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Article

Breaking Platform Silos in Digital Higher Education: A Standards-Based Interoperability Framework for Learning Management Systems, Student Information Systems, and AI Services

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Abstract: Universities now run teaching and administration on many separate platforms. A learning management system (LMS) holds course content and assignment scores, a student information system (SIS) holds enrolments and official grades, and a growing number of AI services, from tutoring chatbots to feedback tools, each need part of that data to work. When these systems are connected through manual exports or one-off custom code, staff enter the same data twice, records disagree, data protection is weak, and AI tools either see too little to be useful or far more than they should. This paper proposes a standards-based interoperability framework that connects LMS, SIS and AI services in higher education. Following design science research, the study analyses current open specifications, including LTI 1.3, OneRoster 1.2, Edu-API, Caliper Analytics 1.2, xAPI 2.0, Open Badges 3.0, the Comprehensive Learner Record 2.0 and W3C Verifiable Credentials 2.0, together with two new protocols for AI systems, the Model Context Protocol and Agent2Agent. The resulting framework has four parts: a layered reference architecture, a system-of-record matrix that names one authoritative source for each data object, an AI gateway that gives AI services only course-scoped context, and a five-level maturity model. The framework is mapped to the four layers of the European Interoperability Framework and illustrated with an end-of-semester grade and credential flow set in the context of Uzbekistan's national higher education information system. The paper also discusses governance, data localisation and security, and outlines steps for empirical validation.

Keywords: interoperability, learning management systems, student information systems, educational technology standards, AI services

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1. Introduction

A university student today meets several software platforms before the end of the first week. Admission and registration happen in a student information system. Course materials, quizzes and assignments live in a learning management system. Lectures may run on a video platform, library resources on a discovery system and plagiarism checks on yet another service. Since 2023 a further category has arrived: AI services that tutor students, draft feedback, summarise course content or answer administrative questions. Each of these systems keeps its own copy of some part of the student's record.

When the systems do not exchange data in a standard way, the cost shows up in daily work. Staff enter the same course and enrolment data twice, grades are copied by

hand from the LMS into the SIS, and reports disagree because they were drawn from different copies of the data. At the University of Dar es Salaam, for example, separate registration of students, programmes and courses in the LMS and in the student records system slowed adoption of the LMS until a web-service integration removed the duplicate step [1]. Problems of this kind led the EDUCAUSE Learning Initiative to propose a next generation digital learning environment assembled from interoperable components rather than built around a single monolithic LMS. Interoperability was the first of its five functional dimensions [2].

AI services make the problem sharper. A tutoring assistant is useful only if it knows which course a student is taking, what the instructor has published and, in some designs, how the student has performed so far. LMS vendors are building AI into their platforms. Moodle, for example, added an AI subsystem in version 4.5 that connects to external model providers and offers actions such as text generation and course summaries [3]. Many institutions also buy or build stand-alone AI tools. Without shared standards, every new AI tool becomes another custom integration with its own way of signing users in, its own copy of the class list and its own logging, or no logging at all. AI tools also bring new security risks. LLM-based applications can be manipulated by instructions hidden in the content they process, a class of attack known as indirect prompt injection [4].

Emerging digital economies face these issues while their higher education systems grow quickly. Uzbekistan is a clear case. Its national Higher Education Management Information System (HEMIS) serves 207 higher education institutions and holds records for about 1.65 million students and 121,800 teaching and other staff [5]. A centralised SIS of this kind is an advantage, because it gives the whole country one authoritative source for enrolment and academic records. It also raises the stakes of integration. Every university connects its own LMS, testing tools and AI services to HEMIS, and if each one does so in its own way, the national system ends up surrounded by hundreds of incompatible interfaces. National policy sets the direction. The Digital Uzbekistan-2030 strategy gives priority to digital public services and education [6]. The 2024 AI strategy calls for a regulatory framework, standards and data infrastructure for AI [7], [8]. The personal data law requires that personal data of Uzbek citizens processed with information technologies be stored on technical means located in the country [9], [10].

Technical standards for educational interoperability already exist. The 1EdTech consortium, formerly IMS Global, maintains specifications for tool launch, rostering, gradebook exchange, learning analytics and digital credentials [11][12]. The IEEE has standardised the Experience API][13][14], and the W3C has published version 2.0 [15] of its Verifiable Credentials data model [16]. Two new protocols aim to standardise how AI systems reach tools and data: the Model Context Protocol (MCP) [17] and the Agent2Agent protocol (A2A) [18]. Learning analytics research has shown what common data formats make possible [19], [20] and documented the policy and privacy problems that arise when data move between systems [21], [22]. What is still missing is a framework that brings these pieces together for the particular triangle of LMS, SIS and AI services, states which system is authoritative for which data, and places AI protocols under the same governance as every other integration.

The objective of this study is to design a standards-based interoperability framework that connects learning management systems, student information systems and AI services in higher education and that institutions in emerging digital economies can adopt step by step. The paper first classifies the forms that platform silos take. It then maps current open standards to integration needs and presents the framework, with a system-of-record matrix, an AI gateway and a maturity model. A scenario from the Uzbek context illustrates how the parts work together.

2. Materials and Methods

The study uses design science research, an approach in which researchers build and evaluate artifacts that solve identified organisational problems [23]. The artifact is a framework made up of a reference architecture, design principles and a maturity model. The research followed the activities of the design science research methodology of Peffers et al.: problem identification, definition of objectives, design and development, demonstration and evaluation [24]. This paper is the communication step.

Two bodies of material were analysed. The first was a set of technical specifications. A specification was included if it was openly published, maintained by a recognised standards body or an open governance foundation, and relevant to at least one integration need of LMS, SIS and AI services. The set comprised the IETF and OpenID Foundation identity standards [25], [26], the 1EdTech specifications 27]-[29], the W3C Verifiable Credentials Data Model 2.0 [16], and the MCP and A2A protocols [30]. Each specification was read in its official published form and coded for five attributes: the data or interaction it covers, its security model, its status and date, the body that governs it, and its dependencies on other standards. The second body of material consisted of peer-reviewed studies, policy frameworks and regulations on interoperability, learning analytics and data protection. These were located through Google Scholar, publisher databases and official legal portals and analysed as an integrative review [31].

Design objectives were derived from the problems reported in the literature and from the principles of the European Interoperability Framework (EIF) [32]. Evaluation was analytical. Each design element was traced to the objective it serves, and the framework was applied to a constructed scenario of an end-of-semester grade and credential flow, in line with the descriptive evaluation methods of design science. No human participants took part and no personal data were processed, so ethical approval was not required. No statistical analysis was carried out; the figures quoted in the text come from the referenced sources.

3. Results

3.1 Four forms of platform silos

Interoperability is usually defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged [33]. The second half of that definition matters, because data can be moved without being understood. The Levels of Conceptual Interoperability Model separates technical, syntactic, semantic, pragmatic, dynamic and conceptual levels [34], and the EIF groups the problem into legal, organisational, semantic and technical layers. Drawing on these models and on the problems reported in education, the analysis identified four forms of silos in digital higher education.

Data silos arise when the same data object, such as an enrolment or a final grade, is stored and edited in more than one system and no rule says which copy is correct. Identity silos arise when each platform keeps its own accounts and passwords. Access rights then drift out of step with enrolment status, and students or staff who have left keep their access. Process silos arise when a workflow crosses systems but the hand-over is manual, as when grades are copied from the LMS gradebook into the SIS at the end of term. Semantic silos arise when systems do exchange data but name or code it differently. One system may record a course section by a local code and another by a national curriculum code, or learning activity events from different tools may use vocabularies that cannot be compared.

AI services add a risk that cuts across all four. An AI tool connected outside the institution's identity and data rules can see more data than its function needs, and it may leave no record of what it did. In the language of the EIF this is at once a legal problem,

because data may leave the country or be used for a purpose nobody approved, and an organisational one, because no one is clearly responsible for the tool's outputs.

3.2 Mapping open standards to integration needs

Table 1 maps the integration needs of LMS, SIS and AI services to current open standards.

Table 1. Open standards for integrating LMS, SIS and AI services.

Integration need	Standard, version and status	What it carries
Sign-on and delegated access	OAuth 2.0 (IETF RFC 6749, 2012); OpenID Connect Core 1.0 (2014)	User authentication; scoped access tokens for services
Launching external tools from the LMS	LTI 1.3 Core and LTI Advantage (1EdTech, 2019); 1EdTech Security Framework 1.0 (2019)	Secure launch with user, role and course context; deep linking of content; return of scores (Assignment and Grade Services); class membership (Names and Role Provisioning Services)
Rosters, course resources and gradebooks	OneRoster 1.2 (1EdTech, final release, 2022)	Organisations, courses, classes, users and enrolments; gradebook line items and results; assessment results, learning objectives and score scales
Enterprise academic data	Edu-API (1EdTech, candidate final)	SIS data exchanged across campus systems, such as personal and demographic data, course catalogues, enrolments and final outcomes
Learning activity events	Caliper Analytics 1.2 (1EdTech, 2020); xAPI 2.0 as IEEE 9274.1.1-2023	Time-stamped actor, action and object events from tools, sent to an event endpoint (Caliper) or a Learning Record Store (xAPI)
Digital credentials	Open Badges 3.0 (1EdTech, 2024); CLR 2.0 (1EdTech, 2025); W3C Verifiable Credentials Data Model 2.0 (W3C Recommendation, 2025)	Cryptographically signed, tamper-evident badges, certificates and learner records that holders keep in digital wallets
AI access to tools and context	Model Context Protocol (introduced 2024; under the Agentic AI Foundation of the Linux Foundation since Dec. 2025)	JSON-RPC 2.0 messages between AI hosts and servers that expose tools, resources and prompts
Communication between AI agents	Agent2Agent protocol (Google, 2025; Linux Foundation project since Jun. 2025)	Agent discovery through Agent Cards and exchange of tasks and messages across vendors

The mapping shows three things. First, the core needs of LMS and SIS integration are covered by mature, certifiable standards. LTI 1.3 replaced LTI 1.1, whose support and certification ended in 2022, with a security model based on OAuth 2.0, OpenID Connect and JSON Web Tokens. OneRoster 1.2 added assessment results, learning objectives and score scales to rostering and gradebook exchange. Second, the SIS side for higher education is less settled. Edu-API builds on the earlier Learning Information Services specification and on experience with OneRoster and LTI, and it targets the more complex academic structures of universities, but at the time of writing it was still in candidate final status. Third, the AI protocols are young. MCP was released in November 2024 and was transferred to the newly formed Agentic AI Foundation in December 2025 [35]. A2A was announced in April 2025 and became a Linux Foundation project two months later [36]. Neither protocol contains anything specific to education. Security researchers have already described tool poisoning attacks, in which malicious instructions are hidden in MCP tool descriptions [37], and a critical command injection flaw was found in a widely used MCP client library in 2025 [38].

3.3 Reference architecture

Figure 1 shows the proposed reference architecture. It has four horizontal layers and one vertical governance layer.

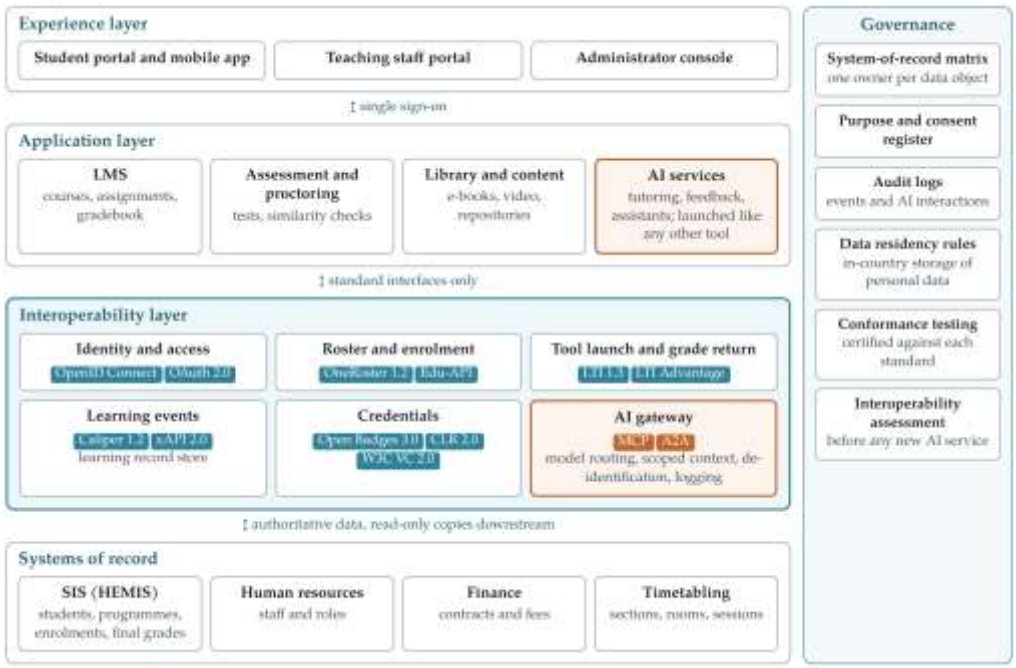

Figure 1. Standards-based interoperability framework for LMS, SIS and AI services.

At the base are the systems of record: the SIS, which in Uzbekistan is the national HEMIS platform, and administrative systems for human resources, finance and timetabling. These systems hold the authoritative version of the data objects they own.

Above them sits the interoperability layer, which is the core of the framework. It contains six services, each built on the standards in Table 1. An identity and access service provides single sign-on and issues scoped tokens to every other component through OpenID Connect and OAuth 2.0. A roster and enrolment service publishes courses, sections, people and enrolments from the SIS to all consuming systems through OneRoster 1.2, with Edu-API as the target for richer higher education data once it is final. A tool launch and grade return service handles LTI 1.3 launches from the LMS to external tools and AI services, including deep linking and the return of scores. An event service collects learning activity events in Caliper or xAPI format and keeps them in a learning record store. A credential service issues Open Badges 3.0 and CLR 2.0 records as W3C verifiable credentials. The sixth service, the AI gateway, mediates every interaction between AI models and institutional data (Section 3.5).

The application layer contains the LMS, assessment and proctoring tools, library and content platforms, and AI services. The main design choice is that AI services are treated as ordinary applications. They are launched from the LMS through LTI and receive the user's identity and role from the launch. They read class lists through the same OneRoster interface as other tools, write events to the same event store and return scores through the same grade service. They do not get a separate back door into the SIS.

At the top, the experience layer covers the portals and mobile applications used by students, teaching staff and administrators. Because identity is handled centrally, a student moves between them with one account.

The vertical governance layer applies to all the others. It holds the system-of-record matrix (Section 3.4), a register of data processing purposes and consents, audit logs from the event service and the AI gateway, rules on data residency, and records of conformance testing that show which components have been certified against which standard.

3.4 System-of-record matrix

Most data silos disappear once one system is declared authoritative for each data object and all other systems receive read-only copies through a standard interface. Table 2 gives the proposed matrix.

Table 2. System-of-record matrix for core academic data.

Data object	System of record	Distributed through	Main consumers
Person and identity attributes	SIS (HEMIS) and HR system	OpenID Connect claims; OneRoster users	All systems
Programmes, curricula and course catalogue	SIS	OneRoster courses; Edu-API (target)	LMS, timetable, AI gateway
Course sections and enrolments	SIS	OneRoster classes and enrolments	LMS; AI services through the LTI launch context
Assignment-level scores	LMS, or an external tool through LTI	LTI Assignment and Grade Services; OneRoster gradebook	LMS gradebook, analytics
Final course grades	SIS, after approval by staff	OneRoster gradebook results sent from LMS to SIS	Transcript, credential service
Learning activity events	Event service (learning record store)	Caliper events or xAPI statements	Analytics; AI services in aggregated form
Credentials and learner records	Credential service	Open Badges 3.0 and CLR 2.0 as verifiable credentials	Students' wallets, employers, other universities
AI interaction records	AI gateway	Internal audit log; xAPI statements for learning-related use	Instructors, data protection officer

Two rows need comment. Final grades flow from the LMS to the SIS, but the SIS becomes their system of record only after a member of staff approves them. The formal academic record therefore stays under human control even when scores were calculated or drafted by an AI tool. The second row concerns AI interaction records, a new kind of data that most institutions do not yet manage. Making the AI gateway their system of record means that prompts, retrieved context and outputs are kept in one place, with retention limits, where they can be audited.

3.5 The AI gateway

The AI gateway is where the framework departs most from existing models of educational interoperability. Its purpose is to apply to AI services the principle that LTI already applies to external tools: a service should receive only the context it needs for the current task, tied to a known user, role and course. The gateway has four functions.

It routes requests to approved models, which may be hosted in the country or abroad depending on the data involved. It assembles context. When a student opens an AI tutor inside a course, the gateway uses the LTI launch to identify the course and exposes only that course's published materials, and the student's own scores if the instructor allows it, as MCP resources. It enforces policy. Direct identifiers are removed before any request leaves the country, tools that have not been reviewed are blocked, and only MCP servers on an approved list can be connected, which reduces the exposure to tool poisoning and prompt injection. Finally, it records each request, the context supplied and the response, and writes learning-related interactions to the event store as xAPI or Caliper events.

Some tasks need several AI agents to work together. A tutoring agent may, for instance, ask a scheduling agent for a student's upcoming deadlines. The A2A protocol provides discovery and task exchange for such cases. In the framework these exchanges

also pass through the gateway, so that an agent cannot obtain through another agent data that it would not be allowed to read directly.

The gateway also helps with regulation. Under the EU AI Act, AI systems used to evaluate learning outcomes or to steer the learning process are high-risk and must support human oversight and record-keeping [39]. Uzbek universities are not directly bound by the Act in most cases. Still, the logging and the staff approval points built into the gateway and the grade flow are what such rules require, and the same design meets the localisation rule of Uzbek personal data law [10].

3.6 Fit with the European Interoperability Framework

The EIF was written for public administrations, but its four layers fit higher education well, especially where a national SIS exists. At the legal layer, the framework asks institutions to check each data flow against personal data law, including localisation, and to record a lawful purpose in the governance register. For data exchanged with partners in the European Union, the GDPR applies as well [40]. At the organisational layer, the system-of-record matrix and staff approval of final grades define who is responsible for what. At the semantic layer, shared code lists for programmes, courses and grading scales, published through the roster service, prevent the same course from appearing under different codes in different systems. At the technical layer, the standards in Table 1 supply the interfaces. The Interoperable Europe Act of 2024 requires public bodies to carry out interoperability assessments before changing digital public services that cross borders [41]. A similar assessment, applied whenever a university adds an AI service, would be a cheap way to stop new silos from forming.

3.7 Maturity model

Institutions do not move from manual exports to a governed ecosystem in one step. Table 3 sets out five levels that can be used for self-assessment and planning.

Table 3. Interoperability maturity levels for LMS, SIS and AI integration.

Level	Typical practice	Main risk	Next step
L0 Manual	CSV exports; duplicate data entry; grades copied by hand	Errors and delays in academic records	Declare systems of record; introduce single sign-on
L1 Point-to-point	Custom scripts or vendor connectors between pairs of systems	Integrations break on upgrades; no shared security model	Replace connectors with OneRoster and LTI 1.3
L2 Standards-based core	Single sign-on with OpenID Connect; roster synchronisation with OneRoster; tools launched through LTI 1.3	AI tools still added outside the standards	Route all AI services through LTI and an AI gateway
L3 Event-ready	Automated grade return; learning events in Caliper or xAPI; system-of-record matrix in force	Analytics outpace data protection rules	Purpose register; retention rules; review of analytics uses
L4 Governed AI ecosystem	AI gateway with an MCP allow-list and mediated A2A traffic; verifiable credentials; conformance testing of all components	Dependence on young AI protocols	Track changes in standards; publish national profiles

The AI-specific elements appear only at level 4, and this is deliberate. An institution that cannot yet keep its class lists in sync will not be able to control what data its AI tools see.

3.8 Illustrative scenario

The following constructed scenario traces one data flow through the framework at a state university that uses HEMIS as its SIS together with an open-source LMS. At the start of term, sections and enrolments for a microeconomics course are published from HEMIS through the roster service. The LMS creates the course and its class list automatically, and students sign in with their university accounts.

During the term students use an AI writing-feedback tool that is launched from the LMS through LTI 1.3. The launch tells the tool who the student is, what role they have and which course they are in, and nothing more. When a student asks for feedback, the AI gateway supplies the assignment brief and the rubric as context and removes the student's name and identifier before it calls an external model. The tool's comments are stored with the submission, and an xAPI statement records that AI feedback was requested.

At the end of term the instructor marks the final essays in the LMS, partly using rubric scores suggested by the AI tool. Scores reach the LMS gradebook through Assignment and Grade Services. The instructor reviews and approves the final grades, which are then sent to HEMIS as OneRoster gradebook results. Only at that point does HEMIS become the record of the final grade. Students who pass receive a digital course certificate as an Open Badges 3.0 credential, signed by the university and stored in their own wallets. A future employer or a partner university abroad can verify it without contacting the registrar.

Each hand-over in this flow uses a published standard, and the AI tool never holds more than the brief, the rubric and an anonymised essay. If the university later replaces the AI tool, the new one connects to the same interfaces.

4. Discussion

The framework builds on earlier proposals. The NGDLE report argued for a learning environment made of interoperable components and treated interoperability as its foundation but it predates current AI services and says little about the SIS side. Learning analytics research has shown how standard event formats such as xAPI make it possible to combine data from many tools [42] and has set out principles for the ethics and privacy of analytics [43]. The present framework joins these lines of work and adds two elements: a system-of-record matrix that also covers AI interaction data, and an AI gateway that subjects AI services to the same rules on identity, data minimisation and logging as any other tool.

For emerging digital economies the main argument for standards is economic. Point-to-point integrations are cheap to start and expensive to maintain, and they tie institutions to particular vendors. Open standards let a university change its LMS or its AI provider without rebuilding every connection, which strengthens its position in negotiations with suppliers [44]. In Uzbekistan the existence of a single national SIS creates an unusual opportunity. If HEMIS offered a OneRoster 1.2 interface, and later an Edu-API interface, every university and every vendor would integrate against the same specification once, instead of each university commissioning its own connectors. A national profile that fixes which optional fields and code lists are used would settle most semantic questions at the same time. Such a profile would also serve the aims of the national AI strategy, which calls for standards and data infrastructure to support AI.

The framework has costs and risks. Certification against standards and the work of mapping local data to standard models require skills that are scarce in many universities. Edu-API was not yet final at the time of writing, and the AI protocols are changing quickly. The security problems reported for MCP in 2025 show that AI protocols should be introduced behind a gateway with an allow-list, not opened directly to every model. Data localisation adds a further constraint, because many capable AI models are hosted abroad. De-identification at the gateway is a partial answer only. Free-text student work can

contain personal information that automated tools miss, so some uses will require in-country hosting.

Better interoperability also makes it easier to collect and combine learner data, which raises the cost of misuse. A review of learning analytics policies found that institutions often lack clear rules on purpose, consent and access. A systematic review of learning analytics for study success found promising but still limited evidence that analytics improve student outcomes [45], which argues for collecting data for defined purposes rather than collecting everything that the new interfaces make available. The governance layer of the framework, with its purpose register and retention rules, is there to keep integration from turning into surveillance.

The study has limitations. The framework has been evaluated analytically and through a constructed scenario, not in a live deployment. The analysis covered open international standards; national and vendor-specific interfaces, including the current interfaces of HEMIS, were outside the scope of the document analysis. Standards also change, so Table 1 reflects their state at the time of writing. Future work should test the framework with two or three universities and measure, before and after adoption, the time spent on manual data handling, the number of discrepancies between LMS and SIS records, and the effort needed to add a new AI service. A national OneRoster or Edu-API profile for HEMIS would be a useful practical output of such a study.

5. Conclusion

Platform silos in higher education are an old problem, but AI services make them more expensive. Each AI tool connected outside institutional standards adds another copy of student data, another login and another stream of decisions that nobody audits. This paper proposed a standards-based framework that connects LMS, SIS and AI services through a shared interoperability layer, names one system of record for each data object, and places AI services behind a gateway that limits their context and logs their actions. The framework relies on mature open standards where they exist, treats the new AI protocols with the caution their age calls for, and offers a maturity model so that institutions can progress in stages. For Uzbekistan, where a national information system already holds the records of most students, standard interfaces at the national level could connect more than two hundred institutions to their teaching and AI tools without each of them building and maintaining its own integrations.

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