and eIDAS, the system supports interoperability. Central services handle authentication and verification, while local institutions retain control over certificate issuance. The architecture includes components for secure and efficient operation:

- Certificate Authority (CA): Issues and manages cryptographic keys for signing
- Registration Authority (RA): Authenticates institutions and authorized personnel
- Vault: Securely stores private keys for signing digital certificates
- Trust Service: Handles authorization rules for issuing credentials
- Validation Service: Enables public verification of issued credentials
- REST APIs: Facilitate integration with school administration systems and document management platforms

The signing process of this component follows BSI (Federal Office for Information Security) Standard TR-02102 and employs advanced electronic signatures to guarantee document reliability.

4.2 Wallet

The Wallet component enables users to maintain full sovereignty over their data, which includes identity information created by the user and standardized data types. It also stores activity or achievement data shared by services within the NDEE prototype or institutional infrastructure (Walia et al., 2024). The wallet can represent multiple digital identities for the user. Key objectives, such as sovereignty and data privacy, are central to its design and implementation. The architecture includes:

- App: A mobile end-user client. This client provides the user experience for managing digital identities. It allows the user to interact with the functions of the NDEE infrastructure. A single app can support multiple identities, and a single identity can be used across multiple apps.
- Backbone: The central system in the enmeshed framework facilitates communication within the NDEE infrastructure and between user devices. It provides encrypted storage for messages, files, and tokens until expiration, ensuring access, backup, and synchronization. To accommodate offline user devices, it caches encrypted data and sends push notifications. Built on a microservices architecture with Docker containers, the backbone is highly virtualized and efficiently scalable.
- Connector: The client for organizations, therefore hosted within the organization's infrastructure (NDEE or Institution), is easily integrated with the host systems thanks to a rich REST API. The connector represents the identity of the organization.

4.3 Metadata Management and Data Space

The Metadata Management component is a dynamic, database-like system that adapts to evolving requirements for learning opportunity data. It stores data from institutional and ecosystem sources, enabling flexible, on-the-fly creation of new structures. This ensures long-term relevance and supports diverse use cases with shared attributes. It handles structured, semi-structured, and unstructured data, offering high flexibility and scalability (Rörtgen et al., 2023). The architecture includes:

- Data Storage User Interface (Expert Tool): A web application used by administration to create and change data structures as well as enables the input of data attributes and full datasets for single entries
- REST-API: An interface to automatically import big amounts of data from institutional infrastructure with automated validation
- Search Engine: A fast and flexible way to query the data for referencing the institutional data from within the NDEE infrastructure

This structure ensures that the management of metadata can efficiently support evolving educational data needs while integrating seamlessly into institutional infrastructures.

4.4 Learning Path Finder

The Learning Path Finder helps users find suitable educational offers for further education. It has been prototyped and evaluated in the context of Ukrainian refugees (Ziemann et al., 2023). To provide the most accurate recommendations, it uses metadata from the offers in the metadata management system and personal information shared via the wallet at runtime. Users are presented with subject areas, each with several topics related to education. For each topic, the Learning Path Finder suggests digital offers from service providers. Subject areas, topics, and offerings are presented using curated process descriptions and decision tables. The architecture includes:

- Camunda Workflow Engine which maps processes using the Business Process Model and Notation (BPMN)
- Decision Model and Notation (DMN), which is leveraged from the Camunda Workflow Engine and used to automate decisions

The Learning Path Finder is integrated into the Liferay platform. Current work includes the integration of AI support to provide suggestions for keywords.

4.5 Buddy Finder

The Buddy Finder component is designed to facilitate anonymous interactions between users by enabling the submission and request of learning support offerings with customizable attributes. Using homomorphic encryption, the component ensures that comparisons can be performed on encrypted data without exposing the protected information. In addition, by distributing the processes of encryption and comparison of the hashes across several servers, an additional layer of security is included. The system securely stores the encrypted search, offers profiles provided by users and compares them upon request. If the encrypted profiles match, the system enables user connection while ensuring data confidentiality (Eilebrecht et al., 2025). The architecture includes:

- Multi-layer access architecture that securely encapsulates back-end access compliant to the NDEE architecture
- Encryption Engine with high performance, which is limited to input only
- Matching Engine: Limited communication due to homomorphic encryption requirements

Performance improvements still need to be finalized for this component, and Zero Trust extensions need to be prepared.

4.6 Shared Workspace

The Shared Workspace supports users in self-directed learning by providing a customizable place to cooperate (Erdmann et al., 2025). Users can add and arrange various tools, including external ones not hosted on the BIRD infrastructure. Materials and tools are organized into projects and can be edited in both full-screen and split-screen mode, and shared with others to enable synchronous and asynchronous collaborative work. Shared workspaces can also include video conference rooms for communication with contacts. The Shared Workspace is implemented as a widget in Liferay and utilizes Liferay's onboard functionalities for selecting and adding widgets to a page. Users can arrange various communication and collaboration tools in the respective workspaces using drag and drop.

4.7 BIRD Portal

The BIRD Portal is based on Liferay and brings together all listed components that are directly visible to the user via the web front-end with a common look and feel. It provides dynamic content delivery, customizable dashboards with drag-and-drop widgets, and a responsive design for mobile compatibility. Strong security and compliance features, including authentication, encryption, audit logs, GDPR support, and extensible security policies, are included as well. The BIRD Portal integrates:

- User Management with Single Sign-On (SSO), role-based access control (RBAC), and structured group/organization permissions
- Built-in CMS with versioning, workflows, document repository, and multilingual support
- Workflow and business process automation via Camunda BPMN, DMN-based decision-making, and custom approval processes
- REST & GraphQL APIs, enterprise system integration, and multi-database support

This architecture is based on an OSGi-based system for customization, plugin extensibility, and microservices compatibility. It enables flexible deployment options across on-premise, cloud, and hybrid environments, supports Kubernetes/Docker, high scalability, and built-in monitoring/analytics.

5 Current Status and Next Steps

The final status of the BIRD pilot project[5] is characterized by the completion and handover of central core components of the NDEE prototype to the federal innovation agency SPRIN-D. The components include digital proofs of identity, digital identities, the wallet and the learning path finder, which are ready for further scaling and implementation. The source code for the components is published as open source[6] to ensure transparency and reusability. Other central components of the NDEE are being further developed as part of the prototyping project. These include the metadata management, data space, an AI-enhanced version of the learning path finder, the buddy finder, and the shared workspace. These developments are aimed at expanding the interoperability and functionality of the platform. In addition to this more detailed specification of the solution architecture, a generic, automatic mapping of the BIRD scenarios has revealed the current overlap of BIRD and the typical HEIs (von der Heyde & Goebel, 2025). This mapping will allow us to plan the interfaces and necessary components in such a way that typical HEIs will connect their infrastructure and data flows more easily. Further work will concentrate on mapping to the business reference models of the other education domains. In addition, reference implementations must be finalized and adapted to the required interfaces and standards.

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