From Silos to Manifolds:
Strategies for Improved Learner Record Administration

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ABSTRACT

The ability of modern technologies to generate learner-related data, coupled with an evolution in our understanding of job requirements, has redefined how we can and must learn. The current way learner records are managed across the Department of Defense (DoD) is insufficient for the evolving needs of instructors, learners, and organizations. Today, a transcript is generally used to record learners' permanent academic records, but these typically only include the most basic of information such as courses taken, grades received, and degrees conferred from a formal academic or training institution. Transcripts and "signature pages" provide little visibility into details of individuals' past performance, such as what other instructors have noted about them, the informal or nontraditional learning they've experienced, or their strengths, weaknesses, and individual needs.

Numerous efforts across academia, the military, and industry are being undertaken to modernize the way learner records are defined, managed, and shared. Community working groups, pilot projects, and other collaborative research efforts are being managed by public-private partnerships and various standards organizations.

This paper summarizes these initiatives with a focus on harmonizing related learner record data standards and defining requirements for harnessing DoD learner data across the continuum of lifelong learning. Two broad perspectives emerge in using discoverable and verifiable learner records: the management of individual lifelong learning and the organizational human capital supply chain. These perspectives point to the need for an approach to interface with existing authoritative learner records in a loosely coupled network, rather than a single standalone repository.

ABOUT THE AUTHORS

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INTRODUCTION

The rapid pace of innovation continues to enable new forms of training and education that generate massive amounts of rich learner data. At the same time, the learning and development community is moving away from the traditional classroom model that employs an ineffective "one size fits all" style of learning and towards a learner-centric model. This personalized learning paradigm is more efficient and effective, but it relies on robust data. Added to this, there is a growing focus on a lifelong learning model, where learning is guided by a learner's previous training, education, and experiences, current interests, preferences, and skills. Lifelong, personalized learning requires a data-driven approach that adapts to a learner's needs, current skill level, changing preferences, and available resources (e.g., what devices a learner has access to).

Managing the extensive and heterogenous collection of data about individuals' learning throughout their schooling, careers, and, ultimately, their entire lives requires a data strategy. This strategy must work with data distributed across learning activities, systems, platforms, and institutional boundaries. However, there are many challenges in achieving the requisite data interoperability across these boundaries. For example, learner data are currently stored in a variety of disparate data sources, which are often part of legacy systems. This creates proprietary data silos where access to data is limited to one group in an organization, and it makes learners' data immobile, confined to the specific organizational contexts and usage that originally generated the data.

Additionally, learner data generated from academic institutions are typically captured in a formal transcript and are limited to course-level information (e.g., courses completed, grades received). These data do not capture the full range of an individual's learning experiences (e.g., internships, workforce training programs, clubs, and volunteer activities) (Green & Parnell, 2017). In other words, today's learner records tend to overrepresent formal learning experiences (Walcutt & Malone, 2019).

Furthermore, relevant workforce data are usually stored in the form of resumes, self-report job applications, and formal credentials (e.g., degrees, licensures). However, such is rarely integrated with the other training and education output data, and even when workforce data are considered, it is difficult to harmonize the training/education data with the job/task experience data. In part this is because the Knowledge, Skills, Abilities, and Other characteristics (KSAOs) represented by these workforce artifacts are not universally defined, making verification of their practical value difficult (American Workforce Policy Advisory Board, 2019). As such, they often lack the requisite level of granularity to make informed data-driven workforce decisions.

Many organizations are conducting research to address these challenges, which will eventually facilitate a modern and more effective data strategy for describing, storing, and transporting learner data. Specifically, organizations are researching portable, sharable, and extensible learner records as well as supporting lines of effort related to data standards, privacy (e.g., protection of Personally Identifiable Information (PII)), governance, bandwidth (data scalability), and evidentiary chains (preservation of source data integrity). One such data solution is a *data fabric*.

In this paper, we discuss several prominent learner record efforts across academia, industry, and the Department of Defense (DoD) as well as considerations for their continued improvement. Moreover, we examine a data fabric approach as a potential solution for achieving enterprise interoperability. Finally, we outline several challenges that must be addressed prior to the implementation of an enterprise-wide solution.

BACKGROUND: NUMEROUS LEARNER RECORD STANDARDS, SPECS, AND PROJECTS

The Many Specifications and Standards for Learner Record Data

Data standards prescribe how data are packaged and communicated to other systems. Many different organizations are working to create data standards for learner data. These are meant to enable the reliable and ethical distribution of learner data across systems and organizations.

One of the largest and most ambitious efforts comes from the T3 Innovation Network (T3 Network). As part of their larger effort to transform the talent marketplace, the T3 Network is working with data standards organizations to support the public-private adoption of open data standards (Tyszko, 2020). The T3 Network was established through the collaboration of the U.S. Chamber of Commerce Foundation and Lumina Foundation. They are comprised of over 400 organizations, with a focus on changing the way we provide, access, and use educational and workforce data.

Through their 2019 work on learner records (originally referred to as the Comprehensive Learner Worker Military Record (CLWMR)), the T3 Network compiled a list of relevant candidate standards and specifications (see Table 1).

Table 1. CLWMR Charter List of Standards and Specifications

Data Standard Title	Data Standard Publisher
Common Education Data Standards	CEDS
Credential Transparency Description Language (CTDL)	Credential Engine
CTDL Achievement Standards Network (ASN)	Credential Engine
Assessments	HR Open Standards
Candidate	HR Open Standards
Position Opening	HR Open Standards
Screening	HR Open Standards
Resume or CV Standard	HR Open Standards
Open Badges 2.0	IMS Global
Competencies and Academic Standards Exchange (CASE) 1.0	IMS Global
Comprehensive Learner Record 1.0 (Candidate Final)	IMS Global
Schema.org	Schema.org/W3C
College Transcript	PESC
Common Credential	PESC
High School Transcript	PESC
PESC EDEXCHANGE	PESC
GEO CODE	PESC
ELMO	CEN / EMREX (EU)
EDCI	European Commission
Europass	European Commission and Cedefop
CCI	Lumina
Professional Profile	MedBiquitous, AAMC
Educational Achievement	MedBiquitous, AAMC
W3C Verifiable Credentials and Distributed Identifier (DID)	W3C
IEP and Student Demographics	A4L
Joint Services Transcript*	DoD
Enterprise Learner Record Repository	DoD
Total Learning Architecture	DoD

As the table above implies, there is a need to harmonize or reconcile the various standards and specifications that will play a role in achieving learner data interoperability. The T3 Network is attempting to do this, but they are not alone. For example, the Institute of Electrical and Electronics Engineers (IEEE) Learning Technology Standards Committee (LTSC) established the "1484.2 Integrated Learner Records" study group in early 2020 to examine interoperability across learner record standards and help address requirements established by related initiatives. Similarly, the U.S. Department of Commerce American Workforce Policy Advisory Board (AWPAB) has identified interoperable learner records as a key area of focus.

Pilot Projects and Supporting Research

T3 Innovation Network
The T3 Network is leading a series of pilot projects focused on the convergence of Web 3.0 technologies to create a more responsive, dynamic, and equitable workplace and to better equip learners—with data and technology—to succeed in a data-driven marketplace (T3 Network, 2018). Of these, the Learner Record Standards and Data Harmonization project team are harmonizing related data standards. In doing so, they have generated five primary use cases for interoperable CLWMRs. These include the following (T3 Network, 2019):

1. Publish professional profile on the open web and social networking sites
2. Exploring career opportunities
3. Apply for, enroll in, and complete education, training, and credentialing opportunities
4. Apply for and accept employment opportunities
5. Manage career advancement and transition

Initially, two project teams explored public-private standards for supporting these use cases, and now they are conducting pilot tests to enhance those standards and promote their use to support interoperability.

American Workforce Policy Advisory Board
The AWPAB is designing an Interoperable Learner Record (ILR) to translate the culmination of a learner's education, training, and work experience into a seamless record. Their goal is to improve the communication of a learner's skills between workers, employers, and institutions to support career growth. As shown in Figure 1, the ILR is comprised of an open-standards four-layer approach. These layers include the:

1. *File cabinet,* which allows the curation and sharing of learner credentials
2. *Envelope,* which verifies the integrity of credential data and validates the identity of the issuer and learner
3. *Letter,* which contains details about each credential issued to a learner
4. *Ontology,* which represents common language and schemas for occupations, jobs, competencies/skills, and credential types
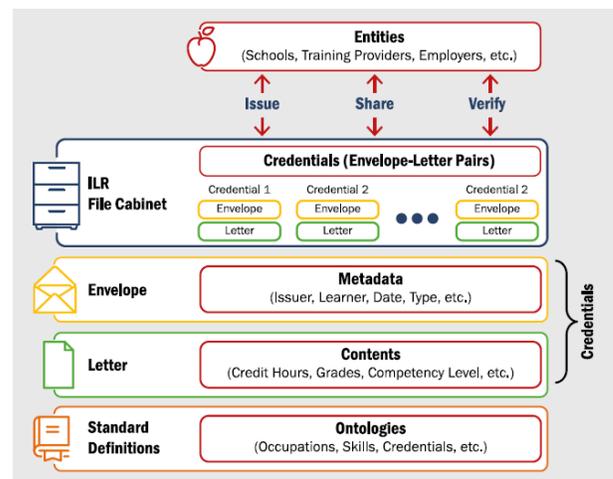

Figure 1. Interoperable Learning Record

This approach supports a use case where learners can use their own ILR to manage career growth, and employers can leverage these records to support their human capital supply chains (AWPAB, 2019).

AACRAO, NASPA, and NILOA
The American Association of Collegiate Registrars and Admissions Offices (AACRAO), National Association of Student Personnel Administrators (NASPA), and National Institute for Learning Outcomes Assessment (NILOA), partnered to develop and deploy Comprehensive Learner Records (CLRs) across higher education institutions. This effort is partially supported by grants from the Lumina Foundation. The goal of the CLR was to showcase individuals' learning from a variety experiences inside and outside of the classroom (e.g., co-curricular engagements, learning outcomes, and learning artifacts).

In Phase I (2015-2017), a model for developing these records was established. Next, 12 institutions used this model to implement digital student records (e.g., e-portfolios, co-curricular transcripts, and badges). For example, the University of Maryland Global Campus implemented an extended transcript that could be shared with employers. This transcript captured gained competencies during a student's experience at various universities. As a result, employers were able to better understand student's knowledge and performance capabilities based on the context of their overall performance (Green & Parnell, 2017).

Phase II (2018-2019) focused on implementing the CLRs in approximately 150 colleges and universities while also working to standardize CLR components through partnership with Competency-Based Education Network (C-BEN; AACRAO, 2019). Data integration challenges, potential solutions, and opportunities for tracking outcome and competency progress were explored (AACRAO, 2018). The culmination of these phases resulted in institution-specific learner records, that while useful in their given context, could not be distributed across boundaries (e.g., other institutions or licensing agencies).

Following the CLR developments, IMS Global Learning Consortium (IMS Global) worked with institutions in C-BEN to develop the first CLR data specification. In their 2020 CLR standardization report, AACRAO concluded that the IMS Global CLR standard was the only "standard in place today that meets the objectives of an official institutional learning-focused and comprehensive learner record" (AACRAO, 2020). More specifically, the CLR specification is tailored towards institutions, learners, and the digital credentials ecosystem to support verifiable and interoperable academic records.

The Digital Credentials Consortium
The Digital Credentials Consortium (DCC), led by the Massachusetts Institute of Technology (MIT), is designing an infrastructure that issues, stores, displays, and verifies digital credentials of academic achievement. This credential system utilizes a transparent governance learner-centric model. Institutions can issue verifiable digital diplomas and credentials without a human registrar, and learners can take ownership of how they communicate their learning experiences to external parties (e.g., employers).

The credential system has several distinguishing features. First, a flexible identity model supports multiple options for expressing identity that also tie into existing real-world identities (e.g., university ID, self-sovereign ID). Secondly, it includes reliable credential revocation mechanisms and lifecycle management. Thirdly, it gives learners direct agency over credential lifecycle management (e.g., direct ownership over what, where, and to whom credentials are exchanged). Lastly, it attempts to create consistency among credential formats (e.g., machine-readable data, human-readable data, and paper or digital copies) (DDC, 2020).

Furthermore, the World Wide Web Consortium's (W3C) Verifiable Credentials (VC) Data Model supports the overarching interoperable credentialing ecosystem by digitally expressing credentials in a way that is learner-centric and tamper-evident. This ecosystem has five major components (DDC, 2020):

1. *Issuer:* Entity issuing credentials to the learner (e.g. university)
2. *Wallet:* Software a learner interacts with to manage their credentials and profiles
3. *Agent:* Software assisting the learner in the management, storage, and exchange of credentials
4. *Hub/Vault:* Learner-chosen secure encrypted storage location
5. *Relying Party*: Organization or party the learner chooses to share a credential with (e.g., potential employer)

DCC will continue to refine their initial work on a digital credential infrastructure through future pilot projects.

U.S. Department of Education, Office of Educational Technology
In February 2020, the U.S. Department of Education, via their Office of Educational Technology, launched the Education Blockchain Initiative (EBI) managed by the American Council on Education (ACE). EBI focuses on evaluating blockchain technology for its potential in improving the educational workforce pipeline. To provide context, a blockchain is a shared, distributed ledger technology of cryptographically signed transactions that are arranged into blocks. Each block is cryptographically linked to the previous block through a consensus and encryption process. As a result, the stored data is tamper-proof and trusted (ACE, 2020).

Phase I of this effort centered on foundational research to better understand the application of blockchain in education. In support of this research, 71 active blockchain efforts were reviewed and analyzed. These efforts ranged from various stages of development, research, and planning. Their findings pointed to potential new opportunities for advancing social equity in areas of personal data agency, lifelong learning, and the power of connected ecosystems. On the other hand, several concerns emerged such as the cost of adding or shifting to new systems and how data ownership and control would be addressed. Further, the nascent state of blockchain and other distributed ledgering technologies, points to the need for additional research and testing to understand the value proposition for use in the educational context (ACE, 2020).

Following Phase I, ACE launched the Blockchain Innovation Challenge. Specifically, organizations were invited to design pilots that explored how blockchain could connect or create ecosystems where learners could exercise agency over their learner records and gain improved economic mobility. Future efforts will continue to explore the opportunities and risks of blockchain in improving the existing education-to-employment paradigm.

DoD Efforts

The initiatives discussed so far largely focus on the interoperability of data between academic and industry organizations through trusted credentials and shared definitions of competency. However, the DoD is also pursuing various development efforts. For example, the Airman's Learning Record (ALR) is an initiative that falls under Air Education and Training Command (AETC). The ALR program is part of the Force Development Registrar that maintains the integrity and authenticity of learner records through an institutionalized process for developing definitions of competency, validating the alignment between activities and competencies, and verifying digital credentials through trusted chains of evidence.

The ALR captures and consolidates the entirety of an Airman's training, education, experiential development, and competencies obtained on the job, off-duty throughout their career, and prior to joining the military. This requires integration with numerous authoritative sources for learner data within the Air Force. Data ownership, data stewardship, and Authorities to Connect drive towards a data fabric approach for enabling interoperability between these systems. Current learner record standards are focused on the exchange of credentials across organizational boundaries. The ALR also requires the collection and storage of more granular learner data to help understand the current state of the learner. Instructors and, eventually, automated systems will use this data to remediate learner misconceptions or misperceptions. This data will also be used to provide an evidentiary chain of learner data to support competency-based learning (Roberson & Stafford, 2020).

A similar effort is underway from the Army Training Information System (ATIS), which is a formal governance and acquisition program that is part of the U.S. Army and Program Executive Office Enterprise Information Systems (PEO EIS). The objective of ATIS is to develop an enterprise system of capabilities, that will result in a worldwide distributed learning system to ensure on-demand training. One such capability is the Army Learning Management System (ALMS), a centrally managed and funded system for training management. In addition to training and education resource, scheduling, delivery, distribution, and registration management, ALMS provides permanent record keeping of training activities and results, increasing overall training value (ATIS, 2020).

Finally, the DoD Chief Management Office (CMO) Enterprise Digital Learning Modernization (EDLM) reform is developing an Enterprise Learner Record Repository (ELRR). The EDLM goal is to build an enterprise-wide digital learning environment to include streamlined and centralized acquisition of new education and training capabilities, an enterprise catalog of education and training courses, and the aforementioned ELRR for all training and education records. This environment will enable improved and more rapid acquisition and greater cost-optimization for education and training products and services (Sims et al., 2020).

Section Summary: Considerations for Learner Record Redefinition

While not a comprehensive list of related learner record standards, specifications, and projects, it does represent current thinking and identifies similarities across different architectural approaches. When looking across the projects and approaches, several lessons learned stand out.

First, early architectural reviews indicate a reliance on point-to-point messaging topologies. A point-to-point topology is a simple technical design that works for very small networks. In particular, they require explicit connections between every system that shares data. While this is manageable for a small number of systems, as the systems of systems grows in complexity, so too does the cost and technical management complexities. For this reason, a point-to-point approach is not a recommended solution for supporting the DoD's transition to enterprise capabilities and services (Department of Defense, 2019).

Secondly, future efforts should expand on existing use-cases to ensure transportability across disparate academic, industry, and DoD boundaries. As it stands now, the majority of learner record initiatives are focused on the academic-workforce pipeline. For this reason, a deeper understanding of the policies and barriers that exist within DoD is needed to adequately inform and ensure representation within ongoing standards development. Likewise, security and privacy constraints should also be considered to ensure DoD requirements are met (Department of Defense, 2014).

Thirdly, learner records are shifting towards a credential or micro-credential approach. In this approach, the evidentiary requirement is the digital signature of an authoritative source. In other words, the signature signifies the trust established with the authoritative body, but an evidentiary chain is not established. As such, the originating data where learning actually occurred is not preserved. This is the data that is most valuable to the training and education community because it affords us the opportunity to better understand what a learner knows.

For example, an Airmen learner receives a 90% grade in a course that teaches multiple job-related competencies. While they still receive an "A" in the course, they continually demonstrate a misconception of a critical competency. This reveals a missing KSAO that should be addressed. By their nature, credentials establish a baseline of expected learner capabilities. However, not all credentials provide visibility into the specific learner pathways that define individual capabilities over their career, as well as the individual strengths and weaknesses that can be used to adapt learning experience to specific learner needs (e.g., to address identified gaps).

Finally, legacy training and education architectures rely upon messaging architectures that make new copies of source data in a local repository in order to limit the message payload size and ensure scalability. This results in an over-normalization of residual data to manage message sizes. Further, after ingesting this data, most systems process it locally without consideration of other systems that need it. Instead, an architecture that can encode the lineage of learner data from its source (and all of the transformations it has undergone between the current application and that source) in all its rich complexity is needed to improve and maintain readiness. Specifically, detailed learner performance data can provide insights into human elements of mission success, leading to rapid and improved analyses (Sharif & Schramm, 2018). As a result, these data can contribute to concurrency of learning events and reduced learning outcome variances that will culminate in overall readiness improvements.

To address the limitations identified in this section, we recommend a data fabric approach to encoding, storing, transforming, and sharing learner data. The next section describes that technical design in detail.

DATA FABRIC ARCHITECTURAL DESIGN

The sheer number of different applications and platforms that generate learner-related data make data management difficult (Department of Defense, 2019). Within DoD, learning-related data are generated by and stored across multiple disconnected data stores around the Department. Consequently, the data cannot be easily shared horizontally (across sister organizations) nor vertically (from local schools to top-level leadership). However, we can define an enterprise approach for learner record management that allows data to be safely transferred across systems. This approach requires a modern data architecture with the appropriate tools and technologies to provide a logically integrated solution with global access (Department of Defense, 2019).

One solution is to use a data fabric, which is an architecture and set of data services that acts as a framework to manage, transport, and protect data across distributed and diverse data sources. It is comprised of several layers, including applications and services, ecosystem integration, data management, storage management, transport, and endpoints. A data fabric typically employs tools and technologies that preserve data lineage as well as reference to the relationships between (among) data elements.

Using a data fabric approach, learner data can be physically distributed, while still maintaining logical connections and access. This occurs through federated connections across multiple sites. These sites rely on a combination of on-premise data stores, cloud environments, and potentially any number of learner devices, interfaced through a standard Application Programming Interface (API). These distributed learner data stores connect through a set of data access applications allowing any authorized user or analytic application to search and audit learner data through the API. The logical connection is maintained by linking between concepts so they can be shared, instead of copying them (Third & Domingue, 2017).

Current data owners need to maintain ownership of their data within a larger organization (Department of Defense, 2015). As a result, source integrity for applications that rely on learner data is preserved, and the ability to scale arithmetically is ensured. Furthermore, applications only require a single connection to the data fabric via an API instead of multiple connections to multiple applications. Finally, a data fabric connection presents a single-entry point for all learner service requests.

What is more, linked data resolves semantic differences across data, such as competency definitions, credential frameworks, runtime learner data, learning activity metadata, and local/global learner attributes (e.g. preferences). As a result, the context surrounding learner performance can be unlocked while also supporting scalability and

extensibility. Additionally, linked data can support future initiatives like the automation of key processes, machine learning and artificial intelligence. Ultimately this can lead to increased efficiency and improved insights into readiness of capable manpower across the DoD, and a more responsive workforce and training and education pipeline.

To put it more simply, let us imagine this scenario: A qualification record in the Navy's Personnel Qualification System (PQS) states that a Sailor must demonstrate the ability to "start a bilge pump" to be qualified to stand a watch station. Now, imagine the technical manual for the pump is updated. This may impact personnel who were trained on the old standard. What if we could digitally link these concepts so we knew the standard was updated (via the normative reference)? Further, what if we could search for who was trained and under which version, thereby ascertaining that those personnel needed updated training? As it is done now, the PQS only records the credential. As a result, none of the details of when or how the subordinate elements in demonstrating "start a bilge pump" are preserved. However, by linking data through a data fabric approach, we can unlock the ability to perform the type of ad hoc analyses discussed in the above scenario.

Technical Approach

Scalable interoperability across systems requires both technological (syntactic) interoperability and semantic precision. The semantic interoperability piece refers to a common vocabulary for how we describe data elements associated with competencies, credentials, activities, and other data frameworks. The alignment of learner records to these underlying data structures promotes interoperability across contexts, institutions, and employers.

Due to the wide range of systems that currently store learner data, any technical approach for aggregating and sharing data must be built around commercially available standards. In other words, to expose the learning data currently locked in silos and scattered across various organizations, shared approaches for encoding, transporting, and processing those data are needed. Additionally, those data standards need to address four areas (Gordon et al., 2020):

1. Learning opportunities – Data describing available learning experiences, e.g., courses, job assignments
2. Learning activity streams (runtime) – Data on runtime performance, e.g., quiz item answers, course paradata
3. Learner profile (longitudinal) – Data aggregated and abstracted from runtime performance, e.g., transcripts
4. Competencies – "Common currency" across the other data pillars that creates semantic interoperability

Most applicable for this discussion are pillars two, three, and four.

The *Experience Application Programming Interface* (xAPI; IEEE 9274) provides the foundation for the collection of learner data from all training and education activities at the most tactical level (pillar 2) (Barbieru, 2014). The corresponding *xAPI Profile Specification* (IEEE 9274.2) also offers a common way to document the vocabulary (or semantic interoperability) of xAPI data elements; this is required for xAPI to be implemented consistently across the spectrum of learning activities that an individual will encounter. Using xAPI, the learner data generated from various learning activities (e.g., simulators, gradebooks, tablet, online course, observer/controller ratings) can be distilled into common formats and terms, and then populated into a specialized data store called a Learning Record Store (LRS). LRSs are the server-side component of xAPI that enables the sharing of learner data across different systems. LRSs follow specific rules for receiving and sending data.

LRSs can be federated across different systems and locations. Edge systems (e.g., learning activities such as e-learning or gradebooks) can collect granular (or "noisy") data and then normalize those data for use in the core systems. Learning activities store raw learner performance data in a *noisy LRS* at the local level; noisy LRSs manage every xAPI statement generated by a learner within a given activity. Next, the *Master Object Model* (MOM; IEEE 9274.3) abstracts performance adjudication to edge systems by following the *learning event lifecycle* defined using cmi5 xAPI Profile verbs to report failure or success. This xAPI Profile normalizes the learner data as it rolls up from the noisy LRS to the *transactional LRS*. The transactional LRS aggregates learner data from all learning activities in an organization.

A competency management system parses the MOM statements to pull metadata about each activity, defined in IEEE P2881 Standard for Learning Metadata (part of data strategy pillar 1). It also pulls metadata about the formal definitions of each competency set that an activity is aligned with, as defined using IEEE 1484.20.1 Reusable Competency Definition (RCD; part of pillar 4). Competency management requires the generation of rich, traceable data about learning experiences, how they relate to skill proficiency, and the KSAOs that individuals need to do their job. Additionally, competency data often require the certification or authentication of a trusted agent. This is where credentials come into play. Credentials are defined using the Credential Transparency Description Language (CTDL),

which references the RCD. Digital signatures are then written to an *authoritative LRS* that captures learner credentials with pointers to the original learner performance data (pillar 3).

The data fabric approach allows us to extend the credential model and adopt a competency to credential evidentiary chain. Further, by not requiring a change in ownership or stewardship, all current data owners can maintain the data they already own. Credentials are still valid, and are generally accepted as the currency of personnel capabilities, but now they can be supported by a trusted chain of evidence. This evidentiary chain tracks the specific context and learning pathways that led to the conferral of credential. These benefits include:

1) Making data about the learner beyond the credential baseline available (e.g., to show additional skills and experiences that may be useful)
2) Preserving the learner specific-preferences and characteristics that facilitate individualized adaptive learning
3) Providing the data required to continuously improve the integrity of credentialing and related training products based on the efficacy of the training and related assessments, as well as downstream impacts on readiness

A data fabric approach provides these benefits by retaining links between data sources that can be navigated as a response to specific queries. More specifically, a data fabric uses intermediate indexing and caching of data to enhance computational performance. In this way, the entire content of a particular concept does not need to be sent along with every message request. This approach not only captures credentials but creates a common approach for storing and accessing original learner data across organizational levels. In other words, this approach preserves data lineage (for improved reliability and validity) and enables bidirectional data exchange across organizational echelons (for improved data utility).

Vertical Interoperability: Data Exchange Across Organizational Echelons

The data stored in an enterprise learner record must, necessarily, connect from low (tactical) organizational levels to high (strategic) ones. The requirements and uses of those data vary across organizational levels. In general, the uses of learning data across echelons can be abstracted into five levels (or control loops; see Figure 2). Each control loop has its own data sources and sampling requirements (Gordon et al., 2020). The control loops include:

1. **Learning Activities**: Learner data for the current learning activity or used to optimize the task at hand.
2. **Credentials**: Data supporting the sequencing and planning of learning activities in pursuit of credentials, which may require completion of multiple courses.
3. **Job Performance**: Data about a learner use to optimize obtainment of a set of competencies and credentials in support of an individual's current job. This includes feedback mechanisms for de-credentialing if proficiency is not maintained in certain skills.
4. **Career Arc**: Lifelong learning data to support the planning, placement, and evaluation of individual career growth, including planning development trajectories that are aligned with organizational needs.
5. **Career Transition**: Selecting a new career goal along with all of the associated competencies, credentials, training, education, and other experiences.

As shown in Figure 2, optimization of learning and workforce activities within each control loop helps to contribute to mission effectiveness. That is, each one provides unique and additional value.
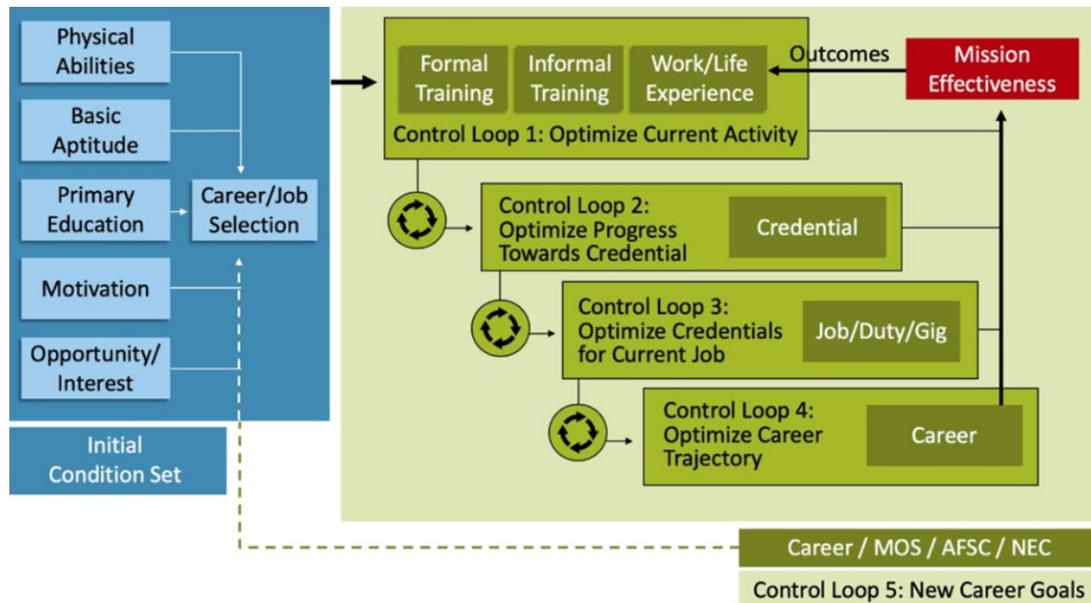
Figure 2. Learning Control Loops

Implementation Challenges

The data fabric approach is complex to implement and maintain. For example, an overall governance strategy is required to facilitate the careful management of the data. Configuration management of the major data elements that comprise each learner record, including naming conventions and namespaces, must be managed globally. This also requires cascading status accounting because links will change as elements (e.g., competency definitions) are updated over time. This is a solvable problem, however; the Internet Corporation for Assigned Names and Numbers (ICANN) does this already for Internet Protocol (IP) addresses and Domain Names. (In many ways applying the data fabric concept to learner data within the overall training and education enterprise creates an "internet for learning" as its future learning ecosystem.)

Another issue involves identity management—ensuring that all (and only) the data associated with a unique person is tagged with that person's identity. Fortunately, there are already efforts aimed at addressing this issue. In DoD, a Defense-wide approach for managing user identity already exists under a set of Federal guidelines, processes and constraints known as "Federated Identity, Credential and Access Management" (FICAM). FICAM provides procedures for validating and verifying user identity, limiting access to system resources based on that identity, and establishing a set of roles and permissions associated with each learner's access across DoD networks. Identity verified through technical credentials (e.g., passwords, Personal ID Verification cards) provides a globally unique digital signature that is tied back to an authoritative data store used to resolve learner identity and relevant personal information. This standardized approach to identity needs to be implemented across all training and education activities connected to the data fabric (Gordon et al., 2020).

The use of linked data presents another potential challenge due to the necessary use of cross-domain scripting. Missing links can lead to potential stability issues. Additionally, links to untrusted sources provide a potential vector where malicious mobile code can be introduced (Joint Task Force Transformation Initiative, 2013). To mitigate this vulnerability in the DoD context, use of linked data should be designed around the use of a DoD schema.mil capability—that is, an authoritative source within the DoD security boundary. This supports the anchoring of linked data definitions and fully qualified namespaces.

Further, cybersecurity risks for the PII data must be addressed. For example, encryption for data at rest is required to protect against malicious code. This should occur at the points of origin and destination (e.g., for xAPI messages and derivative badging data). Additionally, learning record providers (e.g., learning management systems, mobile learning apps) and learning data consumers should be separated and protected. The use of Transport Layer Security (e.g., HTTPS) to provide encryption of data in transit also helps prevent the introduction of malicious code and data from unauthorized applications, and procedures for registering all devices into the future learning ecosystem offer additional measures of protection (Dierks & Rescorla, 2008).

Overcoming these challenges provides value across industry, academia, and government workforce by enabling the federation of data across the cloud and on-site learner data and facilitating just-in-time access to all relevant learner data via an API.

CONCLUSION

One of the principal goals for modernizing learning records is to enable a learner-centric lifelong learning path, that supports improved human capital supply chain management. Within DoD, this means providing servicemembers the ability to pursue and acquire skills that are suited to them as individuals, while ensuring the optimal accession, training, education, detailing and evaluation of manpower and personnel to perform assigned missions. Ultimately these system improvements can realize downstream positive effects of improving readiness and maintaining readiness in the future with better cost performance.

A data fabric approach presents a modern solution for overcoming data preservation and scaling challenges that exist when dealing with interoperable learner data across boundaries. The use of a data fabric approach results in connected, searchable repositories of detailed learner performance data that provides many benefits like reducing the time required to perform periodic reviews of credentialing requirements, curricular structure and learning materials available. These contribute to maintaining concurrency of learning events by providing a formal mechanism to determine all the places in which a platform/system configuration change may impact training materials in all potential fields and applications. They also reduce learning outcome variances, by accounting for individual characteristics and preferences, while improving the rate of return on asset by eliminating less efficacious learning experiences in favor of ones that have shown empirically to have positive impact on readiness, instead of just making those decisions based on total ownership cost.

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