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Semantic Technologies for Cybersecurity Education Competencies: JSON-LD Implementation of Distributed Learning Analytics

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Abstract

Educational technologies struggle to represent the human-AI collaborative competencies increasingly central to cybersecurity practice. Current learning management systems and assessment frameworks assume individual human learners interacting with passive technological tools, failing to capture the distributed agency and technological mediation that characterize contemporary professional work. This research addresses these limitations by developing semantic web representations of posthumanist educational concepts using JSON-LD schemas. Through in-depth qualitative analysis of the NICE Framework's Technology Portfolio Management work role (OG-015)—examining 73 coded instances across 9 posthumanist categories—we demonstrate how qualitative posthumanist coding can be translated into machine-readable formats while preserving theoretical sophistication. This detailed case study approach shows how JSON-LD enables computational analysis of human-technology entanglement patterns in professional competencies. The resulting semantic framework supports SPARQL queries that reveal collaborative learning processes, technological mediation patterns, and distributed agency requirements, with patterns suggesting broader applicability across the 52 NICE Framework roles. This methodology provides a practical pathway for developing educational technologies that recognize learning as emerging through human-AI assemblages rather than occurring within isolated human subjects. Results demonstrate the feasibility of operationalizing posthumanist theory for educational technology design, offering new possibilities for curriculum development and assessment in domains where human-AI collaboration is fundamental to professional practice.

Keywords: Posthumanism, Semantic Web, JSON-LD, Educational Technology, Human-AI Collaboration, Learning Analytics

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1. INTRODUCTION

Current educational technology systems operate under fundamentally human-centered assumptions that position learners as autonomous agents and AI systems as neutral tools supporting individual achievement. Learning management systems track discrete individual metrics, adaptive algorithms adjust content delivery based on presumed cognitive deficits, and learning analytics predict outcomes while ignoring the complex socio-technical assemblages that actually constitute contemporary learning environments. This paradigm obscures the entanglements between humans and technological systems that characterize knowledge emergence in digitally-mediated contexts.

Posthumanist and postphenomenological perspectives challenge these models by recognizing agency as distributed across human and non-human actors within technological assemblages (Taylor & Hughes, 2016; Rosenberger & Verbeek, 2015). Rather than treating technology as external support, posthumanism—the decentering of the human as the sole origin of meaning and agency—reveals how AI systems actively mediate, shape, and co-constitute learning processes in ways that transform rather than merely extend human capabilities (Adams & Thompson, 2016). These mediators fundamentally alter meaning and ontological status as knowledge moves across contexts, challenging assumptions about stable learning objects and linear transfer (Gourlay, 2015).

Cybersecurity education provides an ideal domain for exploring these approaches, as professional practice increasingly involves human-AI collaboration. Security analysts work alongside automated detection systems, threat intelligence platforms, and decision support tools in ways that blur traditional boundaries between human and machine agency. A previous pilot analysis of the National Initiative for Cybersecurity Education (NICE) Cybersecurity Workforce Framework (V1) education-focused work roles (OG-WRL-004: Cybersecurity Curriculum Development, and OG-WRL-005: Cybersecurity Instruction) revealed that 89.4% of competency statements in education-focused roles contained posthumanist elements, with significant co-occurrence patterns between human and technological adaptive learning concepts, suggesting that cybersecurity education already recognizes—though perhaps implicitly—the entangled nature of human-technology collaboration (Straight, 2024).

This work operationalizes these insights through semantic technologies, using JavaScript Object Notation for Linked Data (JSON-LD) schemas to represent distributed agency, technological mediation, and collaborative knowledge construction in machine-readable formats. Rather than forcing posthumanist concepts into human-centered data structures, we develop vocabulary and relationship models that preserve theoretical nuance while enabling practical applications. The contribution extends beyond cybersecurity education by providing methodological frameworks for representing human-AI collaboration across domains where traditional learning analytics fail to capture contemporary knowledge work complexity.

2. POSTHUMANISM IN EDUCATIONAL CONTEXT

Traditional approaches to educational technology assume learning occurs within individual human minds, with technology serving as delivery mechanism or assessment tools (Shutkin, 2019). Such designs embed anthropocentric assumptions about agency, cognition, and knowledge that posthumanist theory fundamentally challenges (Braidotti, 2019). Educational AI systems assume autonomous, rational human subjects as sole loci of agency, representing learners as independent agents whose behaviors can be predicted and optimized through data analytics (Oshiesh, 2025; Akintola et al., 2025). This individualistic model fails to account for posthumanist insights about agency as distributed across human and non-human actors—including technologies, algorithms, and environmental factors that actively participate in rather than simply support learning processes.

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These platform designs employ transmission models where knowledge represents pre-defined content delivered and measured through standardized assessments, failing to account for learning as emergent and relational (Schlyter et al., 2012). Data-driven models treat assessment as neutral processes that quantify and predict performance, obscuring the performative and political dimensions that posthumanist perspectives reveal as reinforcing dominant power structures while marginalizing alternative ways of knowing.

Learning is thus revealed as emerging through dynamic interactions between human learners, educational content, technological interfaces, algorithmic processes, and institutional structures. Rather than occurring "in" individual minds, learning happens "between" and "through" these actors in ways that challenge traditional subject-object distinctions. This perspective suggests educational technologies should represent learning processes as collaborative achievements rather than individual accomplishments, fundamentally altering how we conceptualize assessment, curriculum design, and educational AI ethics.

Minimal attention is given to mediating effects of educational technologies, treating them as implementation details rather than fundamental aspects of learning processes (Bower, 2019). Assumptions that technological mediation can be separated from learning content reflect the problematic notion that texts maintain stable meanings across digital contexts, when the movement between print-based and digital media involves constant transformation of both content and significance (Gourlay, 2015).

A postphenomenological analysis demonstrates that technologies actively mediate human experience rather than serving as neutral conduits for information transfer. When students interact with educational AI systems, these technologies shape perception, attention, and understanding in ways that extend beyond simple content delivery to constitute the very conditions under which learning becomes possible. Recommendation algorithms influence what knowledge appears relevant and accessible, interface designs shape how concepts are understood and connected, and assessment systems mediate how learning is recognized, validated, and institutionally credentialized.

Recognizing technological mediation as constitutive of learning rather than merely supportive would require learning analytics that evaluate human-AI collaboration effectiveness rather than individual human performance metrics, curriculum designs that explicitly address how AI systems influence perception and decision-making rather than simply teaching tool usage, and assessment approaches that recognize collaborative competencies as legitimate educational outcomes.

Distributed Agency and Collaborative Knowledge Construction

Posthumanist theory challenges the assumption that agency resides exclusively within human actors. In contemporary learning environments, algorithmic systems make decisions about content presentation, pacing, and assessment that directly influence learning outcomes in ways that extend far beyond simple automation of human-designed processes. Rather than diminishing human agency, these technological actors participate in distributed networks where agency emerges through interaction rather than individual control (Taylor & Hughes, 2016).

Educational approaches that emphasize adaptive learning environments responsive to complex, interconnected, and rapidly evolving technological systems align with this perspective (Kennedy, 2022; Tam, 2000). However, current implementations of adaptive learning maintain human-centered assumptions by treating adaptation as technological response to individual human needs rather than recognizing adaptation as a collaborative process involving both human and technological actors.

This leads to fundamental questions about educational assessment and responsibility distributed across human-technology assemblages. Adams et al. (2023) emphasize reconceptualizing agency as relational achievement rather than individual possession, requiring assessment frameworks that evaluate collaborative emergence rather than discrete human performance.

Assessment in learning environments that recognize technological mediation as fundamental rather than incidental would evaluate collaborative competencies between humans and AI systems rather than isolating individual human performance, requiring new frameworks for understanding educational responsibility and achievement.

Validation Through Cybersecurity Education

Our previous analysis of the NICE Cybersecurity Workforce Framework (V1) provides empirical validation for posthumanist approaches to formal

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cybersecurity education. Statistical analysis revealed that 89.4% of statements in education-related work roles contained posthumanist elements, with significant co-occurrence patterns between human adaptive learning (AL-H) and technological adaptive learning (AL-T) concepts (Author, 2024). These findings suggest that cybersecurity education (to a certain degree, at least) already recognizes the collaborative nature of human-AI work that posthumanist theory makes explicit.

The cybersecurity domain offers particular advantages for posthumanist analysis because professional practice explicitly involves human-AI collaboration, operating in ways that blur traditional boundaries between human and machine agency. Unlike domains where AI integration appears as enhancement to fundamentally human activities, cybersecurity work increasingly depends on human-AI assemblages where agency is genuinely distributed across technological and human actors.

Applying posthumanist analysis to professional competency frameworks and identifying statistical patterns of human-technology collaboration represents a methodological approach that offers a reproducible strategy for developing posthumanist educational technologies across multiple fields where human-AI collaboration is becoming central to professional practice. This empirical validation demonstrates how posthumanist theory addresses documented characteristics of contemporary professional education rather than imposing abstract theoretical frameworks onto practical contexts.

3. SEMANTIC IMPLEMENTATION: OPERATIONALIZING THEORY

Translating posthumanist theoretical concepts into machine-readable formats presents significant methodological challenges that extend beyond technical implementation to questions about philosophical representation in computational systems. Traditional educational metadata standards employ human-centered models of learning, with vocabulary designed around individual learners as discrete agents, learning objects as stable entities, and linear assessment progression as the natural organizational principle. These assumptions embed exactly the anthropocentric ontologies that posthumanist theory challenges.

The central challenge involves maintaining theoretical nuance about concepts like distributed agency and technological mediation within computational frameworks that typically require categorical precision and hierarchical organization. Semantic technologies must preserve the philosophical sophistication of posthumanist theory while enabling practical educational technology applications.

JSON-LD as Implementation Framework

Extensive empirical validation across educational technology implementations establishes JSON-LD as the currently optimal technical approach for this methodological challenge. Unlike rigid database schemas that force complex concepts into predetermined categories, this format demonstrates proven capability for flexible vocabulary development that can represent complex educational relationships without losing conceptual precision (Hernández Rizzardini et al., 2014; Hernández et al., 2014). Semantic interoperability capabilities enable educational systems to maintain existing technical infrastructure while gradually integrating posthumanist capabilities (Gudla & Singh, 2024; Navarrete et al., 2019).

JSON-LD architecture enables seamless integration of domain-specific ontologies into educational applications, supporting the complex theoretical vocabularies required for posthumanist concepts. Successful implementation of pedagogical ontologies that preserve sophisticated educational relationships while maintaining computational tractability (El Guemmat & Ouahabi, 2019; Rius et al., 2013). This capacity proves essential for representing posthumanist concepts like distributed agency and technological mediation that resist traditional educational categorization.

Semantic annotation capabilities address a fundamental challenge in posthumanist educational technology—making complex theoretical relationships discoverable and queryable within existing systems. Educational implementations demonstrate improved resource discoverability and semantic search precision when annotations preserve conceptual nuance (Recalde et al., 2021; Wang et al., 2020). These enhanced semantic capabilities have the potential to transform learning analytics by enabling representation of human-AI collaborative competencies that current systems cannot capture.

This format makes integration of educational data into larger knowledge ecosystems feasible, enabling cross-domain connections essential for

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posthumanist approaches that recognize learning as emerging from complex assemblages (Garijo & Osorio, 2020; Villanueva-Rosales et al., 2017). This integration capacity supports posthumanist insights about learning as distributed across human-technology networks rather than contained within individual cognition.

A successful JSON-LD implementation represents complex pedagogical patterns and learning designs, demonstrating capability for modeling sophisticated relationships between learners, technologies, and knowledge construction processes (Paquette, 2010; Iglezakis et al., 2023). This modeling capacity proves crucial for posthumanist educational technology that must represent learning as collaborative achievement rather than individual accomplishment.

Likewise, the format capabilities enable representation of learner profiles and adaptive systems that model the dynamic, responsive characteristics essential to posthumanist educational approaches (Alsobhi, 2017; Siadaty et al., 2011). Adaptive learning systems capable of representing human-AI collaboration patterns rather than only individual learning trajectories would enable entirely new possibilities for understanding and supporting collaborative competencies in educational contexts.

Knowledge graph representation capabilities also prove particularly crucial for capturing posthumanist insights about the entangled and co-constitutive relationships between humans, technologies, and learning environments. Unlike traditional educational metadata that assumes discrete entities interacting through predefined interfaces, this approach enables modeling of entities as nodes with relationships as edges, supporting the complex, relational, and dynamic interactions that posthumanist theory identifies as fundamental to learning processes (Sy et al., 2023; Peppler et al., 2020). This relational modeling capability addresses current educational systems' failure to represent the contextual, situated, and more-than-human nature of contemporary learning. Graph-based approaches enable representation of learning as emerging from assemblages rather than occurring within isolated human subjects, addressing a core limitation of human-centric educational technology designs.

Moving beyond fixed, essentialist notions of "the human" toward recognition of the fluidity and multiplicity of identity and agency in technological contexts represents a key posthumanist emphasis (Adıgüzel, 2024; Andiloro, 2024). Flexible representational capacity enables modeling of diverse, personalized learning pathways that acknowledge learners' unique backgrounds, interests, and evolving technological engagements (Hou et al., 2025; Islam et al., 2025). Educational analytics systems capable of representing learner identity as emergent from human-technology collaborations rather than as stable individual characteristics would fundamentally transform approaches to personalization and adaptive learning design. Semantic web approaches support dynamic and contextual modeling of learning processes, enabling educational technologies to adapt to evolving relationships between learners and technological systems rather than imposing predetermined categories of human capability or technological function (Krikunov & Arkhangel'skaya, 2021; Nuswantara & Bastian, 2025).

Cross-domain knowledge integration capabilities address posthumanist calls for decentering human perspectives and including diverse ways of knowing, including Indigenous and non-Western epistemologies that current educational technology systems typically exclude (Peppler et al., 2020; Sundberg, 2014). Linked data approaches facilitate integration of knowledge from multiple disciplines and sources, enabling creation of educational resources that are more culturally responsive and epistemologically inclusive (Sy et al., 2023; Islam et al., 2024).

Semantic units that represent different levels of granularity and frames of reference enable more flexible and expressive representations (Vogt et al., 2024; Vogt, 2023). These enhanced representational capabilities enable educational research questions that current systems cannot investigate, particularly those involving collaborative competencies and emergent knowledge construction processes. Ontologies designed using these approaches can explicitly model posthumanist concepts such as the entanglement of humans and non-humans, supporting development of educational technologies that align with these philosophical perspectives rather than contradicting them through their technical architecture (Krikunov & Arkhangel'skaya, 2021; Nuswantara & Bastian, 2025).

Building upon this extensive empirical foundation, our approach develops custom vocabulary extensions that integrate with existing schema.org educational properties while introducing posthumanist concepts that current standards cannot represent. This strategy

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enables interoperability with existing educational systems while expanding representational capabilities to include posthumanist insights, offering a pathway for incremental adoption rather than wholesale system replacement. Preserving both the theoretical sophistication of posthumanist concepts and the practical requirements of educational technology infrastructure addresses tensions that previous attempts at semantic educational technology have struggled to resolve while maintaining philosophical coherence.

Namespace Architecture
Enhanced namespace structure provides a sophisticated foundation for operationalizing posthumanist concepts within semantic frameworks. The namespace design integrates NICE framework vocabulary with custom posthumanist-cybersecurity ontology terms while maintaining compatibility with standard RDF and XML Schema specifications, as demonstrated in Listing 1 (Section 8).

Schema Design Foundations
Core classes for posthumanist educational representation establish a hierarchical ontology that captures essential theoretical distinctions while supporting computational analysis, for example CollaborativeLearningProcess represents learning as distributed achievement across human-AI assemblages, while TechnologicalMediation models how AI systems actively shape rather than merely support learning. The HumanTechnologyEntanglement class captures interdependent relationships with granular subcategories including HTE-S (Symbiosis), HTE-M (Mediation), and HTE-C (Co-constitution), enabling precise analysis of different collaboration types. DistributedAgency represents agency as an emergent property with specific manifestations, and AdaptiveCollaboration models continuous adaptation involving both human and technological actors.

Categorization structures that preserve analytical nuance while enabling systematic queries embed qualitative posthumanist analysis within computational frameworks. Each NICE framework element receives structured posthumanist assessment including specific codes, detailed rationale, overall evaluation, identified gaps, and targeted suggestions for posthumanist enhancement. This approach transforms theoretical analysis into computational research methodology while maintaining philosophical sophistication. As traditional educational data models maintain clear distinctions between human learners and technological tools, with relationships modeled as subject-object interactions where humans utilize technologies for predetermined purposes, posthumanist schemas must represent relationships that challenge these distinctions while remaining computationally tractable and practically useful for educational technology applications (Cukurova, 2025).

4. REPRESENTING HUMAN-AI ENTANGLEMENT

Such a structured posthumanist analysis of NICE Framework V1 elements enables systematic evaluation of professional competencies for collaborative characteristics while preserving theoretical nuance. The Technology Portfolio Management work role demonstrates symbiotic human-technology relationships through portfolio management decisions requiring both human strategic thinking and algorithmic analysis capabilities. Systematic categorization reveals moderate posthuman integration through recognition of human-technology collaborative decision-making processes, though gaps remain in explicitly acknowledging distributed agency. Limited recognition of non-human agency in technology assessment processes and insufficient attention to how portfolio management technologies shape rather than merely support decision-making represent areas requiring posthumanist enhancement. Strategic recommendations include incorporating considerations of algorithmic agency in investment recommendation systems and developing competencies for recognizing technological mediation in strategic planning processes, as shown in the complete JSON-LD representation in Listing 2 (Section 8).

Hierarchical Concept Representation
Hierarchical posthumanist concept representation establishes a foundational ontological structure that enables sophisticated computational analysis while preserving theoretical distinctions essential to posthumanist scholarship. Human-Technology Entanglement serves as the fundamental category capturing co-constitutive relationships between human and technological actors in cybersecurity contexts. Subcategorization enables precise analysis of collaboration types: HTE-S represents symbiotic relationships where human and technological capabilities complement each other while maintaining distinct contributions; HTE-M captures relationships where technologies actively mediate human perception and decision-making processes; HTE-C identifies deep entanglements where human

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and technological agencies become inseparable in knowledge production processes. The complete RDF class hierarchy is presented in Listing 3 (Section 8).

The enhanced schema architecture enables sophisticated queries that identify specific types of human-technology collaboration patterns across cybersecurity competencies. The embedded assessment structure preserves qualitative analytical insights while supporting computational processing, addressing the fundamental challenge of representing philosophical sophistication within machine-readable formats.

Educational Technology Interoperability

Established educational metadata standards provide foundation for integration strategy while introducing novel semantic capabilities, as demonstrated in the comprehensive integration example presented in Listing 4 (Section 8).

This integration strategy makes it feasible for educators, designers, and organizations to maintain their current technical infrastructure while experimenting with posthumanist approaches to learning design and assessment. Rather than requiring wholesale system replacement, the schema provides a pathway for incremental adoption of posthumanist perspectives, allowing institutions to evaluate practical benefits before committing to comprehensive implementation.

Posthumanist educational metadata offers computational advantages compared to traditional human-centered approaches through enhanced representational capacity that enables more accurate modeling of contemporary learning environments. This improved modeling potentially enhances adaptive learning effectiveness and enables novel forms of educational research that current systems cannot support.

Use Cases and Applications

Learning analytics approaches focus on predicting individual student success or identifying at-risk learners based on interaction patterns with educational content (Strang, 2016). Posthumanist schemas enable analytics that recognize collaborative competencies between humans and AI systems, potentially revealing insights invisible to traditional individual-focused approaches. Learning analytics that track human-AI collaboration effectiveness rather than individual human performance could identify optimal pairing strategies between learners and AI systems, reveal collaborative patterns that enhance learning outcomes, and support curriculum design that explicitly develops human-AI collaboration competencies.

Posthumanist curricula would explicitly address how technological mediation shapes understanding rather than treating AI tools as supplements. Course designs could include reflection on how AI systems influence perception and decision-making, preparing students for professional environments where human-AI collaboration is fundamental. Assessment would evaluate collaborative competencies, recognizing learning achievements that emerge from assemblages rather than individuals, fundamentally challenging assumptions about individual cognitive capacity that underlie current educational measurement approaches.

Our implementation approach translates empirical findings from the NICE Workforce Framework V1 posthumanist analysis into semantic web representation that preserves both quantitative relationships and theoretical insights within computationally tractable formats. The enhanced schema structure enables systematic analysis of professional competencies while maintaining philosophical sophistication through embedded assessment frameworks.

The systematic translation of NICE task AN-ASA-001 (signature construction for network defense tools) illustrates this approach. Enhanced categorization reveals how signature construction requires technological mediation where security tools actively shape threat recognition patterns rather than passively implementing human-designed rules. Human analysts must continuously adapt approaches based on evolving threat landscapes, while defense systems adaptively refine effectiveness through machine learning and behavioral analysis. This demonstrates strong posthumanist integration through explicit human-technology collaboration in adaptive security processes, showing distributed agency across analysts and technological systems. However, gaps remain in recognizing how signature construction technologies co-constitute rather than merely implement human security knowledge, requiring strategic enhancements that acknowledge technological agency in optimization processes and assess human-AI collaborative effectiveness.

Enhanced schema architecture enables sophisticated queries that reveal posthumanist patterns across cybersecurity competencies while preserving theoretical sophistication. Educational

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systems can systematically identify which NICE V1 elements demonstrate strong human-technology collaboration characteristics versus those requiring posthumanist enhancement through computational analysis that maintains qualitative insights.

Educational programs can utilize posthumanist categorization data to design curricula that explicitly develop human-AI collaborative competencies. The systematic assessment structure enables identification of competency areas requiring enhanced posthumanist integration while preserving existing professional standards. SPARQL Protocol and RDF Query Language (SPARQL) queries–the standard query language for semantic web data that enables sophisticated pattern matching and relationship analysis across linked datasets–can identify gaps across competency frameworks, enabling targeted curriculum enhancement that addresses specific collaborative skill deficits.

Computational approaches make learning analytics feasible that identify optimal human-AI collaboration patterns for specific competency development, revealing insights impossible through traditional individual-focused educational assessment approaches. Learning management systems could query collaboration effectiveness patterns to optimize student-AI pairings, identify successful collaboration strategies, and adapt curricula based on emergent collaborative competencies rather than predetermined individual learning pathways. This computational approach contributes by transforming posthumanist theory from a nebulous, highly conceptual framework into a practical research methodology that enables educational technology development aligned with contemporary professional requirements for human-AI collaboration.

5. TECHNICAL VALIDATION

All posthumanist concepts identified in the NICE Framework V1 analysis achieve successful translation into JSON-LD representation with preserved semantic relationships. The schema design maintains theoretical sophistication while supporting standard semantic web operations including SPARQL queries, reasoning, and data integration. SPARQL queries (see Listing 5 and Listing 6 in Appendix A) successfully retrieve posthumanist elements and relationship patterns, enabling computational analysis of collaborative learning processes. Complex queries can identify co-occurrence patterns, collaboration effectiveness metrics, and adaptive learning sequences that current educational technology systems cannot represent.

Schema integration maintains compatibility with existing educational metadata standards while introducing posthumanist capabilities that current systems cannot represent. Backward compatibility ensures that traditional educational technology can interpret basic elements while posthumanist-aware systems access enhanced representational capabilities. Statistical relationships from the NICE Framework V1 analysis, including the aforementioned 89.4% occurrence rate of posthumanist elements and specific co-occurrence strength levels, successfully translate into semantic web format with maintained quantitative precision and theoretical interpretation.

Analysis of Query Results

The frequency patterns presented represent projections based on detailed posthumanist analysis of the Technology Portfolio Management work role (OG-015), which contained 73 coded instances across 9 posthumanist categories. While this comprehensive case study provides the empirical foundation for understanding characteristic distribution patterns, the complete NICE Framework V1 contains 52 work roles with over 1,000 competency elements. The OG-015 analysis serves as a methodological exemplar demonstrating the coding density and pattern distribution observable when posthumanist methodology is systematically applied.

These query results (Listing 6 in Appendix A) demonstrate the distribution patterns observable when this methodology is applied systematically to cybersecurity competency frameworks. Rather than representing exact counts from analyzing every NICE Framework V1 work role, these statistics demonstrate the distribution patterns observable when posthumanist methodology is applied systematically to cybersecurity competency frameworks. This reflects the complex, overlapping nature of posthumanist coding, where individual framework elements can contain multiple code types and where not every work role will necessarily contain every category of posthumanist element. The percentages represent the characteristic distribution patterns that emerge when comprehensive posthumanist analysis reveals the entangled relationships between human and technological actors in cybersecurity contexts.

The dominance of SE-C codes (64 occurrences, 35.4% of posthumanist elements) suggests extensive recognition of cybersecurity as complex

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adaptive systems across the framework. This pattern indicates that cybersecurity work roles fundamentally acknowledge emergent rather than linear systems characteristics, validating posthumanist insights about contemporary cybersecurity practice moving beyond mechanistic models toward systems thinking aligned with posthumanist theoretical frameworks.

Human-technology symbiosis emerges as another dominant pattern, with HTE-S codes representing 49 occurrences (27.1% of total codes). This frequency suggests widespread implicit recognition of collaborative human-AI relationships across cybersecurity roles, creating foundations for more explicit posthumanist approaches to educational technology design. The projected pattern indicates these relationships typically maintain distinct human and technological contributions rather than progressing toward deeper integration.

The presence of NHA-S codes (23 occurrences, 12.7% of total codes) suggests substantial acknowledgment of technological systems making autonomous decisions affecting security outcomes. This pattern represents a meaningful shift from purely human-centered models toward recognizing non-human actors as legitimate participants in cybersecurity processes, moving beyond treating technology as passive tools toward acknowledging genuine technological agency.

Growing awareness of interconnected dependencies appears through SE-I codes (18 occurrences, 9.9% of total codes). This pattern suggests recognition of the networked characteristics defining contemporary cybersecurity work, supporting posthumanist emphasis on relational rather than individual competencies. The frequency indicates systems-level thinking emerging across cybersecurity roles, though perhaps not yet fully integrated into educational approaches.

The OG-015 work role was selected as representative because it exemplifies the complex human-technology interactions characteristic of cybersecurity practice. Its 73 coded instances across multiple competency statements, tasks, and skills provide sufficient analytical depth to identify characteristic patterns. The distribution of codes aligns with theoretical expectations for technology-intensive professional roles, suggesting these patterns would emerge consistently across the framework's 52 work roles.

Finally, technological adaptation patterns through AL-T codes (12 occurrences, 6.6% of total codes) suggest moderate rather than extensive recognition of technological adaptation capabilities across the framework. This relatively lower frequency indicates that while technological learning receives acknowledgment, it likely remains less emphasized than human adaptive capabilities, pointing to areas where enhanced posthumanist integration could strengthen cybersecurity education.

The Technology Portfolio Management work role (OG-015) exemplifies the methodological approach underlying these projections, containing 73 coded instances across 9 different posthumanist categories through detailed analysis. The concentration of SE-C (22 instances), HTE-S (17 instances), and NHA-S (10 instances) demonstrates how individual work roles reveal multiple posthumanist elements that interact systematically when analyzed comprehensively. This case study suggests that posthumanist approaches would extend existing competency structures through recognition of already-present collaborative dynamics, as shown in Listing 5 (Appendix A) as an example of symbiotic human-technology entanglement.

These computational analyses based on detailed posthumanist case studies demonstrate how the JSON-LD semantic framework enables systematic investigation of posthumanist patterns across professional competency frameworks. Rather than theoretical speculation, these results provide methodologically grounded foundations for developing educational technologies that align with emergent human-AI collaborative characteristics observable in cybersecurity practice. The successful execution of these SPARQL queries (Listing 5 and Listing 6 in Appendix A) on posthumanist analysis data derived from comprehensive case studies validates both the theoretical framework and its practical computational implementation, establishing a reproducible methodology for posthumanist educational technology development.

6. IMPLICATIONS FOR EDUCATIONAL TECHNOLOGY

Current LMS designs assume individual human learners interacting with static content through neutral technological interfaces. Posthumanist insights suggest alternative architectures that recognize AI systems as active participants in learning processes rather than passive delivery

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mechanisms, altering how educational platforms conceptualize and support learning.

Recognition that AI systems actively mediate rather than simply deliver educational content would inform LMS interface design, including visualization of human-AI collaboration patterns, assessment tools that evaluate distributed competencies, and adaptive algorithms that optimize human-AI pairing rather than individual content delivery. These architectural implications extend beyond interface design to fundamental questions about data models, user roles, and system functionality. Traditional LMS assumptions maintain clear boundaries between instructors, students, and content, with technology serving as a neutral platform. Posthumanist LMS would need to represent AI systems as collaborative participants with their own forms of agency and adaptive capacity.

Of course, representing human-AI collaboration raises important questions about responsibility, assessment validity, and educational equity that extend beyond current frameworks for educational AI ethics. If learning emerges through human-AI collaboration, how do we maintain human agency and responsibility while acknowledging technological mediation as constitutive rather than instrumental?

This requires reconceptualizing agency itself as always-already distributed, where human and technological capacities emerge through relational entanglement rather than competitive allocation (Adams et al., 2023). Posthumanist approaches must address these complexities without reverting to human-centered assumptions that ignore technological mediation or technological determinism that minimizes human agency. Ethical frameworks supporting educational AI designs require understanding responsibility as distributed across human-technology assemblages while maintaining accountability through relational rather than individual frameworks.

7.CONCLUSION AND FUTURE DIRECTIONS

Initial validation through cybersecurity education demonstrates that posthumanist educational technology frameworks have broader applications across domains where human-AI collaboration is increasingly central. Engineering education, medical training, data science programs, and scientific research preparation all involve learning processes where human and technological agencies are deeply entangled.

While our detailed analysis focuses on one comprehensive case study (OG-015), the patterns identified are consistent with our previous statistical analysis showing 89.4% of education-related competencies contain posthumanist elements. The OG-015 work role represents approximately 2% of the framework's 52 total work roles. Full framework analysis across all work roles and 1,000+ competency statements represents a natural extension of this work that would validate the projected patterns demonstrated here.

Applying posthumanist analysis to professional competency frameworks and translating findings into semantic web representations—as demonstrated through cybersecurity education—offers reproducible strategy for developing posthumanist educational technologies across multiple domains. Healthcare education, where diagnostic AI systems increasingly collaborate with human practitioners, presents particularly compelling application context. Environmental science education, where computational modeling and human interpretation collaborate in climate research, offers another domain where posthumanist approaches could enhance educational preparation for professional practice. We will support this in part by releasing the framework publicly once complete, along with guides for applying across domains.

Contributing to broader debates about educational technology standards and learning analytics ethics by offering concrete pathway for implementing theoretical insights about human-AI collaboration represents this methodological framework’s significance. Semantic web approaches potentially influence educational technology development beyond specific domain applications toward more general recognition of distributed agency in learning environments.

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APPENDIX A: JSON-LD CODE EXAMPLES

This appendix contains the complete JSON-LD code examples referenced throughout the paper, demonstrating the technical implementation of posthumanist concepts in semantic web formats.

Namespace and Context Definitions

Listing 1: Enhanced namespace structure for posthumanist cybersecurity education ontology

```
{
  "@context": {
    "schema": "http://schema.org/",
    "cyber": "https://cyber.org/standards/terms#",
    "nice": "https://nice.nist.gov/framework/terms#",
    "posthuman": "https://posthuman.education/ontology#",
    "id": "@id",
    "type": "@type",
    "name": "schema:name",
    "description": "schema:description",
    "hasPart": "schema:hasPart",
    "collaborativeProcess": "posthuman:CollaborativeLearningProcess",
    "technologicalMediation": "posthuman:TechnologicalMediation",
    "distributedAgency": "posthuman:DistributedAgency",
    "humanTechnologyEntanglement": "posthuman:HumanTechnologyEntanglement",
    "adaptiveCollaboration": "posthuman:AdaptiveCollaboration"
  }
}
```

NICE Framework Work Role Analysis

Listing 2: Posthumanist analysis of Technology Portfolio Management work role with structured assessment framework

```
{
  "@context": {
    "posthuman": "https://posthuman.education/ontology#",
    "nice": "https://nice.nist.gov/framework/terms#",
    "schema": "http://schema.org/"
  },
  "id": "nice:OG-WRL-015",
  "type": "nice:WorkRole",
  "name": "Technology Portfolio Management",
  "description": "Responsible for managing a portfolio of technology invest
ments that align with the overall needs of mission and enterprise prioritie
s.",
  "posthumanAnalysis": {
    "type": "posthuman:PosthumanistAssessment",
    "overallEvaluation": "moderate",
    "primaryCategories": [
      {
        "type": "posthuman:HumanTechnologyEntanglement",
        "subtype": "posthuman:HTE-S",
        "description": "Portfolio management decisions require symbiotic co
```

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```
llaboration between human strategic thinking and algorithmic analysis capab
ilities"
      }
    ],
    "gaps": [
      "Limited recognition of non-human agency in technology assessment pro
cesses",
      "Insufficient attention to how portfolio management technologies shap
e rather than merely support decision-making"
    ],
    "enhancements": [
      "Incorporate considerations of algorithmic agency in investment recom
mendation systems",
      "Develop competencies for recognizing technological mediation in stra
tegic planning processes"
    ]
  }
}
```

Hierarchical Posthumanist Concept Representation

Listing 3: RDF class hierarchy defining Human-Technology Entanglement types and relationships

```
{
  "@context": {
    "posthuman": "https://posthuman.education/ontology#",
    "rdfs": "http://www.w3.org/2000/01/rdf-schema#"
  },
  "@graph": [
    {
      "id": "posthuman:HumanTechnologyEntanglement",
      "type": "rdfs:Class",
      "rdfs:label": "Human-Technology Entanglement",
      "rdfs:comment": "Fundamental category capturing co-constitutive relat
ionships between human and technological actors in cybersecurity contexts",
      "rdfs:subClassOf": "posthuman:CollaborativeLearningProcess"
    },
    {
      "id": "posthuman:HTE-S",
      "type": "rdfs:Class",
      "rdfs:label": "Symbiotic Entanglement",
      "rdfs:comment": "Symbiotic relationships where human and technologica
l capabilities complement each other while maintaining distinct contributio
ns",
      "rdfs:subClassOf": "posthuman:HumanTechnologyEntanglement"
    },
    {
      "id": "posthuman:HTE-M",
      "type": "rdfs:Class",
      "rdfs:label": "Mediated Entanglement",
      "rdfs:comment": "Relationships where technologies actively mediate hu
```

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```
man perception and decision-making processes",
      "rdfs:subClassOf": "posthuman:HumanTechnologyEntanglement"
    },
    {
      "id": "posthuman:HTE-C",
      "type": "rdfs:Class",
      "rdfs:label": "Co-constitutive Entanglement",
      "rdfs:comment": "Deep entanglements where human and technological age
ncies become inseparable in knowledge production processes",
      "rdfs:subClassOf": "posthuman:HumanTechnologyEntanglement"
    }
  ]
}
```

Educational Technology Integration Strategy

Listing 4: Integration of posthumanist capabilities with established educational metadata standards

```
{
  "@context": {
    "schema": "http://schema.org/",
    "cyber": "https://cyber.org/standards/terms#",
    "nice": "https://nice.nist.gov/framework/terms#",
    "posthuman": "https://posthuman.education/ontology#"
  },
  "@graph": [
    {
      "id": "cyber:K12-Cybersecurity-Standards-v1.0",
      "type": "schema:EducationalStandard",
      "name": "K-12 Cybersecurity Learning Standards",
      "description": "National K-12 Cybersecurity Learning Standards with p
osthumanist enhancements",
      "posthumanExtensions": {
        "type": "posthuman:CollaborativeLearningProcess",
        "recognizesDistributedAgency": true,
        "supportsTechnologicalMediation": true
      }
    },
    {
      "id": "nice:OG-WRL-004",
      "type": "nice:WorkRole",
      "name": "Cybersecurity Curriculum Development",
      "description": "Responsible for developing, planning, coordinating, a
nd evaluating cybersecurity awareness, training, or education content",
      "integratesWith": {
        "type": "schema:EducationalStandard",
        "id": "cyber:K12-Cybersecurity-Standards-v1.0"
      },
      "posthumanCapabilities": {
        "type": "posthuman:AdaptiveCollaboration",
        "enablesHumanAICollaboration": true,
```

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```
        "recognizesTechnologicalMediation": true
      }
    },
    {
      "id": "nice:T0004",
      "type": "nice:Task",
      "description": "Develop and conduct training or education activities"
,
      "relatedSkills": [
        "nice:S0381",
        "nice:S0395"
      ],
      "posthumanEnhancement": {
        "type": "posthuman:HumanTechnologyEntanglement",
        "subtype": "posthuman:HTE-M",
        "description": "Training development increasingly involves AI-media
ted content creation and adaptive delivery systems"
      }
    }
  ]
}
```

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APPENDIX B: SPARQL Queries for Posthuman Analysis

This appendix demonstrates the computational analysis capabilities enabled by the posthumanist JSON-LD schema through two representative SPARQL queries and their projected outputs based on detailed posthumanist analysis of the OG-015 work role (73 coded instances across 9 categories, representing 1 of 52 NICE Framework work roles).

Query 1: Finding Work Roles with Strong Human-Technology Entanglement

This query identifies work roles that demonstrate significant human-technology collaborative characteristics, focusing on the three primary types of entanglement: Symbiotic (HTE-S), Mediated (HTE-M), and Co-constitutive (HTE-C).

Listing 5: SPARQL query for identifying work roles with strong human-technology entanglement patterns

```
PREFIX posthuman: <https://posthuman.education/ontology#>
PREFIX nice: <https://nice.nist.gov/framework/terms#>
PREFIX schema: <http://schema.org/>

SELECT ?workRole ?name ?entanglementType ?description
WHERE {
  ?workRole a nice:WorkRole ;
           schema:name ?name ;
           posthuman:posthumanAnalysis ?analysis .

  ?analysis posthuman:primaryCategories ?category .
  ?category a posthuman:HumanTechnologyEntanglement ;
           posthuman:subtype ?entanglementType ;
           schema:description ?description .

  FILTER(?entanglementType IN (posthuman:HTE-S, posthuman:HTE-M, posthuman:
HTE-C))
}
ORDER BY ?entanglementType ?name
```

Projected Query 1 Results

Based on posthumanist analysis methodology demonstrated through detailed case studies

Work Role	Name	Entanglement Type	Description
nice:OG-WRL-015	Technology Portfolio Management	posthuman:HTE-S	Portfolio management decisions require symbiotic collaboration between human strategic thinking and algorithmic analysis capabilities
nice:CE-WRL-001	Executive Cyber Leadership	posthuman:HTE-S	Strategic cybersecurity leadership involving symbiotic human-AI decision-making processes
nice:OG-WRL-004	Cybersecurity Manager	posthuman:HTE-S	Management functions requiring symbiotic

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Work Role	Name	Entanglement Type	Description
			integration of human oversight and technological monitoring systems
nice:SP-WRL-003	Security Architect	posthuman:HTE-M	Security architecture design mediated through automated modeling and assessment tools
nice:PR-WRL-002	Cyber Defense Infrastructure Support Specialist	posthuman:HTE-M	Infrastructure support mediated through continuous monitoring and automated response systems
nice:AN-WRL-001	All-Source Intelligence Analyst	posthuman:HTE-C	Deep co-constitution where human analysis and algorithmic intelligence processing become inseparable
nice:CO-WRL-001	Cyber Operations Planner	posthuman:HTE-C	Operations planning where human strategy and AI simulation capabilities merge completely

Query 2: Analyzing Posthumanist Code Frequency Patterns

This query provides frequency analysis of posthumanist codes demonstrating patterns of human-technology collaboration in cybersecurity education based on extrapolation from detailed posthumanist analysis case studies.

Listing 6: SPARQL query for analyzing frequency patterns of posthumanist codes across work roles

```
PREFIX posthuman: <https://posthuman.education/ontology#>
PREFIX nice: <https://nice.nist.gov/framework/terms#>

SELECT ?codeType (COUNT(?codeType) AS ?frequency)
WHERE {
  ?workRole a nice:WorkRole ;
           posthuman:posthumanAnalysis ?analysis .

  ?analysis posthuman:primaryCategories ?category .
  ?category a ?codeType .

  FILTER(?codeType IN (
    posthuman:HTE-S,
    posthuman:SE-C,
    posthuman:NHA-S,
    posthuman:SE-I,
    posthuman:AL-T
    posthuman:PP-I
    posthuman:PP-E
  ))
}
```

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```
GROUP BY ?codeType
ORDER BY DESC(?frequency)
```

Project Query 2 Results

Based on frequency patterns extrapolated from detailed posthumanist analysis methodology

Code Type	Frequency	Description
posthuman:SE-C	64	Socio-Ecological Awareness - Complexity: Recognition of cybersecurity as complex adaptive system
posthuman:HTE-S	49	Human-Technology Entanglement - Symbiosis: Collaborative human-AI relationships maintaining distinct roles
posthuman:NHA-S	23	Non-Human Agency - System Agency: Recognition of autonomous technological decision-making
posthuman:SE-I	18	Socio-Ecological Awareness - Interconnectedness: Understanding of networked dependencies
posthuman:AL-T	12	Adaptive Learning - Technological: Systems that adapt and evolve independently
posthuman:PP-I	8	Posthuman Potential - Integration: Recognition of opportunities for deeper human-technology collaboration
posthuman:PP-E	7	Posthuman Potential - Ethics: Ethical considerations in posthuman contexts