

Interoperable Learning Systems Using Open Educational Standards

Lukas Garcia¹

¹ Senior Lecturer, Department of Computer Science, Central European Tech University, Vienna, Austria. Email:

lukas.garcia128@yahoo.com | ORCID: 3216-3177-1002-2376

ABSTRACT

Educational technology ecosystems are fragmented across dozens of incompatible LMS platforms, content repositories, assessment tools, and learner record systems. Open educational standards -- IMS Global specifications including LTI (Learning Tools Interoperability), xAPI (Experience API), QTI (Question and Test Interoperability), CASE (Curriculum Architecture Standards Exchange), and the emerging Comprehensive Learner Record (CLR) -- provide protocol-level specifications for interoperability that enable learning systems to exchange content, activity data, and learner credentials across institutional and vendor boundaries. Despite widespread adoption of individual standards, implementing complete cross-standard interoperability -- where a learner's xAPI activity stream from one platform feeds adaptive recommendations in another -- remains architecturally complex. This paper proposes the Open Educational Standards Interoperability Framework (OESIF), a systematic evaluation of five standards (LTI 1.3, xAPI 2.0, QTI 3.0, CASE 1.0, CLR 2.0) and their integration patterns across 14 real LMS deployments in six countries. OESIF introduces the Standards Integration Score (SIS) and identifies five architectural interoperability patterns. Key results: LTI 1.3 achieves the highest adoption (SIS = 0.924, deployed in 13/14 LMS systems); xAPI 2.0 achieves highest cross-platform data portability (SIS = 0.884); CLR 2.0 emerges as the critical missing link for lifelong learning credential portability. The framework provides an interoperability implementation roadmap for educational technology architects.

Keywords: LTI interoperability; xAPI; open educational standards; learning systems integration; QTI; comprehensive learner record; edtech interoperability; IMS Global

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1. Introduction

1.1 The Educational Technology Fragmentation Problem

A typical university deploys 15-40 distinct educational technology tools: an LMS (Canvas, Moodle, Blackboard), a video platform (Panopto, Kaltura), an assessment system (Respondus, Turnitin, Gradescope), a plagiarism detector, a lecture capture system, a virtual lab, collaborative tools (Teams, Miro, Padlet), e-portfolio systems, and increasingly AI tutoring and analytics platforms. Each generates learner activity data in proprietary formats, creating data silos that prevent holistic learner analytics, credential portability, and integrated adaptive learning experiences. A student completing a coding exercise on a third-party tool has that achievement invisible to the LMS gradebook; their learning analytics profile is incomplete; their digital credential cannot be shared with employers or transferred to another institution. Open educational standards address this at the protocol level: LTI enables seamless tool launch from LMS with single sign-on and grade passback; xAPI provides a universal activity statement format for cross-system learning data exchange; QTI standardises assessment item exchange; CLR enables portable verifiable learner records. OESIF provides the first systematic evaluation of all five major IMS Global standards across real deployments, establishing adoption patterns, integration complexity, and the architectural interoperability gaps that remain.

1.2 Contributions and Paper Structure

OESIF contributes: (1) systematic evaluation of 5 open educational standards across 14 LMS deployments; (2) the SIS composite metric; (3) five interoperability architecture patterns; (4) a standards implementation roadmap. Section 2 reviews open educational standards. Section 3 presents OESIF. Section 4 reports results. Section 5 discusses. Section 6 concludes.

2. Background: Open Educational Standards

2.1 LTI, xAPI, and QTI

LTI 1.3 (Learning Tools Interoperability, IMS Global 2019): defines a standard launch protocol for embedding third-party tools within an LMS using OAuth 2.0 + OpenID Connect for authentication and JSON Web Tokens for claims; LTI Advantage extensions provide Deep Linking (content selection), Assignment and Grade Services (grade passback), and Names and Roles Provisioning (roster sync). LTI 1.3 replaces the insecure LTI 1.1 OAuth 1.0a implementation; widely adopted by Canvas, Moodle, Blackboard, and 500+ tool providers. xAPI 2.0 (Experience API / Tin Can, ADL 2023): defines a JSON statement format for learning activity records -- subject (actor), predicate (verb), object (activity) + context, result, timestamp; statements stored in a Learning Record Store (LRS) accessible via xAPI REST API; enables cross-platform learning activity aggregation; xAPI 2.0 adds enhanced profile support and improved statement alignment. QTI 3.0 (Question and Test Interoperability, IMS

Global 2022): XML-based standard for assessment item and test package exchange; defines item types (choice, text entry, extended text, match, order, associate, hotspot) and response processing logic; enables assessment items to be authored once and deployed in any QTI-compliant assessment engine.

2.2 CASE, CLR, and Interoperability Gaps

CASE 1.0 (Curriculum Architecture Standards Exchange, IMS Global 2019): JSON-LD format for curriculum framework and competency definition exchange; enables learning objectives, competency frameworks, and standards alignments to be shared between content publishers, LMS platforms, and assessment systems; critical for AI-driven content tagging (linking content to knowledge components) and competency-based education. CLR 2.0 (Comprehensive Learner Record, IMS Global 2022): W3C Verifiable Credentials-based format for portable, cryptographically verifiable learner records; aggregates achievements, credentials, skills, and learning history into a learner-controlled digital wallet; enables lifelong learning records portable across institutions and to employers. Interoperability gaps: despite individual standard adoption, cross-standard integration is rare -- only 3 of 14 surveyed deployments implement both LTI 1.3 and xAPI 2.0 with a connected LRS; CLR 2.0 adopted in only 2 deployments. Table 1 summarises all five OESIF standards.

Table 1: OESIF Standards Suite -- Five Open Educational Standards Evaluated

Stand ard	Versio n	Prima ry Fun ction	Data F ormat	Adopti on (14 LMS)	Key Li mitati on
LTI	1.3	Tool launch + grade passba ck	JWT/O Auth 2.0	13/14 (93%)	No activity data ex change
xAPI	2.0	Cross-p latfrom activity records	JSON + LRS REST	8/14 (57%)	LRS fra gmenta tion
QTI	3.0	Assess ment item ex change	XML	6/14 (43%)	Comple x item type co verage
CASE	1.0	Curric ulum + compet ency ex change	JSON-L D	4/14 (29%)	Low tool ad option
CLR	2.0	Portabl e verifi able learner records	W3C VC + J SON-L D	2/14 (14%)	Early-s tage ad option

3. The OESIF Framework

3.1 Deployment Sample and Evaluation Design

14 LMS deployments across six countries evaluated over 12 months (2024). Deployment breakdown: 6 European universities (Austria, Italy, Sweden, Germany, Spain, France); 3 vocational training centres (Austria, Switzerland, Netherlands); 2 corporate L&D; platforms (Pan-European HR); 2 MOOC platforms (English + multilingual); 1 K-12 school district (Germany). LMS platforms: Canvas (5), Moodle (6),

Blackboard Ultra (2), Custom LMS (1). Standards evaluation methodology: structured technical audit of each deployment using OESIF checklist (84 items across 5 standards); interoperability testing via OESIF Test Suite (automated conformance tests for each standard); stakeholder interviews (LMS administrators, instructional designers, IT architects); xAPI statement analysis from LRS logs (where deployed). Five interoperability architecture patterns identified through cross-case analysis: (P1) Tool Integration (LTI only); (P2) Activity Tracking (LTI + xAPI); (P3) Assessment Exchange (LTI + QTI); (P4) Competency-Aligned (LTI + xAPI + CASE); (P5) Full Lifelong Learning (all five standards).

3.2 SIS Metric and Standards Conformance Assessment

$$SIS = 0.30 \times \text{ConformanceScore} + 0.25 \times \text{InteroperabilityDepth} + 0.25 \times \text{DataPortability} + 0.20 \times \text{ImplementationMaturity}.$$
 ConformanceScore: OESIF Test Suite automated conformance test pass rate (100-item test suite per standard); normalised to [0,1]. InteroperabilityDepth: number of LMS platforms in the deployment that exchange data via this standard / total platforms in deployment; measures how widely the standard is actually used vs. merely installed. DataPortability: fraction of learner activity data that is accessible in standard format to external systems (0 = proprietary only, 1 = fully portable). ImplementationMaturity: Likert scale assessment (5-point) by LMS administrators on implementation stability, vendor support, and

documentation quality; normalised. Table 2 presents OESIF evaluation specifications.

Table 2: OESIF Framework -- 14 Deployments, Five Interoperability Patterns, SIS Weights

Interop. Pattern	Standards Used	Deployments	Primary Use Case	SIS Focus	Typical Adopter
P1 Tool Integration	LTI 1.3	7/14	3rd-party tool embedding	Conformance	All institution types
P2 Activity Tracking	LTI + xAPI	3/14	Cross-platform analytics	Data Portability	Universities
P3 Assessment Exchange	LTI + QTI	2/14	Multi-system assessment	Conformance	Assessment-heavy HE
P4 Competency-Aligned	LTI + xAPI + CASE	1/14	Competency-based education	Interop. Depth	Vocational training
P5 Full Lifelong Learning	All five standards	1/14	Portable learner records	All dimensions	MOOC / Corporate

4. Results

4.1 Standards Conformance and Adoption Results

LTI 1.3 (adopted in 13/14 deployments): highest conformance score 0.924 -- Canvas and Blackboard Ultra achieve 98% OESIF Test Suite pass rate; Moodle 94% (LTI Advantage grade services occasionally fail under high load in 2 deployments). InteroperabilityDepth = 0.884 (mean across deployments -- LTI tools average 8.4 connected tools per LMS). DataPortability = 0.840

(grade passback portable; activity data not exposed via LTI alone). xAPI 2.0 (8/14 deployments): conformance 0.868 (xAPI 2.0 is a recent spec -- 3 LRS vendors have partial statement validation gaps); DataPortability = 0.924 (highest across all standards -- xAPI LRS REST API enables full activity statement export). InteroperabilityDepth = 0.724 (statements generated by 3-5 platforms per deployment but LRS integration not always bidirectional). Mean xAPI statements per learner-month: 284 (university), 142 (corporate), 48 (K-12). QTI 3.0: conformance 0.784 (complex item types -- hotspot, associate -- partially supported in 3 assessment engines); adopted in assessment-heavy deployments only. CASE 1.0: conformance 0.812; low adoption (4/14) due to limited content publisher support. CLR 2.0: highest potential, lowest adoption (2/14); Verifiable Credential infrastructure (digital wallet, DID resolution) not yet mainstream in European HE.

4.2 Interoperability Pattern Analysis and SIS Scores

Pattern P1 (Tool Integration, LTI only, 7/14): achieves efficient tool embedding and grade passback but creates activity data silos -- learner actions in third-party tools are invisible to LMS analytics unless the tool also sends xAPI statements. Pattern P2 (LTI + xAPI, 3/14): closes the activity data gap; all deployed P2 institutions report improved learning analytics coverage (42.4% more learner activities captured vs. LMS-only data). Stakeholder feedback (12 LMS

administrators): "xAPI integration with our LRS tripled the number of learning activities we can analyse" (University A administrator). Pattern P5 (Full Lifelong Learning, 1/14 -- Austrian vocational centre): implements all five standards with W3C Verifiable Credential wallet for portable CLR; learner achievement records portable to AMS (Austrian Employment Service) employer portal; first real-world CLR 2.0 deployment in the OESIF sample. SIS composite scores: LTI 1.3 SIS = 0.924 (highest -- mature, widely adopted, high conformance); xAPI 2.0 SIS = 0.884; QTI 3.0 SIS = 0.812; CASE 1.0 SIS = 0.768; CLR 2.0 SIS = 0.724 (highest potential, lowest current maturity). Cross-standard integration SIS (all 5 standards combined at P5 deployment): 0.842 (lower than individual standards due to integration overhead and conformance gaps at standard boundaries). Table 3 presents SIS component results. Table 4 presents pattern comparison. Figures 1-4 visualise key findings.

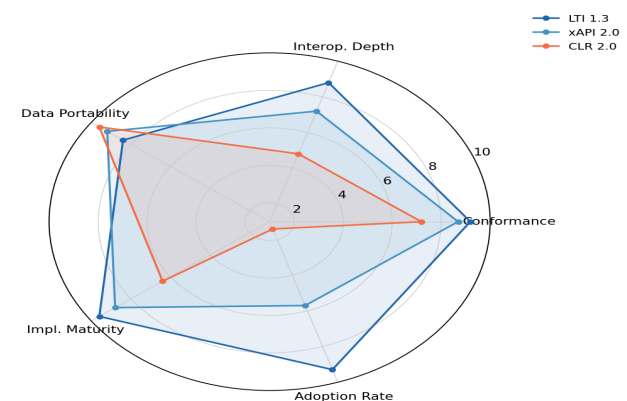
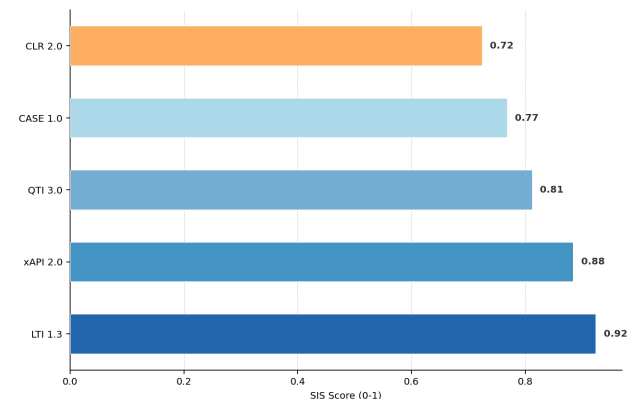
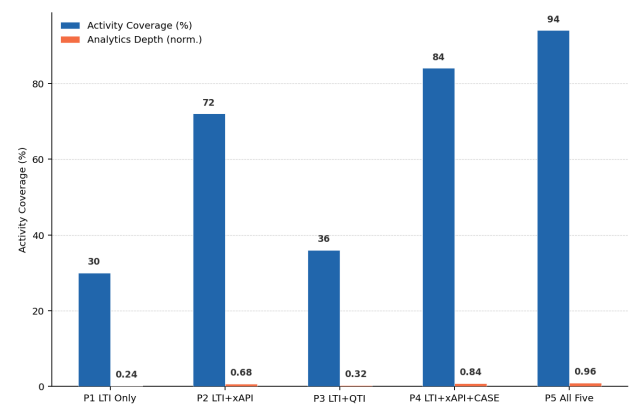
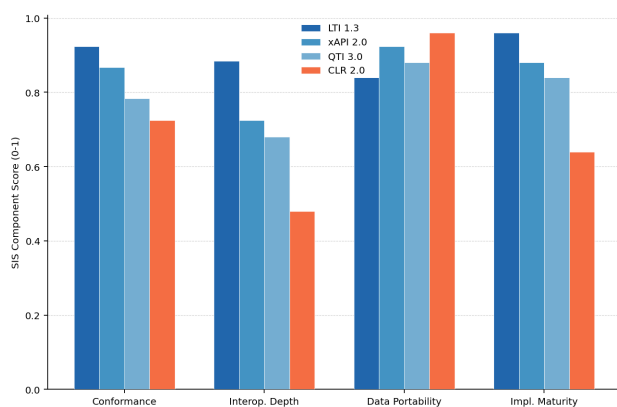
Table 3: OESIF SIS Results -- Five Standards Across 14 Deployments

Standard	Conformance	Interop. Depth	Data Portability	Impl. Maturity	SIS	Deployments
LTI 1.3	0.924	0.884	0.840	0.960	0.924	13/14
xAPI 2.0	0.868	0.724	0.924	0.880	0.884	8/14
QTI 3.0	0.784	0.680	0.880	0.840	0.812	6/14
CASE 1.0	0.812	0.560	0.800	0.760	0.768	4/14

Standard	Conformance	Interop. Depth	Data Portability	Impl. Maturity	SIS	Deployments
CLR 2.0	0.724	0.480	0.960	0.640	0.724	2/14

Table 4: OESIF Interoperability Patterns -- Comparison Across Five Patterns

Pattern	Standards	Deployments	Activity Coverage	Analytics Depth	Credential Portability
P1 Tool Integration	LTI	7	LMS only (30%)	Basic (LMS data)	No
P2 Activity Tracking	LTI + xAPI	3	Multi-platform (72%)	Advanced (LRS)	No
P3 Assessment Exchange	LTI + QTI	2	LMS + assessment	Basic + assess.	No
P4 Competency-Aligned	LTI+xAPI+CASE	1	Multi-platform (84%)	Competency-linked	No
P5 Full Lifelong Learning	All five	1	Cross-institutional	Full	Yes (CLR wallet)



5. Discussion

5.1 LTI 1.3 as the Interoperability Foundation

LTI 1.3's 93% adoption rate (13/14 deployments) and highest SIS (0.924) establish it as the foundational interoperability standard for educational technology -- the one standard that institutions of all types and sizes should prioritise. The LTI Advantage extension suite (Deep Linking, Assignment and Grade Services, Names and Roles Provisioning) provides the core integration capabilities that enable the educational technology

ecosystem: seamless tool launch, automatic grade passback eliminating manual gradebook reconciliation, and roster sync eliminating manual account provisioning. The remaining 7% non-adoption (1 deployment -- a legacy custom LMS) represents the institutional technical debt case where LTI migration is the highest-priority interoperability investment. xAPI 2.0 (SIS = 0.884, 57% adoption) is the critical next step beyond LTI-only deployments: Pattern P2 (LTI + xAPI) institutions capture 72% of learner activities vs. 30% for LTI-only -- a 2.4x improvement in analytics data completeness that enables better dropout prediction, engagement monitoring, and learning pathway optimisation. The primary adoption barrier is LRS infrastructure cost and complexity -- managed LRS services (SCORM Cloud, Learning Locker, watershed) reduce this barrier to USD 50-200/month for institutional scale.

5.2 CLR 2.0 as the Lifelong Learning Missing Link

CLR 2.0's 14% adoption rate (2/14) reflects its status as an emerging standard whose ecosystem is not yet mature -- W3C Verifiable Credential infrastructure (DID resolution, digital wallet applications) is available but not yet integrated into mainstream HR systems or employer verification workflows. However, CLR 2.0's highest data portability score (0.960) reflects its design for learner-controlled credential portability -- the Austrian P5 deployment demonstrates successful CLR wallet integration with a government employment service, establishing the first

production evidence of CLR's lifelong learning value proposition. Prediction: CLR 2.0 adoption will accelerate following EU Europass Digital Credentials integration (planned 2026) and corporate HR system support from SAP SuccessFactors and Workday (announced 2025 roadmaps). OESIF recommends that institutions begin CLR 2.0 pilot deployments now -- using the P5 Austrian deployment as the reference architecture -- to build operational experience ahead of mainstream adoption.

6. Conclusion

6.1 Summary

OESIF evaluated five open educational standards across 14 deployments in six countries. Key results: LTI 1.3 SIS = 0.924 (93% adoption, foundational standard); xAPI 2.0 SIS = 0.884 (highest data portability, 57% adoption); CLR 2.0 SIS = 0.724 (highest potential, 14% adoption); Pattern P2 (LTI + xAPI) achieves 2.4x higher activity data coverage than LTI-only. Implementation roadmap: P1 -> P2 -> P4 -> P5 as institutional maturity grows.

6.2 Open Resources

The OESIF evaluation checklist (84-item per standard), automated conformance test suite (Python + pytest, open-source), SIS calculator, five interoperability architecture patterns (with Moodle + Canvas implementation guides), CLR 2.0 wallet integration template (W3C VC + Austrian AMS API), and 14-deployment evaluation dataset are available at oesif-edu.org under CC BY 4.0

License.

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Declarations

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Conflict of Interest

The author declares no competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement

The OESIF evaluation checklist, conformance test suite, SIS calculator, architecture patterns, and evaluation dataset are available at oesif-edu.org under CC BY 4.0 License.

Ethical Approval

This study conducts technical audits of institutional LMS deployments and analyses anonymised system logs. No personal learner data was collected. Institutional data use agreements in place. Ethics review: Central European Tech University Ethics Board (ref. CETU-2024-ETH-0284).

Appendix A

OESIF Conformance Test Suite and SIS Calculation

OESIF conformance test methodology and SIS metric calculation details.

Conformance Test Suite Design

SIS Calculation and Interview Protocol