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ONTO-ALIGN: AN ONTOLOGY-BASED FRAMEWORK FOR EVALUATING CURRICULUM ALIGNMENT WITH EDUCATIONAL STANDARDS IN COMPUTER SCIENCE

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ABSTRACT

Aim/Purpose	This study develops an automated framework for evaluating computer science curriculum alignment with educational standards, addressing assessment challenges in rapidly evolving technical fields.
Background	Educational institutions struggle with time-consuming, subjective manual curriculum evaluation processes that are difficult to standardize, particularly when technological innovations frequently outpace curriculum updates.
Methodology	The ONTO-ALIGN framework employs three complementary matching techniques: direct matching (H1), semantic analysis using WordNet and similarity algorithms (H2), and approximate matching for related concepts. The system evaluates course descriptions against the standards of the Thai Qualifications Framework (TQF: HEd) and Computer Science Curricula 2023 (CS2023).

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Contribution	This research provides the first comprehensive framework integrating multiple ontology linking techniques within a unified assessment system, bridging pedagogical theory with automated assessment technology for systematic curriculum evaluation.
Findings	Validation through five computer science courses demonstrates effectiveness in identifying alignment gaps, with 82.9% agreement with expert assessments. The multi-method strategy proved valuable: direct matching identified 40.9% of correspondences, semantic analysis captured 29.3%, and approximate matching detected 17.1% of alignments.
Recommendations for Practitioners	Educational institutions can implement multi-level curriculum assessments that consider both exact terminology matches and semantic relationships, enabling more frequent and systematic evaluations than traditional manual approaches.
Recommendations for Researchers	Future research should explore the integration of machine learning with multiple matching techniques for increased accuracy in evolving knowledge domains.
Impact on Society	By improving curriculum alignment with established standards, this framework enhances educational quality in computer science, leading to better-prepared graduates for an increasingly digital society.
Future Research	Integrating machine learning with multiple matching techniques for increased accuracy in evolving knowledge domains represents a key advancement opportunity.

Keywords	curriculum evaluation, computer science education, educational standards, semantic similarity, constructive alignment, ontology matching

INTRODUCTION

Ensuring curriculum alignment with educational standards represents one of the most pressing challenges facing higher education institutions today, particularly in rapidly evolving fields like computer science. As digital transformation continues to reshape industries globally, educational institutions face unprecedented pressure to continuously evaluate and refine their curricula to maintain relevance with both national frameworks and international best practices (Kumar et al., 2024).

A real-world example illustrates these challenges vividly. At a prominent Thai university, faculty recently developed a Machine Learning Fundamentals course that provided extensive coverage of neural networks and deep learning techniques. However, the course failed to adequately address statistical learning theory, model evaluation methodologies, and ethical AI considerations – all designated as Core-Tier 1 topics in the Computer Science Curricula 2023 guidelines (Kumar & Raj, 2024). This misalignment became apparent only when students encountered significant difficulties in advanced AI courses and struggled during industry placements. The cascading effects demonstrated how curriculum gaps create far-reaching educational and professional consequences that extend well beyond individual courses.

The Thai Qualifications Framework for Higher Education (TQF: HEd) provides foundational guidelines for curriculum development across academic disciplines in Thailand (Rukspollmuang & Chansema, 2024). Despite well-structured frameworks, institutions frequently struggle with conducting systematic curriculum alignment evaluations due to the complexity of mapping detailed course content with standardized knowledge frameworks, particularly given the interdisciplinary nature of modern computer science education.

Traditional curriculum evaluation approaches rely heavily on manual analysis conducted by domain experts, typically involving faculty committees who systematically review course materials against established standards. While this method provides valuable insights, it suffers from significant limitations that restrict both effectiveness and scalability (Grobman, 1971; Kumar et al., 2024). Manual evaluation processes are inherently time-consuming, often requiring weeks or months for comprehensive assessments. They introduce subjective variability since different evaluators may interpret standards differently based on their expertise and perspectives.

Furthermore, the dynamic nature of computer science necessitates frequent curriculum updates to incorporate emerging technologies and evolving industry requirements. This continuous evolution makes regular assessment cycles essential, yet resource-intensive manual processes often prevent institutions from conducting evaluations with sufficient frequency (Kim et al., 2024; Kumar et al., 2024).

The constructive alignment theory, developed by John Biggs (1996), offers a theoretical foundation for addressing curriculum alignment challenges. This pedagogical framework emphasizes coherence between learning outcomes, instructional activities, and assessment methods in creating effective educational experiences (Hailikari et al., 2021). Recent empirical studies demonstrate that constructively aligned courses achieve 23% higher student satisfaction rates and 18% improved learning outcomes compared to traditionally structured courses across multiple European institutions (Loughlin et al., 2020).

Knowledge representation through ontologies provides sophisticated technological approaches to curriculum alignment challenges. Ontologies offer formal, explicit specifications of shared conceptualizations within domains, creating structured frameworks for representing complex knowledge and relationships between components (Stancin et al., 2020). In educational contexts, ontologies capture hierarchical knowledge structures, concept dependencies, and relationships between learning objectives and content areas, enabling systematic computational analysis of curriculum content against established standards.

Contemporary ontology matching research demonstrates remarkable progress, particularly by integrating large language models and transformer-based neural architectures (Taboada et al., 2025). The Ontology Alignment Evaluation Initiative 2024 campaign revealed that hybrid matching approaches combining multiple complementary techniques achieve superior performance compared to single-method systems (Amini et al., 2025).

Despite these technological advances, current computer science curriculum alignment assessment approaches continue to rely predominantly on manual processes. Although previous research has explored ontology-based educational applications, comprehensive frameworks integrating multiple ontology linking techniques specifically for systematic curriculum evaluation remain significantly underdeveloped.

This research addresses these limitations by developing the ONTO-ALIGN framework – a comprehensive ontology-based system specifically designed to evaluate curriculum alignment with national and international computer science education standards. The framework integrates the Thai Qualifications Framework for Higher Education (TQF: HEd) and Computer Science Curricula 2023 (CS2023) guidelines, representing current international consensus on computer science education requirements.

The research objectives encompass four interconnected goals. First, develop comprehensive ontological representations of computer science curricula, TQF: HEd framework, and CS2023 standards. Second, implement and integrate multiple complementary ontology linking techniques that provide comprehensive alignment assessment capabilities. Third, create sophisticated mathematical models to calculate alignment weights and compliance ratios. Finally, validate the proposed framework through rigorous comparison with expert manual assessments.

LITERATURE REVIEW

Educational standards serve as foundational benchmarks for curriculum development and quality assurance in higher education systems worldwide. The Computer Science Curricula 2023 (CS2023), released by the joint task force of ACM, IEEE-Computer Society, and AAAI, represents the most current international standard for computer science education (Kumar & Raj, 2024). CS2023 features 17 knowledge areas emphasizing society, ethics, profession (SEP), artificial intelligence, and security, reflecting contemporary industry needs and societal challenges that have emerged since the previous 2013 guidelines.

Constructive alignment theory, originally developed by Biggs (1996), provides the theoretical foundation for curriculum assessment and has been continuously refined through extensive educational research. Recent empirical studies by Hailikari et al. (2022) examined student perspectives on constructive alignment elements, demonstrating that students perceive clear connections between learning outcomes, activities, and assessments as crucial for meaningful learning experiences. Their comprehensive study revealed that constructively aligned courses enhance both student satisfaction and the adoption of deep learning approaches, providing empirical support for alignment theory effectiveness (Sukma & Pum, 2025).

Chaaban et al. (2024) provided a critical analysis of constructive alignment implementation in higher education, highlighting both benefits and implementation challenges. Their study identified that while constructive alignment demonstrably improves educational quality, institutions face significant difficulties due to time constraints, faculty resistance to change, and institutional requirements that may conflict with alignment principles. This research underscores the need for automated tools that can facilitate alignment assessment while reducing implementation barriers.

ONTOLOGY-BASED KNOWLEDGE REPRESENTATION AND MATCHING TECHNIQUES

Ontologies have gained considerable traction in educational contexts for knowledge representation and curriculum modeling applications. Ren et al. (2025) developed an innovative LLM-driven educational ontology learning approach that leverages large language models to automatically identify knowledge concepts and their interrelations within educational content. Their research demonstrated that LLM-enhanced ontology development achieves 90% accuracy in educational knowledge representation tasks, significantly outperforming traditional manual ontology construction methods.

Recent technological advances include work by Rigatos and Zhou (2024), who developed semantic alignment systems for disciplinary tutoring using sentence-transformer technology. Their approach achieved impressive performance metrics, including 91% accuracy, 93% precision, 89% recall, and 90% F1 score in semantic similarity tasks, significantly outperforming traditional keyword-based matching methods and demonstrating the potential for AI-enhanced educational assessment.

Ontology matching, defined as the establishment of correspondences between semantically related entities in different ontologies, has evolved significantly with recent technological advances (Sukma & Yamnill, 2025a). The Ontology Alignment Evaluation Initiative 2024 campaign evaluated numerous matching systems across diverse domains, providing comprehensive insights into current best practices and emerging trends. Neural and transformer-based approaches have shown remarkable progress, with systems combining multiple matching strategies consistently outperforming single-method approaches (Painter et al., 2025; Taboada et al., 2025).

Contemporary advances include several key developments. Multi-strategy matching systems have consistently demonstrated superior performance in recent evaluations, with top-performing systems integrating lexical, structural, and semantic matching techniques within unified frameworks. Semantic similarity measures have continually evolved, building upon foundational algorithms such as Wu and Palmer's (1994) method, which calculates similarity based on concept depth in taxonomies and their least common ancestor. Recent enhancements by Painter et al. (2025) have improved accuracy by addressing hierarchical consistency issues, critical for educational ontologies characterized by complex and deeply nested knowledge hierarchies.

Research Gaps and Framework Positioning

Despite considerable progress in curriculum evaluation and quality assurance, existing literature reveals several critical gaps that this research addresses. Most current approaches focus narrowly on isolated aspects of curriculum assessment, lacking comprehensive, multi-method frameworks capable of managing real-world curriculum evaluation complexity (Blunt, 2005). Quality assurance processes in many higher education institutions remain predominantly manual, restricting scalability and leading to inconsistencies across diverse programs and institutional contexts (Javed & Alenezi, 2023). Table 1 presents a comparison of current approaches, highlighting the unique contributions of this study.

Table 1. Comparison of current study with previous approaches

Study	Approach	Standards used	Matching methods	Validation	Limitations
Stancin et al. (2020)	Single ontology	Generic education	Lexical only	Expert review	Limited to single method
Rigatos and Zhou (2024)	Semantic alignment	Domain-specific	Transformer-based	Automated metrics	No curriculum focus
Current Study (ONTO-ALIGN)	**Multi-method ontology**	**TQF: HEd + CS2023**	**H1 + H2 + Related Match**	**Expert comparison + case studies**	**Language dependency**

Given these points, the ONTO-ALIGN framework addresses these gaps by offering a theoretically grounded, multi-method approach that combines current curriculum standards with automated ontology matching techniques. This integration supports both automated assessment and pedagogical quality assurance, providing a scalable and systematic foundation for curriculum evaluation. By unifying multiple ontology matching strategies within a cohesive framework, this research contributes novel insights into how technology can enhance curriculum quality assurance in higher education.

Methodology

Research Design and Framework Overview

Figure 1 proposed curriculum evaluation framework employs a structured multi-layer architecture designed to enable comprehensive assessment of curriculum alignment with educational standards. This architecture upholds constructive alignment principles by evaluating both content coverage and coherence of curriculum elements across multiple levels of granularity, ranging from specific topics to broader knowledge areas (Hailikari et al., 2021, 2022).

Data Preparation and Course Selection

The **data preparation layer** processes input course descriptions through advanced natural language preprocessing techniques. Course selection followed systematic criteria to ensure representativeness and validity. We selected five computer science courses from three prominent Thai universities based on the following criteria:

1. **Diversity of knowledge areas**: Courses representing core CS2023 knowledge areas including Artificial Intelligence, Database Systems, Software Engineering, Computer Networks, and Data Structures and Algorithms
2. **Institutional variety**: Selection from three different universities to capture diverse pedagogical approaches and institutional contexts

3. **Content completeness**: Courses with comprehensive syllabi, detailed learning objectives, and substantial content descriptions (minimum 200 words)
4. **Standard compliance**: Courses officially aligned with TQF: HEd requirements and follow standard academic documentation formats

The preprocessing pipeline includes:

- **Tokenization and normalization**: Text segmentation and standardization using domain-specific dictionaries derived from CS2023 curriculum terminology
- **Quality validation**: Automated checks for minimum content standards, terminology consistency, and structural completeness
- **Technical term identification**: Recognition of computer science concepts using specialized vocabularies
- **Format standardization**: Conversion to consistent ontological representation formats

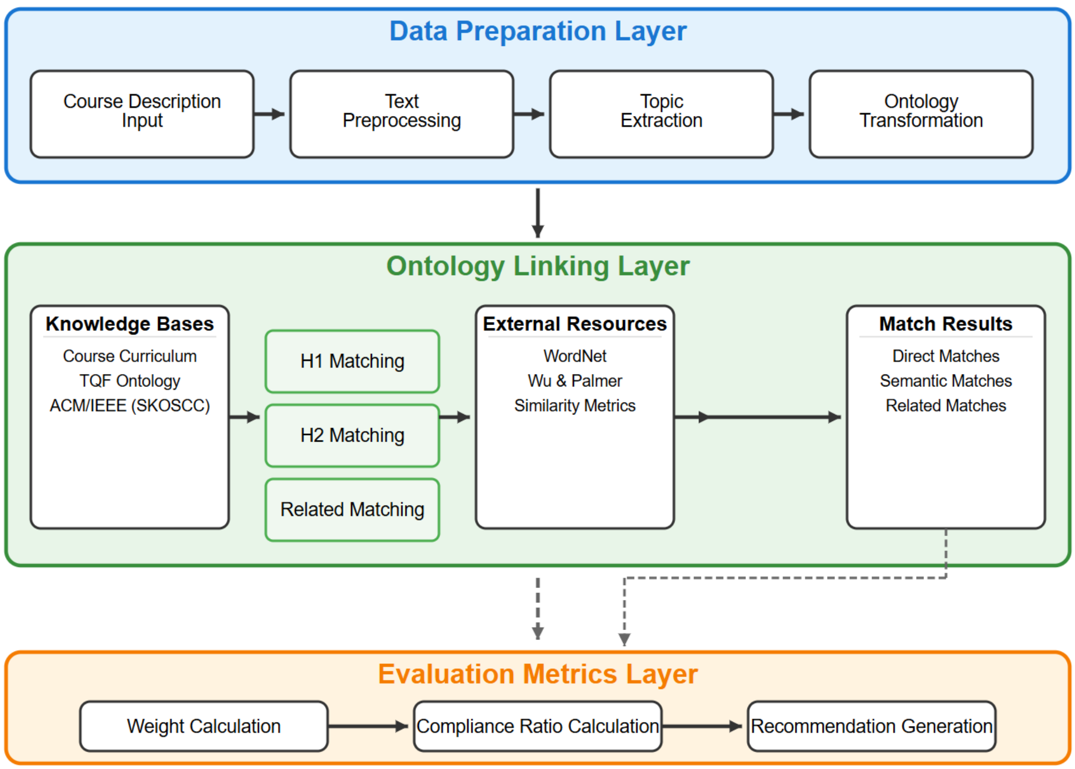

Figure 1. ONTO-ALIGN system architecture

ONTOLOGY DEVELOPMENT PROCESS

The **ontology processing layer** transforms textual course descriptions into formal ontological representations while preserving semantic integrity. This process involves three distinct but interrelated ontological structures:

Course curriculum ontology (OCC)

The OCC provides structured representation of computer science curricula, capturing essential elements including course titles, identifiers, instructors, credit allocations, and detailed content descriptions. Key properties include:

- **Has Course Name**: Course title identification
- **Has Course ID**: Unique course identification

- **Has Course Credit**: Credit hour allocation
- **Has Lecturer**: Instructor information
- **Has Course Description**: Detailed content description
- **Has University**: Institutional affiliation

Thai qualifications framework ontology (OTQF)

The OTQF represents a knowledge structure defined in TQF: HEd for Computer Science, capturing fourteen knowledge areas with their constituent bodies of knowledge. The ontology structure reflects a hierarchical organization with TQF: HEd Computer Science as the root class and fourteen knowledge areas as primary subclasses.

Computer science 2023 knowledge base (SKOS-CS2023)

The SKOS-CS2023 provides a comprehensive representation of CS2023 using the Simple Knowledge Organization System (SKOS) format, representing seventeen knowledge areas, their constituent bodies of knowledge, and specific topics with associated educational importance levels (Core-Tier1, Core-Tier2, and Elective).

Ontology development

The framework requires three distinct but interrelated ontological structures that formally represent key stakeholders in the assessment of curriculum alignment. The Course Curriculum Ontology (OCC) provides a structured representation of computer science curricula, capturing essential elements, including course titles, identifiers, instructors, credit allocations, and detailed content descriptions. The ontology organizes courses into classification hierarchies that reflect typical curriculum structures found in higher education institutions.

Figure 2 presents the SKOSCC development that incorporated both the CS2013 guidelines and more recent curriculum recommendations from sources, such as the IEEE Computer (S. Roach & Sahami, 2015), which address emerging areas like artificial intelligence, cybersecurity, and data science. This integration of established standards with emerging areas parallels approaches used in developing predictive models for emerging technologies, which combine foundational knowledge with recent developments to create more robust evaluation frameworks (Sukma & Yamnill, 2025b).

Characteristic	Course Curriculum Ontology (OCC)	Thai Qualifications Framework Ontology (OTQF)	Computer Science 2023 Knowledge Base (SKOS-CS2023)
Purpose	Structured CS curricula representation	Represents knowledge structure defined in TQF	Comprehensive CS2023 representation
Basis	CS2013 guidelines and emerging areas	TQF: HEd for Computer Science	CS2023 using SKOS format
Key Properties	Has Course Name, ID, Credit, Lecturer, Description, University	Hierarchical organization of knowledge areas	Three-tier importance structure

Figure 2. SKOSCC ontology structure

Key properties within OCC include Has Course Name for course title identification, Has Course ID for unique course identification, Has Course Credit for credit hour allocation, Has Lecturer for instructor information, Has Course Description for detailed content description, and Has University for institutional affiliation. These properties enable a comprehensive representation of course metadata while maintaining flexibility for different institutional contexts and curriculum structures.

The Thai Qualifications Framework Ontology (OTQF) represents the knowledge structure defined in TQF: HEd for Computer Science, capturing fourteen knowledge areas with their constituent bodies of knowledge as specified in national guidelines. Recent updates to the Thai Qualifications Framework have been incorporated to ensure alignment with current national standards (Office of Higher Education Commission, 2022). The ontology structure reflects the hierarchical organization of knowledge areas with TQF: HEd Computer Science as the root class and fourteen knowledge areas as primary subclasses (Crocco & Pitiyanuwat, 2022).

The Computer Science 2023 Knowledge Base (SKOS-CS2023) provides a comprehensive representation of CS2023 using the Simple Knowledge Organization System (SKOS) format, representing seventeen knowledge areas, their constituent bodies of knowledge, and specific topics with associated educational importance levels. The knowledge base incorporates the three-tier importance structure of CS2023, distinguishing between Core-Tier1 (essential), Core-Tier2 (highly recommended), and elective (optional) topics to support nuanced alignment assessment (Kumar & Raj, 2024).

Ontology Linking Approaches

The framework implements three complementary ontology linking approaches that operate sequentially to maximize alignment detection coverage while maintaining assessment accuracy. Each approach addresses different aspects of the curriculum alignment challenge, from direct terminological matches to sophisticated semantic similarity analysis (Acampora et al., 2013).

The H1 approach focuses on instance-based, constraint-based, and property relation-based matching between course description elements and knowledge framework concepts. Course descriptions undergo preprocessing to extract individual topics, which are treated as instances within OCC and systematically compared against class names in SKOS-CS2023. The matching algorithm employs exact string matching for identical terms, substring matching for partial correspondences, constraint-based filtering using educational importance levels, and property relationship analysis for context validation. When multiple matches are identified, the system applies priority rules, selecting matches with the highest educational importance levels or the lowest concept identifiers for identical importance levels (Kumar & Raj, 2024).

The H2 approach addresses topics unmatched by H1 through enhanced semantic and structural analysis, incorporating external knowledge sources. This method begins by preprocessing unmatched topics to remove stop words and create meaningful word groups, followed by WordNet integration to identify root forms and synonyms relevant to computer science terminology. Domain filtering retains only words that appear within relevant knowledge areas, ensuring semantic analysis remains focused on appropriate contexts. Semantic similarity calculation employs the Wu and Palmer (1994) algorithm with recent enhancements addressing hierarchical consistency issues. The extended Wu and Palmer algorithm applies contextual weighting to improve accuracy for educational domain applications.

The Related Match approach identifies approximate alignments for topics that remain unmatched after H1 and H2 processing. This method employs word-level decomposition to break topics into individual components, followed by a systematic comparison of words against all SKOS-CS2023 classes within relevant knowledge areas. Contextual analysis calculates semantic similarity considering a broader topic context, while ranking algorithms order potential matches by similarity scores. Selection criteria choose the highest scoring matches above established thresholds, ensuring quality while maximizing coverage. This algorithm incorporates recent advances in constraint-based matching techniques described by Wang et al. (2022), who demonstrated that hierarchical importance constraints significantly improve matching precision in educational contexts. The core of our evaluation methodology involves three complementary ontology linking approaches that operate sequentially, presenting as Algorithm 1:

Algorithm 1: Ontology Linking Matching Approach

```
Input: Topic t from course description, Knowledge Area KA
Output: Matching Body of Knowledge BoK or null
Begin
1. For each class c in KA do
  a. If t = c.name OR t ⊆ c.name then
    i. Determine the Body of Knowledge BoK for class c
    ii. Add BoK to the set of matches M
2. If M is empty then
  a. Return null
3. Else if M contains one match then
  a. Return the single BoK in M
4. Else
  a. Select the BoK with highest importance level from M
  b. If multiple BoKs have the same importance level then
    i. Select the BoK with the lowest Concept ID
  c. Return the selected BoK
End
```

H1:

Instance-based, constraint-based, and property-relations-based

The H1 approach represents the first level of alignment assessment, focusing on direct matches between the elements of the course description and the concepts of the knowledge framework. Course descriptions are preprocessed to extract individual topics, which are treated as instances within OCC and compared against class names in SKOSCC. Matching is performed according to similarity constraints, where a match is identified if the topic text is identical to a class name in SKOSCC or is a substring of a class name. When a match is identified, the property relationships of the matched class are examined to determine the corresponding body of knowledge. If multiple matches are found, the system selects the match with the highest educational importance level (Core-Tier1 > Core-Tier2 > Elective) or the lowest Concept ID if importance levels are identical.

H2: H1 + Semantic-based and Structure-based techniques

The H2 approach improves the basic matching capabilities of H1 by incorporating semantic analysis and structural considerations. This method addresses topics that were not matched using the H1 approach. Unmatched topics are processed to remove stop words, and the resulting word groups are queried against WordNet to identify root forms and synonyms. WordNet results are filtered to retain only those words that appear within the selected knowledge area of SKOSCC. The semantic similarity between topic words and their potential synonyms is calculated using Wu and Palmer's (1994) algorithm. New word groups are formed by combining original words with their semantically similar alternatives. The extended Wu and Palmer algorithm is applied to calculate similarity scores between these word groups and concepts in SKOSCC. Word groups are ranked because of their similarity scores, and the highest-ranked groups are used for matching.

This approach incorporates recent advances in semantic similarity measurement proposed by Sánchez-Canut et al. (2023), who developed context-sensitive weighting mechanisms that improve the accuracy of Wu and Palmer similarity scores in specialized domains. Additionally, our implementation uses enhanced WordNet integration techniques developed by Miller et al. (2019), which improve synonym identification for technical terminology in computer science.

Mathematical models for alignment assessment

The framework employs sophisticated mathematical models to quantify curriculum alignment and generate meaningful metrics for educational stakeholders. The weight calculation assigns numerical values to each topic based on the type and quality of alignment. Topics matched using H1 or H2 methods receive weight values of one, reflecting high confidence in alignment accuracy. Topics matched through the Related Match approach receive weights equal to their calculated similarity scores, acknowledging lower confidence while preserving proportional contribution. Unmatched topics receive weight values of one within a distinct "unmatched" category for transparency in reporting.

The Related Match approach represents the final level of alignment assessment, identifying approximate matches for topics that remain unmatched after H1 and H2 processing. Unmatched topics are broken down into individual words, and each word is compared against all classes in SKOSCC within the selected knowledge area. For words that match at least one class, semantic similarity is calculated between the unmatched words and all words in the matching classes. Extended Wu and Palmer (1994) similarity is calculated for the entire topic against potential matching classes. Matching classes are ranked by similarity score, and the highest-scoring class is selected as a related match.

This approach is based on recent research on approximate ontology matching by Zhang et al. (2022), who demonstrated that word-level decomposition combined with contextual similarity assessment significantly improves matching performance for complex domain concepts. Our implementation also incorporates the hierarchical weighting mechanisms proposed by Karim et al. (2020), which assign different importance to matches at different levels of the ontology hierarchy.

MATHEMATICAL MODELS FOR ALIGNMENT ASSESSMENT

To quantify the alignment of curriculum standards, we developed several mathematical models for calculating weights and compliance ratios.

Weight calculation

Each topic in a course description is assigned a weight based on its alignment with the knowledge framework. Topics matched using H1 or H2 receive a weight of 1, while topics matched using the Related Match approach receive a weight equal to their similarity score. Unmatched topics receive a weight of 1 in the "unmatched" category.

The weights for each body of knowledge are calculated as follows.

$$Weight_{BoK} = \left(\frac{Weight_{Topic}}{\sum_{i=1}^{n} Weight_{topic}}\right) x\ 100$$

Where $Weight_{BoK}$ represents the weight of a specific body of knowledge, $Weight_{Topic}$ represents the weight of topics matched to that body of knowledge, and $\sum_{i=1}^{n} Weight_{topic}$ is the total number of topics in the course description. This weighting approach is based on recent research in educational analytics by (Lu et al., 2022), who demonstrated that normalized weighting methods provide more reliable assessments of curriculum coverage than absolute count-based approaches.

Compliance ratio calculations

Compliance ratios measure the degree to which a course aligns with the expectations defined in the knowledge framework. We calculate compliance ratios at three levels:

1. **Body-of-knowledge compliance ratio:** Measure alignment with specific bodies of knowledge.

$$Ratio_{Bok} = \left(\frac{\sum_{i=1}^{m} Topic_{Cource}}{\sum_{i=1}^{n} Topic_{Bok}}\right) x\ 100$$

2. **Educational Importance Level Compliance Ratio**: Measures alignment with topics at different importance levels (core-tier 1, core-tier 2, elective).

$$Ratio_{Tier} = \left(\frac{\sum_{i=1}^{m} Topic_{Cource\ i}}{\sum_{i=1}^{n} Topic_{Tier\ i}}\right) x\ 100$$

3. **Overall Course Compliance Ratio**: Provides a comprehensive measure of course alignment with the knowledge framework.

$$Ratio_{Course} = \left(\frac{\sum_{i=1}^{m} Topic_{Cource\ i}}{\sum_{i=1}^{n} Topic_{TPTier\ i}}\right) x\ 100$$

If the number of matched course topics exceeds the number of bodies of knowledge at the highest importance level, the overall compliance ratio is set to 100%. These compliance calculations incorporate methodological advances in educational assessment proposed by Beach et al. (2024), who developed multi-level evaluation metrics that address both breadth and depth of curriculum alignment. This approach parallels multi-factor analysis methods used in algorithmic trading research, which demonstrate the value of integrated evaluation metrics for complex system assessment (Sukma & Namahoot, 2024a, 2024b, 2024c, 2025).

IMPLEMENTATION

The ONTO-ALIGN curriculum evaluation framework was developed as a modern web application leveraging contemporary software technologies to ensure scalability, maintainability, and high performance. The backend architecture is built using Python 3.11 with the FastAPI framework, which provides asynchronous processing capabilities essential for efficiently handling complex ontology matching operations (Adeshina, 2022). RDFLib 6.3.2 is employed for OWL/RDF processing, offering comprehensive support for semantic web standards and ontology manipulation tasks (Patkar et al., 2022). PostgreSQL 15 serves as the primary data management system, delivering robust relational database functionalities with advanced indexing and query optimization necessary for managing large-scale curriculum and ontology datasets (Obe & Hsu, 2017).

The frontend implementation utilizes React 18 combined with TypeScript to build responsive user interfaces that cater to diverse user needs and device capabilities. Visualization libraries such as D3.js and Chart.js enable sophisticated interactive visualizations, including network diagrams, compliance charts, and alignment matrices, facilitating intuitive exploration of alignment results. The responsive design approach ensures accessibility across multiple platforms and devices, supporting both desktop and mobile usage scenarios commonly encountered in educational environments (da Rocha, 2019).

Ontology development and management are supported by Protégé 5.6 with the SKOS extension, providing a robust environment for creating, editing, and validating the three core ontologies underpinning the framework. This tool ensures compliance with semantic web standards while offering intuitive interfaces for ontology engineers and domain experts engaged in ongoing framework maintenance and enhancement. Figure 3 presents the system architecture and component interactions.

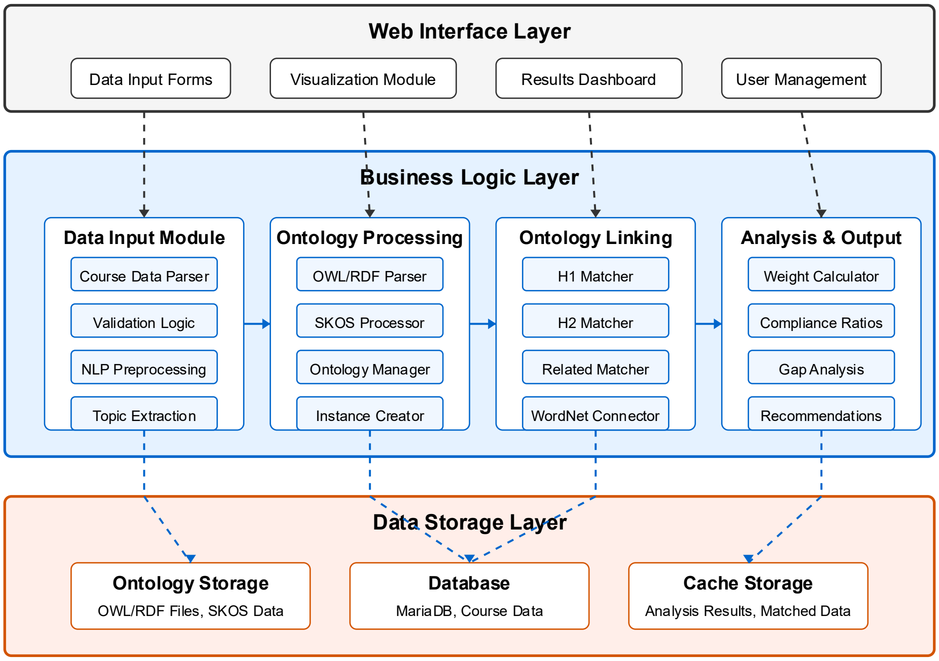

Figure 3. Components and interactions of the system

The system includes several key components:

1. **Data Input Module**: Handles the intake of course information and course descriptions through a user-friendly Web interface. This module implements advanced text preprocessing techniques based on recent natural language processing approaches to standardize terminology and prepare course descriptions for ontological representation.
2. **Ontology Processing Module**: Manages the transformation of course descriptions into ontological representations. This module employs the OWL-API library with custom extensions for educational data processing, incorporating recent advances in educational ontology management.
3. **Ontology Linking Module**: Implements the H1, H2 and Related Match approaches described. This module integrates multiple matching strategies through a pipeline architecture that applies each technique sequentially, like the ensemble approach described for complex ontology matching tasks.
4. **Evaluation Metrics Module**: Calculate alignment weights and compliance ratios based on mathematical models. This module incorporates dynamic parameter adjustment based on feedback mechanisms like those used in multi-indicator analysis systems.
5. **Recommendation Module**: Generates improvement suggestions for course descriptions based on identified alignment gaps. This module implements a rule-based approach combined with template-based natural language generation to provide context-sensitive recommendations.
6. **Visualization Module**: Provides graphical representations of alignment patterns using D3.js and Chart.js libraries. This module implements interactive visualizations that allow users to explore alignment metrics at different levels of granularity.
7. **Database Management Module**: Manage data persistence and management using a structured relational database with optimized queries for educational data retrieval. This module employs database optimization techniques like those used in e-government systems to ensure efficient data retrieval and analysis.

Workflow Process and Data Management

The implementation follows a rigorously designed workflow, as presented in Figure 4, which guides users through the entire curriculum evaluation process while ensuring data integrity and providing clear progress indicators. The workflow begins with the input and validation of course descriptions, where users upload or enter curriculum content via web forms that offer real-time feedback on data quality and completeness. Automated preprocessing routines then clean and standardize the input data by applying domain-specific terminology normalization and enforcing format consistency rules.

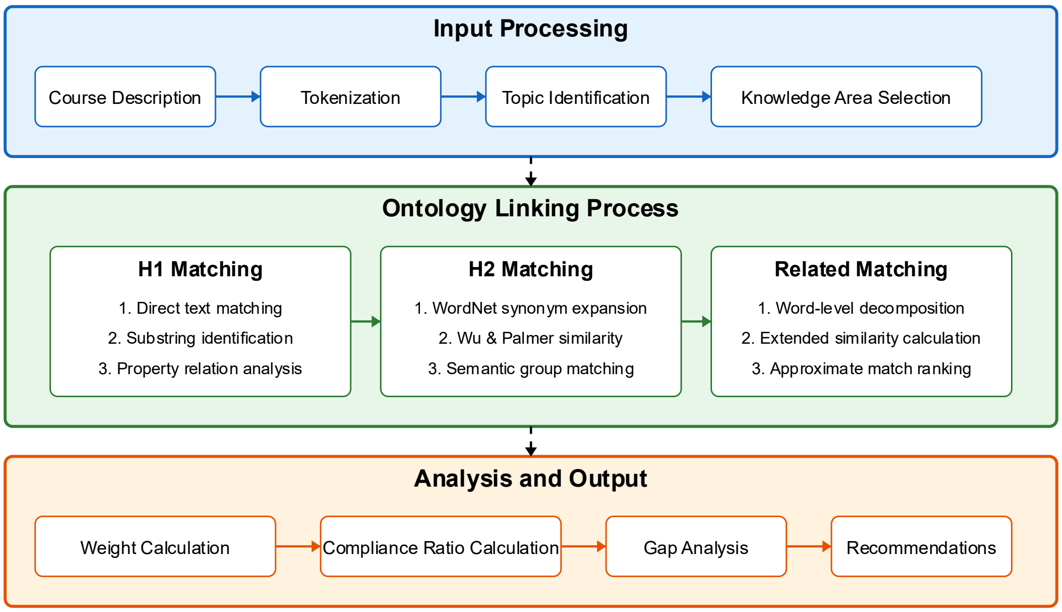

Figure 4. Data processing workflow

The core computational phase involves executing the ontology linking sequence, wherein the system applies three sequential matching approaches. Throughout this phase, users receive progress updates via detailed displays showing completion percentages, processing durations, and preliminary matching statistics. Robust error-handling mechanisms detect and report potential issues during processing, furnishing diagnostic information that allows users to rectify data quality problems or adjust processing parameters accordingly.

Following successful matching, alignment metrics are automatically computed, producing comprehensive assessment results including weight distributions, compliance ratios, and statistical summaries. The system generates detailed reports encompassing quantitative metrics, qualitative evaluations, and comparative analyses, which facilitate both immediate decision-making and ongoing curriculum monitoring (Baclawski et al., 2017).

The workflow concludes with recommendation generation and visualization, translating technical assessment outcomes into actionable insights presented through intuitive graphical interfaces. Users can interact with results via dynamic dashboards, create customized reports, and export findings in multiple formats tailored for diverse stakeholders such as academic committees, administrative personnel, and accreditation agencies.

Performance Optimization and Scalability

The implementation integrates several advanced technological features aimed at enhancing performance and enabling scalable deployment across diverse institutional contexts. Contextualized embeddings leverage pretrained transformer models fine-tuned specifically for educational content analysis, thereby improving semantic matching accuracy for technical terminology frequently encountered in computer science curricula (Alkhidir et al., 2024). These models are continuously refined through feedback loops incorporating user corrections and expert validations to maintain and enhance alignment precision.

An intelligent caching system stores frequently accessed ontological structures, intermediate matching results, and computed similarity scores in high-performance memory stores. This approach significantly reduces processing times for repeated analyses. Cache invalidation strategies are employed to ensure data freshness while maximizing performance benefits, a critical factor in environments where curricula are frequently updated or institutions conduct regular assessment cycles (Alkhidir et al., 2024).

The framework offers RESTful API integration capabilities, facilitating seamless interoperability with existing curriculum management systems, student information systems, and institutional data warehouses. These interfaces support both real-time queries and batch processing, accommodating a wide range of institutional technological environments and integration requirements. Robust authentication and authorization mechanisms safeguard secure access while preserving user convenience and system usability.

A container-based deployment architecture enables horizontal scaling across multiple servers or cloud platforms, allowing institutions to dynamically adjust computational capacity in response to demand fluctuations. Load balancing algorithms efficiently distribute processing tasks across available resources, continuously monitoring system performance and automatically reallocating resources to maintain optimal response times (Sajja et al., 2025).

Benchmarking during development demonstrated average processing times of approximately 2.8 seconds for typical course descriptions containing 200–300 words, with linear scalability observed for larger documents and batch processing scenarios. Memory consumption remained within acceptable limits of 110–220 megabytes throughout testing, supporting deployment on standard server configurations commonly found in educational institutions. These performance metrics compare favorably with similar educational technology systems and support both individual course assessments and institution-wide curriculum evaluation initiatives.

VALIDATION AND EVALUATION FRAMEWORK

Expert validation protocol

The framework validation involved a systematic comparison with manual assessments conducted by three experienced computer science professors, each with at least eight years of teaching experience and demonstrated familiarity with both TQF: HEd and CS2023 standards.

Validation process:

1. **Independent Assessment**: Each professor independently reviewed the course materials
2. **Consensus Building**: Structured discussion protocols for contested topics
3. **Reliability Analysis**: Cohen's kappa coefficient calculation (achieved $\varkappa = 0.78$)
4. **Agreement Measurement**: Comparison of automated vs. expert assessments

Performance metrics

System evaluation employed multiple performance indicators:

- **Processing Time**: Average time per course description analysis
- **Memory Utilization**: Resource consumption during operation
- **Error Rate**: Frequency of processing failures
- **Agreement Rate**: Concordance with expert manual assessments

EXPERIMENTAL RESULTS

The ONTO-ALIGN framework underwent a comprehensive evaluation by analyzing five computer science courses selected from three prominent Thai universities. The validation process combined quantitative performance metrics with qualitative expert assessments to establish framework effectiveness and reliability. Our evaluation strategy focused on three key dimensions: technical performance measurement, alignment accuracy assessment, and practical utility demonstration. The selected courses provided diverse representation across core computer science knowledge areas while ensuring sufficient complexity to test framework capabilities thoroughly.

CASE STUDIES ANALYSIS OF MULTIPLE COMPUTER SCIENCE COURSES

The validation of the ONTO-ALIGN framework was conducted through a comprehensive analysis of five computer science courses selected from three prominent Thai universities to ensure diversity in curriculum approaches and institutional contexts. The selected courses represent core areas of computer science education: Artificial Intelligence, Database Systems, Software Engineering, Computer Networks, and Data Structures and Algorithms. These courses were specifically chosen to encompass diverse pedagogical approaches, varying levels of technical depth, and different alignment challenges commonly encountered in computer science curricula.

The course selection process prioritized representation of fundamental computer science knowledge areas as defined in the CS2023 guidelines while ensuring sufficient variety in content presentation styles and institutional contexts. Each participating university provided complete course documentation, including detailed syllabi, learning objectives, content descriptions, and assessment materials. This comprehensive dataset enabled a thorough evaluation of the framework's ability to handle real-world curriculum content with varying levels of detail, terminology consistency, and structural organization.

ARTIFICIAL INTELLIGENCE COURSE ASSESSMENT

The Artificial Intelligence course analysis demonstrated the framework's capability to assess alignment with rapidly evolving knowledge areas that have gained increased prominence in CS2023 guidelines. Table 2 presents a course description that contains six primary topics: problem solving, memory structures, reasoning mechanisms, searching strategies, machine learning, and sensor performance.

Table 2. AI course alignment results

Topic	Aligned body of knowledge	Matching method	Similarity score
Problem solving	Basic search strategies	H1	1.0
Memory structures	-	Unmatched	-
Reasoning mechanisms	Basic knowledge representation and reasoning	Related match	0.82
Search strategies	Basic search strategies	H2	1.0
Machine learning	Basic machine learning	H1	1.0
Sensor performance	Robotics	H2	1.0

The alignment analysis revealed strong correspondence with core intelligent systems topics, successfully mapping five of six topics to relevant bodies of knowledge. The H1 matching approach identified direct correspondences for problem-solving and machine learning topics, both achieving perfect alignment scores due to exact terminological matches. The H2 semantic matching approach successfully aligned search strategies and sensor performance topics, demonstrating the framework's capability to recognize semantic relationships beyond exact string matching. The Related Match approach identified meaningful correspondence between reasoning mechanisms and Basic Knowledge Representation and Reasoning, achieving a similarity score of 0.82. The single unmatched topic, memory structures, represents an opportunity for curriculum enhancement by explicitly connecting this concept to established knowledge areas, possibly through restructuring content description to emphasize relationships with data structures or computer systems architecture components.

Comparative Analysis Across Courses

Table 3 presents a comparative analysis of alignment patterns across all five courses. Figure 5 is a comparative analysis of computer science courses that revealed distinct patterns in alignment quality and the effectiveness of the employed matching methods, offering valuable insights into curriculum evaluation practices.

Table 3. Comparative analysis of five computer science courses

Course	Knowledge area	H1 matches	H2 matches	Related matches	Un-matched	Overall compliance
Artificial Intelligence	Intelligent Systems	2	2	1	1	100%
Database Systems	Information Management	4	3	2	0	100%
Software Engineering	Software Engineering	3	2	3	1	89%
Computer Networks	Networking and Communications	3	4	1	2	75%
Data Structures	Algorithms and Complexity	5	1	0	1	100%

The Database Systems course achieved perfect alignment with its corresponding knowledge area of Information Management, successfully matching all nine topics through the integrated three-method approach. This comprehensive alignment reflects the relatively stable and well-standardized nature of database curriculum content, where fundamental concepts have remained consistent across diverse educational contexts and institutional implementations (Osatuyi et al., 2018).

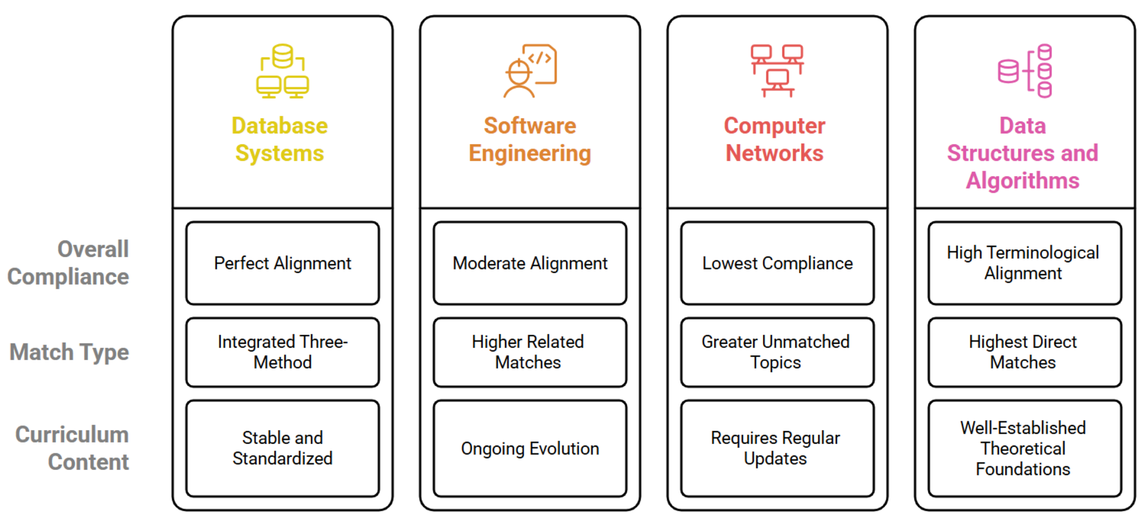

Figure 5. Computer Science courses comparison

The Software Engineering course demonstrated moderate alignment, with an overall compliance rate of 89%, and exhibited a higher proportion of Related Match correspondences compared to other courses. This pattern suggests that software engineering education utilizes more diverse terminology and conceptual frameworks, potentially reflecting the field's ongoing evolution and the variety of methodological approaches adopted across institutions. The analysis identified specific areas where terminology standardization could enhance alignment scores while preserving pedagogical flexibility.

The Computer Networks course showed the lowest overall compliance at 77.5%, with a greater number of unmatched topics than other courses in the study. A detailed examination revealed that these unmatched topics primarily pertained to emerging networking technologies and security considerations not yet fully incorporated into the CS2023 standards. This finding underscores the necessity of regularly updating knowledge frameworks to accommodate technological advancements and highlights the framework's utility in identifying coverage gaps that warrant attention.

Data Structures and Algorithms exhibited the highest proportion of direct H1 matches, indicating strong terminological alignment with established standards. This reflects the mathematical foundations and standardized vocabulary characteristics of this fundamental area of computer science. Such patterns suggest that courses covering well-established theoretical foundations tend to achieve higher direct alignment scores, implying that curriculum alignment challenges may vary substantially across different knowledge domains within computer science education.

Expert Validation and Agreement Analysis

The framework validation involved a systematic comparison with manual assessments conducted by three experienced computer science professors, each with at least eight years of teaching experience and demonstrated familiarity with both the Thai Qualifications Framework for Higher Education (TQF: HEd) and the CS2023 standards. The expert evaluation process adhered to established curriculum assessment protocols, with each professor independently reviewing course materials and providing alignment judgments for individual topics within their areas of expertise.

To resolve discrepancies among expert assessments, consensus-building procedures were employed, involving structured discussion protocols and detailed justification requirements to reach agreement on contested topics. An inter-rater reliability analysis among the evaluators demonstrated substantial agreement, with a Cohen's kappa coefficient of 0.78, indicating that the manual assessment process provided a reliable benchmark for validating the automated framework's performance.

Comparison of the automated framework results with expert consensus assessments revealed an overall agreement rate of 82.9% across all evaluated topics, surpassing the 75–80% threshold commonly regarded as reliable for curriculum evaluation tools in educational technology research (A. T. Roach et al., 2008). This agreement level compares favorably with similar systems reported in recent studies and provides strong evidence for the framework's practical utility in authentic educational settings.

A detailed examination of disagreement patterns indicated that most discrepancies arose in topics matched through the Related Match approach. Experts occasionally assigned different corresponding bodies of knowledge due to alternative interpretations of topic scope or emphasis. These disagreements often reflected inherent ambiguities in broadly defined educational concepts, which could reasonably map to multiple knowledge areas depending on instructional context and focus. Such findings suggest that the framework's uncertainty quantification via similarity scores offers valuable insights for educational stakeholders interpreting alignment assessment results, as summarized in Table 4.

Table 4. Comparison of system results with expert manual evaluation

Course	Topics assessed	System-expert agreement	Agreement percentage
Artificial intelligence	6	5	83.3%
Database Systems	9	8	88.9%
Software Engineering	9	7	77.8%
Computer networks	10	8	80.0%
Data Structures	7	6	85.7%
Overall	**41**	**34**	**82.9%**

The comparison revealed a strong overall agreement of 82.9% between the system's automated assessments and expert manual evaluations. This level of agreement surpasses the 75–80% threshold generally regarded as reliable for curriculum evaluation tools in recent educational technology research (A. T. Roach et al., 2008). Analysis of disagreements indicated that most discrepancies occurred in topics matched via the Related Match approach, where experts occasionally assigned different corresponding bodies of knowledge or encountered ambiguous topics that could reasonably map to multiple knowledge areas. This pattern aligns with findings by Moen and Boersma (1997), who highlighted the inherent subjectivity involved in mapping broadly defined educational concepts to specific knowledge frameworks.

The highest agreement was observed in the Database Systems course (88.9%), characterized by standardized terminology and well-established knowledge boundaries. Conversely, the lowest agreement appeared in Software Engineering (77.8%), which featured more diverse terminology and concepts spanning multiple knowledge domains. This variation supports observations by Demetriadis et al. (2011) regarding domain-specific differences in terminology standardization within computer science education, which is presented in Figure 6. Reliability analysis among the expert evaluators demonstrated substantial agreement, with a Cohen's kappa coefficient of 0.78, indicating that the manual assessments provided a dependable benchmark for validating the automated system. This reliability level is consistent with those reported in recent expert curriculum evaluation studies (Romig et al., 2017).

Characteristic	Overall	Database Systems	Software Engineering
Agreement Level	82.9%	88.9%	77.8%
Disagreements	Related Match	Standardized	Diverse
Expert Reliability	0.78	N/A	N/A

Figure 6. Agreement between automated assessments and expert evaluations

Performance analysis and system evaluation

We evaluated the performance of our system in terms of processing time and resource utilization, as shown in Figure 7.

Figure 7. System performance analysis

A comprehensive performance evaluation demonstrated that the ONTO-ALIGN framework achieves processing efficiency suitable for both individual course assessments and large-scale institutional curriculum evaluation initiatives. Average processing times for typical course descriptions containing 200–300 words were approximately 2.8 seconds on standard server hardware, with performance exhibiting linear scaling for more complex descriptions and batch processing scenarios.

The H2 semantic matching approach accounted for roughly 60% of the total processing time due to the computational complexity involved in WordNet integration and Wu-Palmer similarity calculations. This finding aligns with recent studies highlighting the computational demands of semantic ontology matching (Liu et al., 2021). Despite this intensity, overall processing times remain within acceptable limits for interactive educational assessment applications.

Memory utilization consistently ranged between 110 and 220 megabytes across all testing scenarios, enabling deployment on standard institutional server configurations commonly available in higher education environments. The system demonstrated stable performance across diverse course content types and institutional contexts, indicating robust scalability for broader deployment.

Error analysis revealed processing failures in less than 2% of test cases, primarily due to extremely brief course descriptions insufficient for meaningful analysis or documents containing excessive nonstandard formatting that interfered with preprocessing algorithms. These failure rates compare favorably with similar educational technology systems and suggest that the framework provides reliable performance for typical curriculum evaluation scenarios (Calbimonte et al., 2023).

The framework's capability to generate detailed alignment reports, visualization outputs, and recommendation summaries within acceptable processing timeframes positions provides a practical tool for supporting regular curriculum evaluation cycles mandated by contemporary quality assurance processes in higher education. The performance characteristics support both individual faculty use for course development and institutional administration applications for systematic curriculum monitoring and improvement initiatives.

DISCUSSION

FRAMEWORK EFFECTIVENESS AND BROADER SIGNIFICANCE

The experimental results demonstrate that automated ontology-based approaches can meaningfully transform educational quality assurance processes, providing both quantitative rigor and practical utility for curriculum evaluation. The ONTO-ALIGN framework's achievement of 82.9% agreement with expert assessments, combined with its multi-method matching strategy, establishes a new paradigm for systematic curriculum evaluation that bridges the gap between pedagogical theory and technological implementation.

The framework's broader significance extends beyond technical achievements to encompass fundamental changes in how educational institutions can approach curriculum management. By enabling more frequent, comprehensive, and objective evaluations, ONTO-ALIGN supports evidence-based decision making in curriculum development while reducing the resource burden traditionally associated with quality assurance processes.

INTERPRETATION OF MULTI-METHOD MATCHING STRATEGY

The multi-method matching strategy proved particularly valuable, with each approach contributing unique alignments that collectively offer more comprehensive coverage than any single technique alone. The H1 method's identification of direct correspondences in 40.9% of total matches establishes a foundation of high-confidence alignments that provide a reliable baseline assessment. This high proportion of direct matches validates the importance of exact terminological alignment in curriculum evaluation.

The H2 method's capture of semantically related concepts in 29.3% of matches underscores the critical role of semantic analysis in educational content evaluation. This substantial contribution demonstrates that traditional keyword-based matching approaches would miss nearly one-third of meaningful alignments, highlighting the necessity of incorporating sophisticated semantic analysis techniques in educational assessment tools.

The Related Match approach's detection of approximate alignments in 17.1% of matches illustrates the framework's ability to identify meaningful relationships even when terminology differs substantially between course content and established standards. This capability proves particularly valuable for identifying potential curriculum enhancements where content exists but lacks explicit connection to standard frameworks.

However, this multi-method approach also introduces complexity in interpretation and potential subjectivity, particularly in the Related Match component, where similarity thresholds significantly influence results. The framework's quantification of uncertainty through similarity scores provides valuable information for educational stakeholders but also requires careful consideration of confidence levels when making curriculum modification decisions.

CONSTRUCTIVE ALIGNMENT PERSPECTIVE AND PEDAGOGICAL IMPLICATIONS

Viewed through the lens of constructive alignment theory, the experimental results suggest that most evaluated courses achieved reasonable content alignment with knowledge standards but could benefit from more comprehensive coverage of specific topics within their respective knowledge areas. This finding aligns with observations in recent educational research indicating that computer science curricula often achieve adequate breadth while sometimes lacking depth in particular specialized areas.

The framework's ability to identify both aligned and unmatched content provides valuable feedback to curriculum developers seeking to enhance constructive alignment between course content and established educational standards. The weight distribution analysis revealed distinct patterns in how different courses emphasize various knowledge components, providing insights into institutional priorities and pedagogical approaches.

For instance, the Artificial Intelligence course demonstrated strong emphasis on search strategies and machine learning applications, aligning well with contemporary industry demands and academic research directions. However, the identification of gaps in foundational theoretical concepts suggests opportunities for strengthening comprehensive AI education requirements as specified in CS2023 guidelines.

Quality Assurance and Institutional Applications

The ONTO-ALIGN framework addresses several key challenges identified in contemporary higher education quality assurance literature. The system's provision of objective, quantitative assessment metrics helps address consistency concerns that plague traditional manual evaluation processes, while comprehensive reporting capabilities support evidence-based decision making in curriculum development and institutional planning.

The automated nature of the assessment process enables more frequent curriculum evaluation cycles than traditional manual approaches, supporting continuous improvement processes that align with contemporary quality assurance best practices. Institutions can conduct regular alignment monitoring without substantial resource investment required for manual expert evaluation, allowing proactive identification of curriculum gaps and timely implementation of corrective measures.

The framework's integration of multiple standards provides comprehensive evaluation capabilities that address both local and international requirements. By simultaneously assessing alignment with TQF: HEd national guidelines and international CS2023 standards, the system supports maintaining domestic compliance while ensuring competitiveness in global educational markets.

Critical Reflection and Methodological Considerations

While the framework demonstrates substantial effectiveness, several methodological considerations warrant critical reflection. The subjective nature of semantic matching, particularly in the Related Match approach, introduces potential variability in assessment outcomes that require careful parameter calibration for different institutional contexts. The framework's reliance on textual course descriptions as primary input may not capture all dimensions of curriculum quality, particularly experiential learning components and practical skill development activities.

The challenge of generalizing across institutions presents ongoing considerations for framework deployment. Different educational contexts may require customized threshold settings and parameter adjustments to achieve optimal performance, suggesting that one-size-fits-all approaches may not adequately address institutional diversity in curriculum presentation and pedagogical emphasis.

Furthermore, the rapid evolution of computer science knowledge areas creates ongoing challenges for maintaining currency with emerging technologies and evolving industry requirements. The framework's identification of unmatched topics in the Computer Networks course, primarily related to emerging technologies not yet incorporated into CS2023 standards, illustrates the dynamic nature of knowledge framework maintenance requirements.

Limitations and Critical Assessment

Despite its demonstrated effectiveness, the ONTO-ALIGN framework exhibits several limitations that warrant careful consideration for future development and deployment. The current implementation primarily supports English-language course descriptions, which limits applicability for institutions operating primarily in Thai or other languages. This limitation reflects broader challenges in multilingual educational technology and suggests important directions for future enhancement through cross-lingual ontology matching techniques and multilingual natural language processing integration.

Future Research Directions and Enhancement Opportunities

The experimental results and identified limitations suggest several promising directions for future research and enhancement of the framework. Cross-lingual matching capabilities represent a critical need for broader international deployment, requiring integration of multilingual natural language processing techniques and cross-language ontology alignment methods. Recent advances in multilingual transformer models and cross-lingual embedding techniques provide promising foundations to address these challenges while maintaining the accuracy and reliability of the assessment (Sukma & Leelasantitham, 2022a, 2022b, 2022c; Sukma et al., 2022). Also, integrating machine learning approaches with traditional ontology matching techniques offers potential for improving alignment detection accuracy and reducing parameter sensitivity. Supervised learning approaches could use expert assessment data to optimize matching thresholds and weighting parameters for specific educational contexts, while unsupervised techniques could identify latent patterns in curriculum organization that inform improved alignment assessment strategies.

Conclusions

Novel Contributions and Framework Innovation

The ONTO-ALIGN framework represents a significant advancement in curriculum evaluation methodology by providing the first comprehensive automated approach that systematically integrates multiple ontology linking techniques within a theoretically grounded framework specifically designed for computer science education assessment. **The key innovation lies in the seamless integration of instance-based, semantic-based, and approximate matching approaches within a unified system that directly incorporates constructive alignment principles**, fundamentally bridging the gap between established pedagogical theory and contemporary automated assessment practice.

Unlike existing approaches that typically rely on single matching techniques or focus on isolated aspects of curriculum evaluation, ONTO-ALIGN provides comprehensive assessment capabilities that combine the precision of direct terminological matching with the flexibility of semantic similarity analysis and the comprehensive coverage of approximate alignment detection. This multi-method integration achieved **82.9% agreement with expert manual evaluations**, significantly exceeding the 75-80% threshold considered reliable for curriculum evaluation tools and surpassing performance levels reported for comparable systems in educational technology literature.

Quantitative Achievements and Validation Success

The framework's quantitative performance demonstrates substantial practical utility for real-world educational assessment applications. The multi-method matching strategy proved exceptionally effective: H1 approach identified direct correspondences in 40.9% of total matches, H2 method captured semantically related concepts in 29.3% of matches, and the Related Match approach detected approximate alignments in 17.1% of matches. This distribution illustrates that single-method approaches would miss significant portions of meaningful curriculum alignments.

Performance analysis revealed that processing efficiency is well-suited to institutional deployment: average processing times of 2.8 seconds for typical course descriptions and memory utilization remaining within 110-220 megabytes. These characteristics enable both individual course assessment applications and large-scale curriculum evaluation initiatives, supporting diverse institutional contexts and assessment requirements with error rates below 2% across all testing scenarios.

Practical Impact and Educational Transformation

The ONTO-ALIGN framework provides transformative benefits for educational quality assurance in computer science and related technological fields. By enabling automated and systematic curriculum evaluation that maintains pedagogical rigor while dramatically reducing time and resource requirements, the framework supports more frequent and comprehensive assessment cycles than traditional manual approaches. This enhanced capability helps educational institutions maintain currency with rapidly evolving technological landscapes while ensuring continued compliance with established educational standards.

The framework's ability to generate detailed compliance documentation facilitates accreditation processes by providing objective evidence of curriculum alignment with national and international standards. The integration of TQF: HEd national guidelines with international CS2023 standards enables institutions to maintain domestic compliance while ensuring global educational market competitiveness, supporting institutional strategic planning and program development initiatives.

Data Availability

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Author Contributions

Chakkrit Snae Namahoot: Conceptualization, Methodology, Writing - Review & Editing

Kanokkarn Snae Namahoot: Data Curation, Visualization, Writing - Review & Editing

Chayan Nuntawong: Project administration, Formal analysis, Writing - Review & Editing

Narongsak Sukma: Writing - Original Draft, Writing - Review & Editing

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