
Digital Attestation of Vocational Education Certificates: Transitioning to Smart Job Markets and Borderless Workforces

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Abstract

Vocational education and training (VET) certificates remain the dominant currency through which mid-skill competence is communicated to employers, yet the mechanisms for attesting them were designed for paper documents, national labour markets, and manual verification. This article examines how digital attestation, understood as the cryptographically verifiable issuance, holding, and checking of credentials, can reposition VET certificates within algorithmically mediated job markets and increasingly cross-border workforces. The study is an integrative review of peer-reviewed research and institutional policy sources published mainly between 2015 and 2026, identified through scholarly databases and verified against original records. The analysis is organised through a four-layer conceptual framework developed in the article: a cryptographic trust layer that secures the authenticity of the certificate; a semantic interoperability layer that renders its meaning machine-readable across systems; an institutional recognition layer that connects verification to quality assurance and qualifications frameworks; and a labour-market utilisation layer in which verified credentials

function as hiring signals inside data-driven matching platforms. The review finds that technical verification is the most mature layer, while semantic and institutional alignment lag behind and constrain the value of attested certificates for cross-border employment. Equity emerges as a cross-cutting condition, since infrastructural and skills gaps can exclude the very workers VET serves. The framework offers policymakers and credentialing bodies a structured basis for sequencing investment, and identifies the coupling between attestation infrastructure and skills-based hiring as a priority for empirical research.

Keywords: digital credentials, vocational education and training, blockchain attestation, micro-credentials, labour mobility, skills recognition, verifiable credentials

1. Introduction

The certificate is the point at which education systems and labour markets meet. For vocational education and training, whose graduates typically enter employment directly rather than progressing to further study, the credibility of that document carries particular weight: it is often the principal evidence of competence a worker can present to an employer who has never met them. Yet the infrastructure through which vocational certificates are issued, authenticated, and interpreted has changed far less than the labour markets in which they are used. Employers increasingly recruit through digital platforms that parse applications algorithmically (Broecke, 2023), advertise roles in terms of discrete skills rather than whole qualifications (Bone et al., 2025), and hire across borders at a scale that manual document checking was never designed to support (Chakroun & Keevy, 2018).

The mismatch produces two well-documented failures. The first is fraud. Paper certificates and scanned copies are vulnerable to forgery, and verification through direct correspondence with issuing institutions is slow, costly, and inconsistent (Rustemi et al., 2023;

Said et al., 2025). Fraudulent credentials corrode the meritocratic function of both education systems and hiring processes, because employers who cannot distinguish genuine from counterfeit documents rationally discount all of them. The second failure is illegibility. Even an authentic vocational certificate frequently fails to communicate, in terms a foreign employer or an algorithmic matching system can interpret, what its holder can actually do (Keevy et al., 2026). A welding qualification from one country reaches a recruiter in another as an unfamiliar document title, not as a structured statement of competences aligned to a recognised framework.

Digital attestation addresses both failures in principle. Cryptographic techniques can make certificates tamper-evident and instantly verifiable without contacting the issuer (Capece et al., 2020; Rani et al., 2024). Data standards and qualifications frameworks can make their content machine-readable and comparable across borders (Council of the European Union, 2022). Self-sovereign identity architectures can place the credential under the control of the worker rather than the institution (Grech et al., 2021; Chan et al., 2025). A substantial technical literature now demonstrates feasibility, and policy instruments such as the European digital credentials infrastructure indicate institutional appetite. What the literature has not yet resolved is how these strands connect: research on verification systems, on micro-credentials and recognition policy, and on labour-market signaling has developed in largely separate communities, and studies of blockchain certificate systems rarely engage the economics of hiring, while signaling research rarely considers the verification infrastructure its instruments presuppose. There is, in consequence, no integrated account of what digital attestation must accomplish, across technical, semantic, institutional, and labour-market dimensions at once, for VET certificates to function in smart job markets and to travel with mobile workers.

The stakes of the gap are raised by two converging developments that give this article its subtitle. The first is the emergence of what can be called smart job markets: hiring

environments in which vacancy data, applicant records, and matching decisions are expressed as structured skill information and processed by algorithmic intermediaries (Colombo et al., 2019; Broecke, 2023). In such markets a credential participates in hiring only to the extent that its content can be verified and parsed without human mediation. The second is the normalisation of cross-border and remote work, which detaches the labour market a vocational graduate can access from the national system that certified them. Both developments reward exactly what conventional attestation cannot deliver: instant verification and machine-readable meaning at negligible marginal cost.

This article addresses that gap. It asks two questions. First, what does the existing evidence, technical, educational, and economic, establish about each dimension of digital attestation for vocational certificates? Second, how can these dimensions be integrated into a single framework that explains where current initiatives succeed, where they stall, and what sequencing of effort follows? The contribution is conceptual: an integrative review organised through a four-layer framework of digital attestation, developed inductively from the reviewed literature. The article proceeds as follows. Section 2 reviews the literature thematically. Section 3 describes the review method. Section 4 presents the framework and its four layers. Section 5 discusses implications, limitations, and research directions, and Section 6 concludes.

2. Literature Review

2.1 Certificate fraud and the verification burden

The scale of credential fraud is difficult to measure directly, but the research response to it is extensive. A systematic review of blockchain-based academic certificate verification identified thirty-four relevant studies published between 2018 and 2022 from an initial pool of

more than seventeen hundred records, and organised them into six themes ranging from issuance architectures to revocation (Rustemi et al., 2023). The consistent motivation across this body of work is that conventional verification, in which an employer or admissions office writes to the issuing institution and awaits confirmation, is slow, expensive, and unreliable, particularly across borders and in systems where records are fragmented or have been destroyed (Khan et al., 2021; Castro & Au-Yong-Oliveira, 2021). Proposed systems anchor certificate hashes or full credential objects on distributed ledgers so that any verifier can confirm authenticity without contacting the issuer. Implementations span permissioned architectures for national education authorities (Khan et al., 2021; Rani et al., 2024), public-chain deployments with decentralised storage designed to cover multiple education levels within one country (Said et al., 2025), and institutional pilots built on open standards such as Blockcerts (Capece et al., 2020). Evaluations report acceptable throughput and latency for realistic transaction volumes (Rani et al., 2024), and comparative analyses find cost and speed advantages over both manual verification and centralised digital registries (Said et al., 2025).

Two qualifications recur. First, most systems are prototypes or single-institution pilots; the literature demonstrates feasibility more convincingly than adoption (Rustemi et al., 2023). Second, the technical work concentrates on higher education diplomas, with vocational certificates treated as an afterthought despite VET's larger share of mid-skill labour markets and its greater exposure to informal and cross-border employment (Chakroun & Kevvy, 2018). This imbalance matters because the institutional structure of VET, with many small providers, sectoral bodies, and workplace-based assessment, poses harder issuance and trust problems than a university registry.

2.2 Micro-credentials and the changing unit of certification

A second literature examines what is being certified. Micro-credentials, short and focused records of learning, have moved from the margins of online education into national

and supranational policy (Bideau & Kearns, 2022; Council of the European Union, 2022). A systematic review of stakeholder perspectives finds that learners want short, career-relevant units, institutions emphasise accreditation and trust, employers demand clarity about the competences a credential certifies, and governments seek employability gains, with these expectations only partially aligned (Varadarajan et al., 2023). In VET specifically, micro-credentials are attractive because they can certify discrete competences acquired through work, recognise prior learning, and be stacked toward fuller qualifications (Gamage & Dehideniya, 2025; Pouliou, 2025).

The evidence on employer uptake is mixed. Survey research with human-resource professionals finds recognition of the resume value of micro-credentials alongside persistent doubts about their legitimacy and transferability (Alasmari, 2024). Employer-facing studies of online micro-credentials in soft-skill domains report willingness to treat them as feasible training evidence, conditional on authentic, practice-based assessment (Bruguera et al., 2025). Critical scholarship warns that micro-credentials can function as gig credentials for a gig economy, unbundling qualifications in ways that transfer training costs and risk to individual workers (Wheelahan & Moodie, 2022). The relevance for attestation is direct: as the unit of certification shrinks and multiplies, the volume of documents to be verified grows, and the case for automated, low-cost verification strengthens accordingly (Stanelytè, 2026). Pilot work in East African universities shows that competency-based ePortfolios coupled to digital micro-credentialing can make employability skills visible to employers in contexts where traditional transcripts do not (Maina et al., 2022).

2.3 Credentials as labour-market signals

Economic research supplies the theoretical foundation for why attestation matters at all. In signaling terms, a credential has value to the extent that it credibly communicates unobservable productivity. Experimental work with human-resource managers shows that

signals of cognitive skills, social skills, and maturity on application documents causally affect interview invitations, with the effective signal differing between apprenticeship applicants and graduates (Piopiunik et al., 2020). Field experiments in the German apprenticeship market demonstrate that employers screen on school-report signals of both cognitive and noncognitive skills, applying thresholds rather than linear rankings (Protsch & Solga, 2015). Most directly relevant to VET attestation, a field experiment in Uganda found that certificates disclosing workers' noncognitive skills improved matching between workers and firms and raised earnings, indicating that credible certification of otherwise unobservable competences has real allocative value in labour markets with weak information infrastructure (Bassi & Nansamba, 2022).

The demand side of signaling is itself changing. Analysis of approximately eleven million United Kingdom job postings finds that employers in shortage occupations have begun substituting skill requirements for degree requirements, with measured skills commanding wage premia that rival formal qualifications (Bone et al., 2025). Vacancy-data research shows that machine-readable skill taxonomies now mediate how demand is expressed and matched (Colombo et al., 2019), and reviews of algorithmic recruitment document the spread of automated parsing, shortlisting, and matching alongside concerns about bias, transparency, and explainability (Broecke, 2023). A credential that an algorithm cannot verify and parse is, in such markets, progressively invisible.

2.4 Interoperability, recognition, and the cross-border problem

A fourth strand addresses the infrastructures that make credentials meaningful across systems. UNESCO's analysis of digital credentialing argues that digital learning records challenge conventional models of credential evaluation and that their value depends on synergy with qualifications frameworks and quality assurance rather than on technology alone (Chakroun & Keevy, 2018). The European approach illustrates institutionalisation: a common

definition and standard data elements for micro-credentials (Council of the European Union, 2022), an infrastructure for digitally sealed credentials linked to Europass, and continuing work on aligning credentials to framework levels (Bideau & Kearns, 2022). Recent scholarship extends this agenda to artificial intelligence, examining whether large language models can assist the comparison and levelling of qualifications across frameworks while cautioning that human oversight and accountable governance remain necessary (Keevy et al., 2026).

Learner-centred architectures form part of the same conversation. Self-sovereign identity systems issue verifiable credentials to wallets under the worker's control, allowing selective disclosure to employers without repeated recourse to the issuer (Grech et al., 2021; Chan et al., 2025). Surveys of these systems identify unresolved questions of governance, key management, revocation, and issuer credibility, and note that the gap between promise and practice remains wide in education (Grech et al., 2021).

Finally, an equity literature qualifies the entire agenda. Studies of digital technology access in vocational schooling show that material, motivational, and skills-related access conditions vary sharply by geography (Habibi et al., 2023), and analyses of the digital divide in developing economies and the G20 argue that skills and infrastructure gaps reproduce exclusion unless deliberately countered (Chetty et al., 2018; Niwamanya et al., 2025). Digital attestation inherits these constraints: a verification system usable only by connected, digitally literate actors can disadvantage precisely the workers and small employers that vocational systems serve.

The equity qualification extends inside wealthy systems as well. Access research in Indonesian vocational schools, based on responses from over thirteen hundred participants, found that motivational access predicted skills access more strongly than material access predicted it, and that geography differentiated every access variable measured (Habibi et al.,

2023). The finding matters for attestation design because it locates the constraint not only in devices and connectivity but in the confidence and capability of teachers and learners, which infrastructure spending alone does not repair (Chetty et al., 2018).

Read together, the four strands show mature but siloed knowledge. What is missing is an integrated account that connects verification technology to certification units, signaling economics, and recognition infrastructure, and that is specific to the vocational sector. The present article constructs that account.

3. Method

3.1 Design and rationale

The study is an integrative review with a conceptual contribution. An integrative design was chosen over a systematic review because the relevant evidence is distributed across heterogeneous fields, computer science, education policy, and labour economics, whose research questions, methods, and quality conventions differ too much for a single effect-oriented synthesis, and because the aim is theory construction rather than exhaustive enumeration. A purely conceptual paper without a structured evidence base was rejected because the framework's claims are intended to be anchored in verifiable findings. The research questions stated in the Introduction guide the design: the first requires organised coverage of the evidence in each dimension; the second requires an explicit procedure for deriving an integrating structure from that evidence.

3.2 Search and selection

Literature was identified between June and August 2026 through structured queries of scholarly databases (Consensus, drawing on Semantic Scholar, Scopus, and related indexes) complemented by targeted web searches of institutional repositories (UNESCO, OECD,

EUR-Lex). Eight query families covered the constructs in the title: blockchain and certificate verification; micro-credentials and vocational recognition; digital credentials and cross-border mobility; self-sovereign identity in education; labour-market signaling and skill certification; skills-based hiring; algorithmic job matching; and digital-divide constraints on vocational technology adoption. Inclusion criteria were: peer-reviewed journal articles, or authoritative institutional and legal documents, published principally between 2015 and 2026; direct relevance to at least one framework dimension; and confirmable bibliographic identity. Seminal earlier work was admitted where the argument required it. Exclusion criteria were: purely promotional literature, papers whose metadata could not be verified against the original record, and technical papers with no implication beyond implementation detail. Every retained source was verified against its digital object identifier or publisher record before citation; twenty-nine sources satisfied all criteria and form the evidence base.

3.3 Analytical procedure

Analysis proceeded in three steps. First, retained sources were coded inductively by the principal problem each addresses: authenticity, meaning, recognition, or use. Second, the coded groups were examined for the dependencies among them, asking what each group presupposes from the others; this dependency analysis generated the layered structure presented in Section 4, in which each layer supplies a condition the next layer assumes. Third, the draft framework was tested against the evidence by checking, for each layer, whether the reviewed studies support the claimed function and whether documented failures of attestation initiatives correspond to missing layers. Claims in Section 4 are attributed to sources at the strength the underlying study warrants, and framework-level statements are marked as conceptual.

3.4 Rigor and boundaries

Several measures limited bias. Searches deliberately included critical scholarship on micro-credentials and algorithmic hiring so that the framework would not encode a promotional reading of the technology. No source was cited from memory; all bibliographic records were confirmed against the original publication. The review's boundaries are acknowledged: it synthesises published research and policy documents rather than new fieldwork; the policy material overrepresents the European infrastructure because that is where institutionalisation is most documented; and the framework's validity is conceptual until tested empirically. These boundaries are revisited in the Limitations subsection.

4. A Four-Layer Framework for Digital Attestation of Vocational Certificates

The dependency analysis yields a framework of four layers, each supplying a condition that the next assumes, with equity operating as a cross-cutting condition on all four. Figure 1 summarises the framework, and the subsections develop each layer with its supporting evidence. Table 1 synthesises the principal attestation mechanisms documented in the literature and locates each within the framework.

4.1 Layer 1: Cryptographic trust

The foundational layer secures the authenticity and integrity of the certificate itself. The reviewed systems achieve this through digital signatures, cryptographic hashing, and anchoring on distributed ledgers, whether permissioned architectures operated by education authorities (Khan et al., 2021; Rani et al., 2024), public chains with decentralised storage (Said et al., 2025), or standards-based deployments such as Blockcerts (Capece et al., 2020). The function of this layer is precise: it converts verification from a correspondence process

into a computation, making forgery detectable and checking effectively free at the margin. Evidence indicates the layer is technically mature; performance evaluations report workable throughput and latency (Rani et al., 2024), and comparative analyses document advantages over centralised registries in tamper-resistance and availability (Said et al., 2025). Two design tensions within the layer deserve emphasis because they shape everything above it. The first concerns governance. Permissioned architectures concentrate control in a consortium of issuers, which suits national authorities but reproduces at the technical level the institutional boundaries that cross-border attestation is meant to dissolve (Khan et al., 2021). Public-chain designs distribute trust more widely but leave open who vouches for the issuer whose signature the chain merely preserves (Said et al., 2025). The second concerns permanence and privacy. Immutability is the property that makes ledger-anchored certificates trustworthy, yet credentials sometimes must be revoked, corrected, or removed, and personal data written into permanent structures raises data-protection questions that implementations resolve by keeping credential content off-chain and anchoring only hashes (Rustemi et al., 2023; Chan et al., 2025). Neither tension is fatal, but both show that even the most technical layer embeds institutional choices.

The layer's characteristic failure mode is isolation. A cryptographically perfect certificate whose content no external system can interpret merely proves that an unintelligible document is authentic. This is the condition the second layer addresses.

4.2 Layer 2: Semantic interoperability

The second layer makes the content of the certificate machine-readable and comparable. Its instruments are data standards for credentials, skills taxonomies that decompose qualifications into competences (Colombo et al., 2019), and the standard elements defined for micro-credentials in the European approach (Council of the European Union, 2022). The layer matters because labour-market intermediaries increasingly operate on

structured skill data rather than document images (Broecke, 2023), and because the shrinking unit of certification multiplies the number of records that must be interpreted without human mediation (Stanelytė, 2026). For VET, semantic work is harder than for degrees: vocational competences are more granular, more contextual, and less standardised across countries (Chakroun & Keevy, 2018). Emerging research proposes artificial intelligence as an aid to comparing and levelling qualifications across frameworks, with explicit warnings that such systems require human oversight and accountable governance (Keevy et al., 2026). The layer also governs stackability. If micro-credentials are to accumulate toward fuller qualifications, as both policy and stakeholder research envisage (Council of the European Union, 2022; Varadarajan et al., 2023), the units must share data elements that allow a receiving institution or employer to compute what a given combination amounts to. Without common semantics, stacking is a metaphor rather than an operation. Conceptually, this layer converts an authentic certificate into usable information; without it, cryptographic trust terminates at the document boundary.

4.3 Layer 3: Institutional recognition

The third layer connects verified, interpretable credentials to the institutions that confer standing: quality assurance bodies, qualifications frameworks, professional regulators, and recognition conventions. The literature is consistent that this layer, not technology, is the binding constraint on cross-border value. UNESCO's analysis argues that digital credentials acquire portability only in synergy with qualifications frameworks and quality assurance (Chakroun & Keevy, 2018), and the European instruments operationalise this by tying digitally sealed credentials to framework levels and common data elements (Bideau & Kearns, 2022; Council of the European Union, 2022). Stakeholder research on micro-credentials shows that institutional accreditation is precisely what employers and institutions demand before trusting new credential forms (Varadarajan et al., 2023; Alasmari, 2024). Self-

sovereign architectures redistribute agency within this layer rather than abolishing it: worker-held credentials still derive authority from recognised issuers, and surveys identify issuer credibility and governance as the unresolved core of such systems (Grech et al., 2021; Chan et al., 2025). The characteristic failure mode of initiatives that neglect this layer is the pilot that verifies flawlessly but confers no standing an employer or regulator is obliged to honour.

4.4 Layer 4: Labour-market utilisation

The final layer is where attested certificates do economic work. Signaling research establishes the mechanism: credible certification of otherwise unobservable competences improves matching and can raise earnings, with the strongest experimental evidence coming from certification of noncognitive skills in a developing labour market (Bassi & Nansamba, 2022), and complementary evidence showing employers act on documented skill signals at labour-market entry (Protsch & Solga, 2015; Piopiunik et al., 2020). The demand side is shifting toward exactly the granular, skill-level information that digitally attested credentials can carry: employers in shortage fields increasingly specify skills rather than degrees (Bone et al., 2025), and algorithmic intermediaries parse, rank, and match on structured credential data (Broecke, 2023). Micro-credential pilots that make employability skills visible to employers demonstrate the layer in operation (Maina et al., 2022), while employer scepticism about legitimacy (Alasmari, 2024) shows what happens when the upper layer runs ahead of institutional recognition. The critical scholarship belongs in this layer too: if unbundled credentials feed platforms that intensify contingent work, attestation may amplify precarity rather than mobility (Wheelahan & Moodie, 2022). The framework does not resolve that normative question, but it locates it where it arises.

4.5 The cross-cutting equity condition

Every layer presupposes access: to devices, connectivity, digital skills, and institutional presence. Evidence from vocational schooling shows access conditions vary

sharply within single countries (Habibi et al., 2023), and analyses of developing economies document infrastructure, cost, and educator-capability constraints on vocational digitalisation (Niwamanya et al., 2025), with digital-skills strategy identified as the remedial lever at policy level (Chetty et al., 2018). For a framework aimed at borderless workforces the implication is sharp: the workers with most to gain from portable attested credentials, migrants and workers in low-income systems, are those most exposed to exclusion from the infrastructure that carries them. Equity is therefore modelled as a condition on all four layers rather than a fifth layer, since failure of access disables the stack wherever it occurs.

Table 1

Digital Attestation Mechanisms in the Reviewed Literature, Located Within the Framework

Mechanism	Primary function	Trust anchor	Framework layer(s)	Key evidence	Principal limitation
Permissioned-ledger attestation by education authorities	Tamper-evident issuance and verification of certificates	Consortium of authorised institutions	1	Khan et al. (2021); Rani et al. (2024)	Governance concentrated in issuing consortium; limited cross-border reach
Public-chain certificate systems with decentralised storage	Country-scale verification across education levels	Public blockchain	1	Said et al. (2025)	Adoption and legal standing untested beyond pilot context
Standards-based digital diplomas (e.g., Blockcerts)	Institution-issued verifiable diplomas	Open standard plus public chain	1–2	Capece et al. (2020)	Single-institution pilots; weak link to qualifications frameworks
Self-sovereign identity with verifiable credentials	Worker-held, selectively disclosable credentials	Decentralised identifiers; recognised issuers	1–3	Grech et al. (2021); Chan et al. (2025)	Issuer credibility, revocation, and governance unresolved
Micro-credentials with standard data elements	Granular, stackable certification of competences	Accredited issuers; common definitions	2–3	Council of the European Union (2022); Varadarajan et al. (2023)	Employer trust and transferability still contested (Alasmari, 2024)

Framework-linked digital credential infrastructure (Europass model)	Cross-border legibility and recognition	Qualifications frameworks; sealed credentials	2–3	Bideau & Kearns (2022); Chakroun & Keevy (2018)	Coverage concentrated in Europe; VET granularity challenges
Skill-certificate signaling into hiring platforms	Matching workers to jobs on verified skills	Employer-recognised certification	4	Bassi & Nansamba (2022); Bone et al. (2025)	Depends on all lower layers; algorithmic bias risks (Broecke, 2023)

Note. Layers: 1 = cryptographic trust; 2 = semantic interoperability; 3 = institutional recognition; 4 = labour-market utilisation. The table synthesises mechanisms as characterised in the cited sources; classifications by layer are the author's analytical judgement.

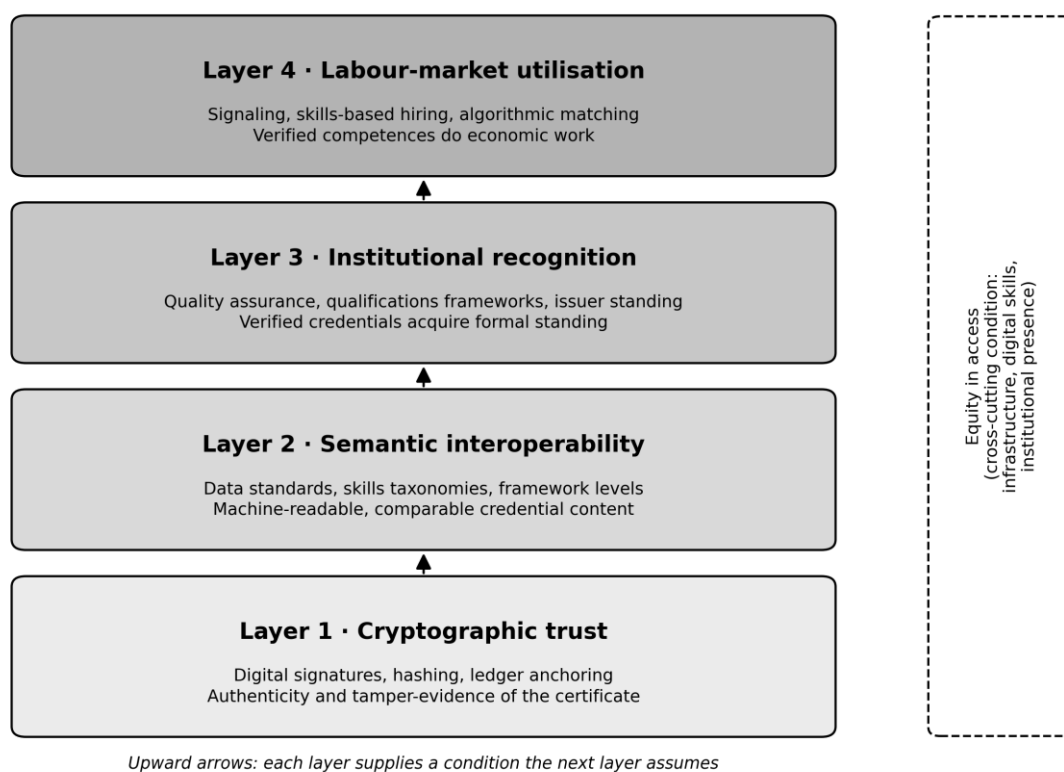


Figure 1. The four-layer framework of digital attestation for vocational education certificates. Each layer supplies a condition the next layer assumes; equity in access operates as a cross-cutting condition on all layers. Source: author's elaboration based on the reviewed literature.

5. Discussion

5.1 Theoretical implications

The framework's central claim is that digital attestation is a stack of dependent conditions, not a technology. This reframing explains a pattern the separate literatures record but do not account for: verification systems that work and are not used. In the reviewed corpus, technically successful systems stall at the semantic layer, when their certificates cannot be interpreted by external systems, or at the institutional layer, when verification confers no recognised standing (Rustemi et al., 2023; Grech et al., 2021). Conversely, signaling research presupposes credibility that only the lower layers can supply at scale; the experimental gains from skill certification observed by Bassi and Nansamba (2022) depended on a certification the employers in that market treated as credible. Connecting these literatures places credential verification inside the economics of information rather than alongside it: the lower layers of the stack are, in signaling terms, technologies for reducing the cost of credibility.

A second theoretical implication concerns the direction of dependence. The layers are ordered by presupposition, not by importance, and value flows downward as well as up. Employer demand for granular skill information (Bone et al., 2025) creates the economic case that justifies investment in semantic standards; recognition instruments give issuers a reason to adopt cryptographic infrastructure they would not adopt for its own sake (Bideau & Kearns, 2022). The framework therefore predicts that attestation ecosystems consolidate fastest where a strong fourth-layer pull, acute skill shortages or high verification costs, meets an existing third-layer architecture, and slowest where technology is supplied without either. The uneven geography of the reviewed initiatives is consistent with this prediction, though it does not test it.

The framework also clarifies what is genuinely different about the vocational case. VET certificates certify granular, contextual competences issued by heterogeneous providers, which raises the difficulty of the semantic and institutional layers relative to university degrees (Chakroun & Keevy, 2018). The literature's concentration on higher education has therefore solved the easier version of the problem. Treating VET as the primary case, as this article does, exposes the semantic layer as the sector's decisive bottleneck.

5.2 Practical and policy implications

For policymakers and credentialing bodies the framework functions as a sequencing device. Investment in cryptographic infrastructure without parallel work on data standards and framework alignment produces authentic but illegible certificates; the reviewed European instruments indicate the alternative order, in which common definitions and framework linkage precede or accompany technical deployment (Council of the European Union, 2022; Bideau & Kearns, 2022). For VET providers, the immediate implication is that issuing digitally sealed credentials aligned to standard data elements does more for graduates' mobility than joining any particular ledger. For employers and platform operators, verified credential data offers a defensible input to skills-based hiring at a moment when degree filters are weakening (Bone et al., 2025), subject to the governance concerns algorithmic recruitment already raises (Broecke, 2023). For development policy, the equity condition implies that attestation programmes in low-income systems must budget for access and capability, not only for technology, and that partnerships with enterprises can carry part of that burden (Niwamanya et al., 2025; Chetty et al., 2018).

The framework also suggests a division of labour among actors that current initiatives blur. Ledger infrastructure and wallet standards are public-good candidates best provided once and shared, as the cost structure of the reviewed systems implies (Rani et al., 2024). Semantic assets, taxonomies, data schemas, and framework mappings require the participation of

sectoral bodies that understand vocational competence, and they decay without maintenance as occupations change (Colombo et al., 2019). Recognition, finally, cannot be outsourced to technology at all: quality assurance and framework alignment remain the province of the institutions the third layer describes, and initiatives that promise to bypass them substitute verification for trust rather than producing it (Chakroun & Keevy, 2018; Grech et al., 2021). Programmes can be audited against this division: an attestation project unable to state which actor sustains each layer is incomplete in a way the framework makes visible in advance.

5.3 Limitations

Three limitations bound these claims. First, the framework is derived from published research and policy documents, not from new empirical observation; it organises existing evidence and its validity is correspondingly conceptual. Second, the evidence base is uneven: the technical layer is documented largely through prototypes and pilots rather than longitudinal adoption studies, and the policy material overrepresents the European infrastructure, so the framework's institutional layer may transfer imperfectly to systems with weaker qualifications architectures. Third, the labour-market layer rests on signaling studies conducted with instruments other than blockchain-attested certificates; the inference that attested digital credentials will reproduce those signaling gains is theoretically grounded but empirically untested. These limitations follow directly from the method and define the research agenda below.

5.4 Future research

The priority is empirical work at the junctions between layers. Field experiments issuing verifiably attested VET credentials into real hiring processes would test whether cryptographic verification changes employer behaviour, extending the design of Bassi and Nansamba (2022) to digital instruments. Comparative institutional research should examine how attestation initiatives fare in qualification systems outside Europe, where the recognition

layer is thinner. Design research on semantic interoperability for vocational competences, including the accountable use of large language models in qualification comparison (Keevy et al., 2026), addresses the bottleneck this review identifies. Finally, longitudinal study of workers using self-sovereign wallets across borders would provide the first direct evidence on whether learner-held attestation supports, or merely accompanies, labour mobility.

6. Conclusion

This article set out to explain what digital attestation must accomplish for vocational education certificates to function in algorithmically mediated, cross-border labour markets. Integrating evidence from computer science, education policy, and labour economics, it developed a four-layer framework in which cryptographic trust, semantic interoperability, institutional recognition, and labour-market utilisation each supply conditions the next layer assumes, with equitable access conditioning the whole. The review found the technical layer mature, the semantic and institutional layers decisive and comparatively neglected for VET, and the labour-market layer theoretically well founded but empirically untested for attested digital instruments. The framework converts a fragmented literature into a sequencing logic for policy and a set of testable junctions for research. As certification fragments into smaller units and hiring migrates onto data-driven platforms, the systems that attest vocational competence will increasingly determine whose skills are visible, and therefore whose work is possible, across borders.

Declarations

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Conflicts of Interest. The author declares no conflict of interest.

Ethics Statement. This study is an integrative review of published literature and involved no human participants, personal data, or animal subjects; ethical approval was therefore not required.

Data Availability. No new data were created or analysed in this study. All sources reviewed are publicly available through the references listed.

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Hashtags:

#SDG4 #QualityEducation #SDG8 #DecentWork #SDG10 #ReducedInequalities
#DigitalCredentials #VocationalEducation #BlockchainAttestation #MicroCredentials
#LabourMobility #SkillsRecognition #VerifiableCredentials #SmartJobMarkets #U7YJournal