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Research Article

OntoCS: Advancing Computer Science Education through Ontology-Driven Knowledge Management for Curriculum Standardization

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ABSTRACT

This research focuses on advancing the knowledge management process within the computer science curriculum through the application of ontology techniques, aligning with established standards such as those outlined by the IEEE and ACM Computer Associations, and the Thailand Qualifications Framework for Higher Education (TQF: HEd). The research introduces three distinct ontologies: (1) a curriculum ontology (OCC) designed to represent course descriptions provided by lecturers, (2) an ontology (OTQF) aligning with the TQF: HEd in Computer Science, serving as a standardized framework for universities in Thailand to guide the preparation and enhancement of teaching and learning curriculum, ensuring uniform quality and standards across educational institutions. Additionally, (3) a knowledge-based ontology for Computer Science standard curriculum (KOSCC) is introduced, utilized as a benchmark for evaluating individual courses and overall curriculum levels. Hybrid matching algorithms, incorporating instance-based, constraint-based, and property relation-based techniques, are employed in the ontology matching process between course descriptions in OCC and KOSCC. The proposed OntoCS, contributes to the enhancement of computer science education by seamlessly integrating ontology-driven knowledge management, thereby fostering a cohesive and standardized educational context. The outcomes of this research provide valuable support for instructors in designing subjects and courses that align consistently with curriculum standards.

Keywords: Knowledge management process, knowledge-based ontology, algorithm, data matching.

INTRODUCTION

Several studies emphasize the importance of creating domain-specific ontologies for CS education [1]. Accurate representation of program structures, courses, and concepts at different levels is crucial [1]. Ontology alignment facilitates interoperability and enables effective utilization of semantic technologies in curriculum design and assessment [1], [2], [9], [11].

Ontology alignment is a critical area of research in the field of Computer Science, particularly in the context of curriculum design and assessment [3]. In the following, we present contributions of recent papers to the knowledge of ontology alignment, identify their limitations, and offer insights for future research in this domain.

Several papers have made significant contributions to the understanding of ontology alignment practices. Cheng and Nunes shed light on the challenges and importance of creating domain-specific ontologies for representing various areas of computing, emphasizing the need for accurate representations of structures and concepts in Computer Science curricula [1]. Liu et al. provided a comprehensive overview of ontology matching approaches, information analysis, and aggregation methods, enhancing the understanding of the methodological differences in the field of ontology matching [4]. Moreover, Neutel and de Boer contributed by applying ontology alignment in a real-world use case within the labor market field, demonstrating the relevance and importance of ontology alignment in facilitating information exchange and tool development in specific domains [5]. Additionally, Stancin et al. offered valuable insights into the use of ontologies in education, highlighting the potential for further advancements and innovations in this area [2].

Despite the valuable contributions, these papers also have limitations that should be considered. For instance, [1] highlighted shortcomings in the evaluation metrics, limited comparison with existing methods, scalability, generalizability, and practical implementation challenges of the proposed Hybrid Ontology Matching Mechanism. Liu et al. pointed out limitations such as the focus on information analysis, limited coverage of specific algorithms, lack of case studies or practical examples, and the need for broader coverage of future work [4]. Also, Neutel and de Boer discussed in [5] limitations related to the lack of focus on specificities, limited availability of complex alignments, challenges in evaluation, and the complexity of representations. Additionally, Zouri and Ferworn highlighted concerns about scalability, interoperability, maintenance and updates, and user adoption of the proposed ontology for curriculum mapping in higher education [6].

The limitations identified in these papers provide valuable insights into the areas where further research and development are needed to address challenges and enhance the effectiveness of ontology alignment in practical applications. Future research in ontology alignment should focus on addressing the identified limitations, such as the need for standardized evaluation metrics and datasets, the development of automated solutions for matching ontologies, and the improvement of expressiveness in alignments. Additionally, there is a need for research that explores the interoperability of ontologies with existing educational systems, strategies for maintaining and updating ontologies over time, and the user adoption and usability of ontology-based systems for curriculum mapping.

OBJECTIVES

Background

The Qualifications Framework refers to guidelines designed to establish common standards for education management and quality assurance. It includes setting educational qualification levels and credit units to help students plan their education systematically, ensure consistency in teaching methods among educational institutions, and assist employers in defining suitable characteristics for hiring graduates. Several countries have implemented national qualifications frameworks to focus on education quality assurance and facilitate school transfers according to student needs.

In Thailand, as mandated by the National Education Act of 1999 and its amendments, the National Education Commission has established the Thailand Qualifications Framework for Higher Education (TQF: HEd). The framework aims to serve as a standard guide for educational institutions in curriculum development, teaching management, and education quality improvement. It aligns with the principles set forth by the National Education Commission and encourages educational institutions to enhance their education management quality continually.

The Qualifications Framework for the Computer Science curriculum in Thailand, outlined in the Ministry of Education's announcement on bachelor’s degree qualification standards for the Computer Science program in 2009, differs from other curriculum frameworks. It provides detailed curriculum structures aligned with the standards of the Ministry of Education and the IEEE and ACM computer societies [10]. The framework includes thirteen subject areas, each comprising a Body of Knowledge related to the field. The content and knowledge in each area can be adjusted based on the progress and discretion of appointed experts by the National Education Commission.

From what has been mentioned above, it can be seen that the qualifications framework established and used in various countries, including Thailand, focuses on setting standards for the level of education, educational qualifications, credit units, and the transfer of schools. However, it does not emphasize the importance of defining standards for the detailed content and essential knowledge (Body of Knowledge) of the curriculum necessary for each program. This lack of emphasis has resulted in a lack of tools to assist instructors in aligning the content of the curriculum with the knowledge framework standards [12-13].

In this research, data on essential content and knowledge as per the mentioned regulations has been utilized to design technology for the National Qualifications Framework for Higher Education. The Computer Science Curriculum Standards is a document developed by the IEEE Computer Society and ACM with the aim of supporting guidelines for creating computer science undergraduate programs globally. This project began in 1968 and has undergone continuous updates and improvements over the years. Each revision involves collaboration with computer science experts from various universities to ensure the highest quality standards and relevance to undergraduate students. Additionally, it serves as a guide to develop knowledge in various aspects of computer science, preparing students for further graduate studies [7]. The latest version of the Computer Science Curriculum Standards, Computer Science Curricula 2013 (CS2013), outlines 18 Knowledge Areas that are essential for teaching in computer science undergraduate programs. These areas include:

1. Algorithms and Complexity (AL)
2. Architecture and Organization (AR)
3. Computational Science (CN)
4. Discrete Structures (DS)
5. Graphics and Visualization (GV)
6. Human-Computer Interaction (HCI)
7. Information Assurance and Security (IAS)
8. Information Management (IM)
9. Intelligent Systems (IS)
10. Networking and Communications (NC)
11. Operating Systems (OS)
12. Platform-based Development (PBD)
13. Parallel and Distributed Computing (PD)
14. Programming Languages (PL)
15. Software Development Fundamentals (SDF)
16. Software Engineering (SE)
17. Systems Fundamentals (SF)
18. Social Issues and Professional Practice (SP)

Each Knowledge Area comprises a Body of Knowledge, which includes various topics related to that specific Knowledge Area. For example, the Algorithms and Complexity (AL) Knowledge Area includes seven bodies of knowledge:

1. Basic Analysis
2. Algorithmic Strategies
3. Fundamental Data Structures and Algorithms
4. Basic Automata, Computability, and Complexity
5. Advanced Computational Complexity
6. Advanced Automata Theory and Computability
7. Advanced Data Structures, Algorithms, and Analysis

Each Body of Knowledge further includes topics recommended for teaching. For instance, the Basic Analysis Body of Knowledge includes topics such as differences among best, expected, and worst-case behaviors of an algorithm, asymptotic analysis, and complexity classes. These topics are categorized into three tiers based on their necessity in the curriculum: Core-Tier 1 (necessary to study), Core-Tier 2 (recommended core knowledge), and Elective (optional) (ACM and IEEE, 2023).

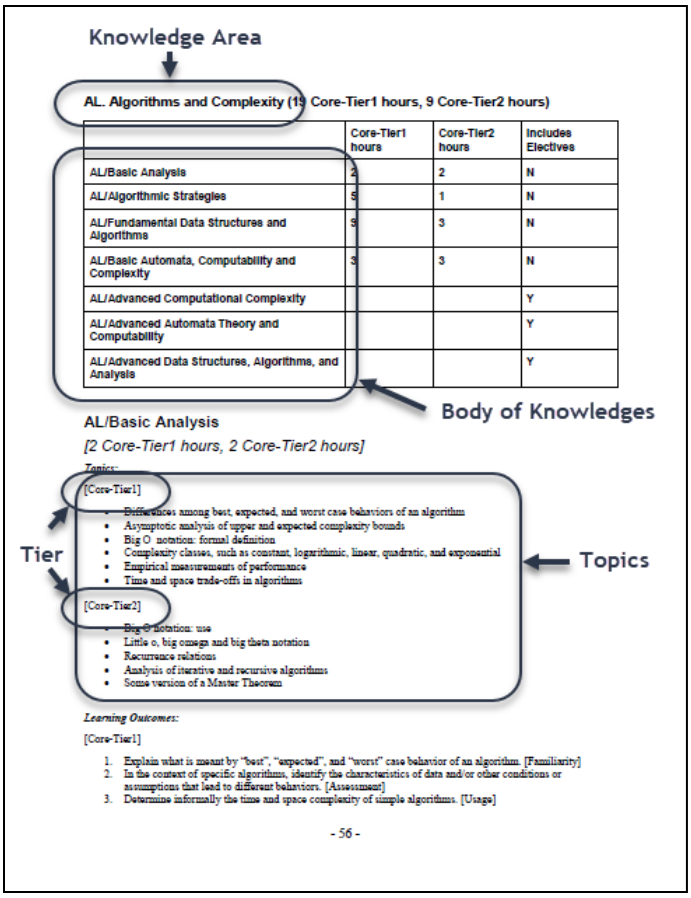

Fig. 1. Examples of the scope of knowledge, bodies of knowledge, topics, and levels of necessity in studying Algorithms and Complexity (ACM and IEEE, 2023)

In this research, the Computer Science curriculum standards have been designed as a knowledge base using the principles of technology-enhanced learning. This is intended to serve as a standard for integrating technology into the curriculum of standard degree programs and the national qualifications framework for higher education.

PRINCIPLES AND TOOLS OF ONTOLOGY TECHNOLOGY

Ontology Technology: In this research, ontology technology principles were used in designing and storing data for the computer science curriculum and the national standard qualifications framework at the advanced level. This is because the information consists of the course structure and descriptions of courses that convey important knowledge in those courses. The ontology technology's designed structure includes classes that store information about courses and various knowledge in those courses. The class names and designed data can be used for semantic and data-driven ontology technology linkage. The structure includes layering and relationships of each class, suitable for finding alignment using linkage techniques, such as structural, property-based, and constraint-based approaches.

OWL (Web Ontology Language): In this study, two parts of ontology technology were used: curriculum ontology and ontology technology for the national standard qualifications framework. The OWL language was utilized to describe and store ontology technology in .owl file format.

SKOS (Simple Knowledge Organization System): SKOS language was employed to design the standard knowledge base for the computer science curriculum. It referenced data from the 2013 version of the Computer Science Curricula, providing a clear structure with aligned Knowledge Areas, Bodies of Knowledge, and Topics. SKOS was deemed suitable for creating a knowledge base from this structured data.

Ontology Mapping: Ontology mapping involves considering the alignment of various components between two ontologies that may have different formats or components. Techniques for ontology mapping include syntax-based, instance-based, constraint-based, structure-based, and property relation-based approaches. The research utilized all five techniques: property relation-based and constraint-based ontology mapping for considering the curriculum ontology, the national standard qualifications framework ontology, and the standard knowledge base for the computer science curriculum. This allowed for easy consideration of alignment and differences in the layered structure, relationship properties, and data conditions within each ontology. Additionally, instance-based ontology mapping was used to assess the characteristics of data within each ontology. Semantic similarity, a part of semantic-based ontology mapping, was employed to consider the meaning alignment between topics in the ontologies, even when using different words or text. This was combined with structural-based ontology mapping to assess the structure of word groups for the most accurate linkage between these two ontologies.

METHODS

Research Methodology

Analysis and Design:

- Utilized principles and related research studied in Chapter 2.
- Analyzed and designed the architecture of the tool to assess the alignment of the curriculum and the national standard qualifications framework.

Data:

- Designed ontology technology for the curriculum.
- Designed ontology technology for the national standard qualifications framework.
- Designed the knowledge base for the computer science curriculum.

Methods:

- Conducted alignment between the national standard qualifications framework and the knowledge base for the computer science curriculum.
- Prepared course description data for the curriculum ontology.
- Combined instance-based, constraint-based, property relation-based, semantic-based, and structure-based ontology mapping techniques.
- Calculated the weight of each aligned knowledge.
- Calculated the alignment ratio to the standard for each knowledge area and memory level in each course.
- Calculated the overall alignment ratio to the standard.

Design and Development of the Tool:

- Developed a tool to assess the alignment of the curriculum and the national standard qualifications framework.

Testing and Tool Usage:

- Tested and utilized the developed tool.

Conclusion and Recommendations:

- Summarized results, discussed findings, and provided recommendations.
- Compiled a report.

Tool Operation Architecture

We designed the architecture of the tool to assess the alignment of the curriculum and the national standard qualifications framework using ontology technology. The steps involved in the tool's operation are as follows:

- **Alignment Analysis:** The tool analyzes and aligns the curriculum and the national standard qualifications framework

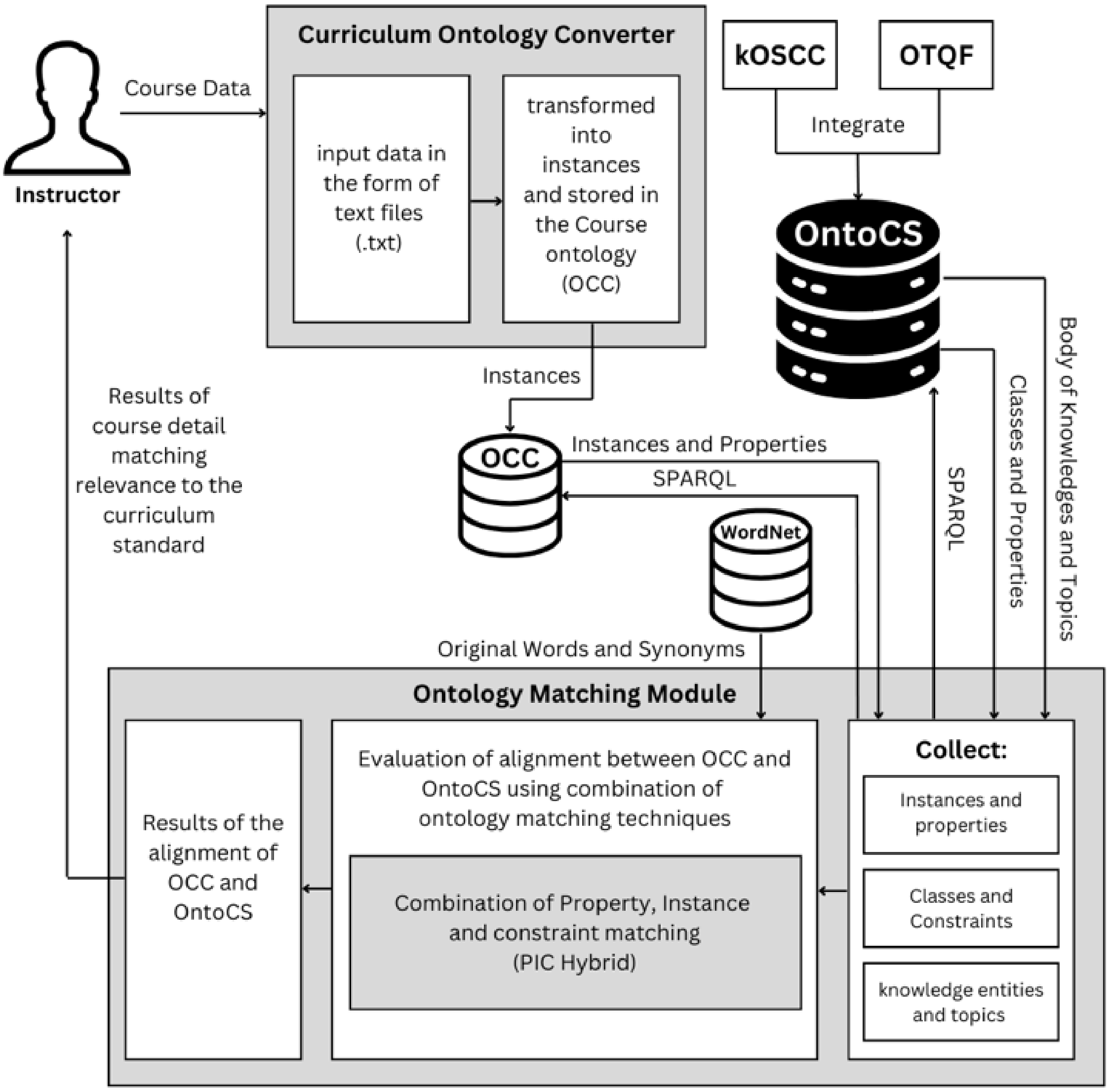

Fig. 2. System architecture

Fig. 2 shows the various components within the architecture of the tool.

1. Curriculum Ontology Converter:

1. Instructors input course data into the Computer Science curriculum, including course name, code, instructor, credits, and course description, all in English. This is done for internationalization and to facilitate comparisons with university curriculums in ASEAN member countries. The input data is in the form of text files with the .txt extension containing course descriptions.
2. The data from 1.1 is transformed into instances and stored in the Course ontology (O_{CC}).

2. Standard ontology Integration (OntoCS): integrate two ontologies together between Standard Computer Science Knowledge Base (KOS_{CC}) and O_{TQF}.

3. Ontology Matching Module: Assessment of Alignment between Course ontology (O_{CC}) and OntoCS using the combination of ontology matching techniques.

1. Instances and Properties are gathered from the Course Ontology, and the structure, knowledge entities, and topics are retrieved in the form of classes from the standard Computer Science Knowledge Base using SPARQL language commands.
2. Evaluation of alignment between Course ontology and the standard Computer Science ontology (OntoCS) is performed using a combination of ontology matching techniques called PIC hybrid method which includes Property, Instance and Constraint matching [8].
3. Results of the alignment for all courses are presented in the form of headings based on the course descriptions that align and do not align with the Computer Science standards (OntoCS). The course details matching relevance to the curriculum standard are provided to instructors.

The algorithm of PIC hybrid method can be shown as follows.

1. Select the knowledge area

2. Topics from the course description (Instance) from O_{CC} and knowledge and topics (Class) from KOS_{CC} were used for comparison.

// Constraint of Similarity

3. Compare each topic with each body of knowledge or topic in that knowledge area with consistency conditions.

- If they are the same (=): Go to 4.

- If it is a part (∈): Go to 4.

- **If not found:** Not consistent and go to 7.

// Constraint of Property Relation

4. Examine the found knowledge or topic in terms of the relationship of properties.

- If it matches the body of knowledge's name:

Corresponds to that knowledge and goes to 5.

- If it matches the topic's name:

RESULTS

The design of the Online Curriculum Configuration (O_{CC}) involves developing a tool capable of importing curriculum data in the O_{CC} format. This design is based on the study of the design structure from the research conducted by [3]. The OCC comprises two main classes: Computer Science and University. Within the Computer Science class, there are Subclasses categorized based on the type of course groups, namely General Education Courses and Professional Education Courses. In the class of Professional Education Courses, there are three types of courses: Core Courses, Major Required Courses, and Major Elective Courses. All classes in O_{CC} are illustrated in Fig 3.

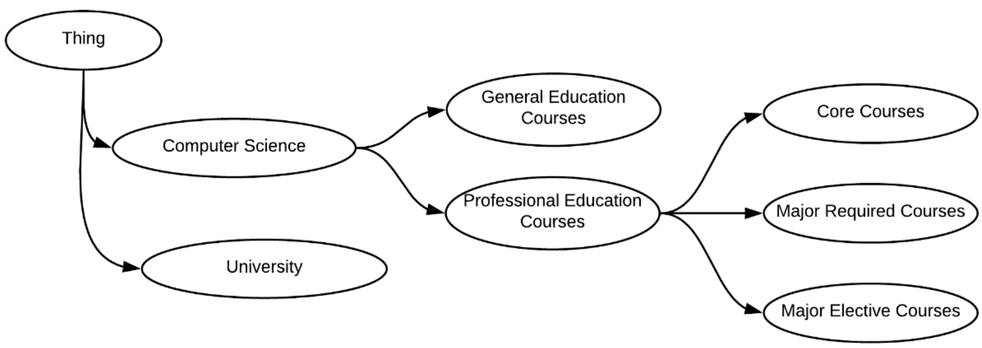

Fig. 3. O_{CC} design

Fig. 4 illustrates an example of O_{CC} storing data for the Artificial Intelligence course. The data includes course details such as course name, course code, instructor name, credits, and course description. These details are stored in the form of instances with properties linked to the instances of core courses, which are subclasses of the major courses class. This major courses class is a subclass of the Professional Education Courses class, which, in turn, is a subclass of the Computer Science class.

As for university-related information, including university name, abbreviation, and website address, it is stored as instances with properties linked to university instances within the University class.

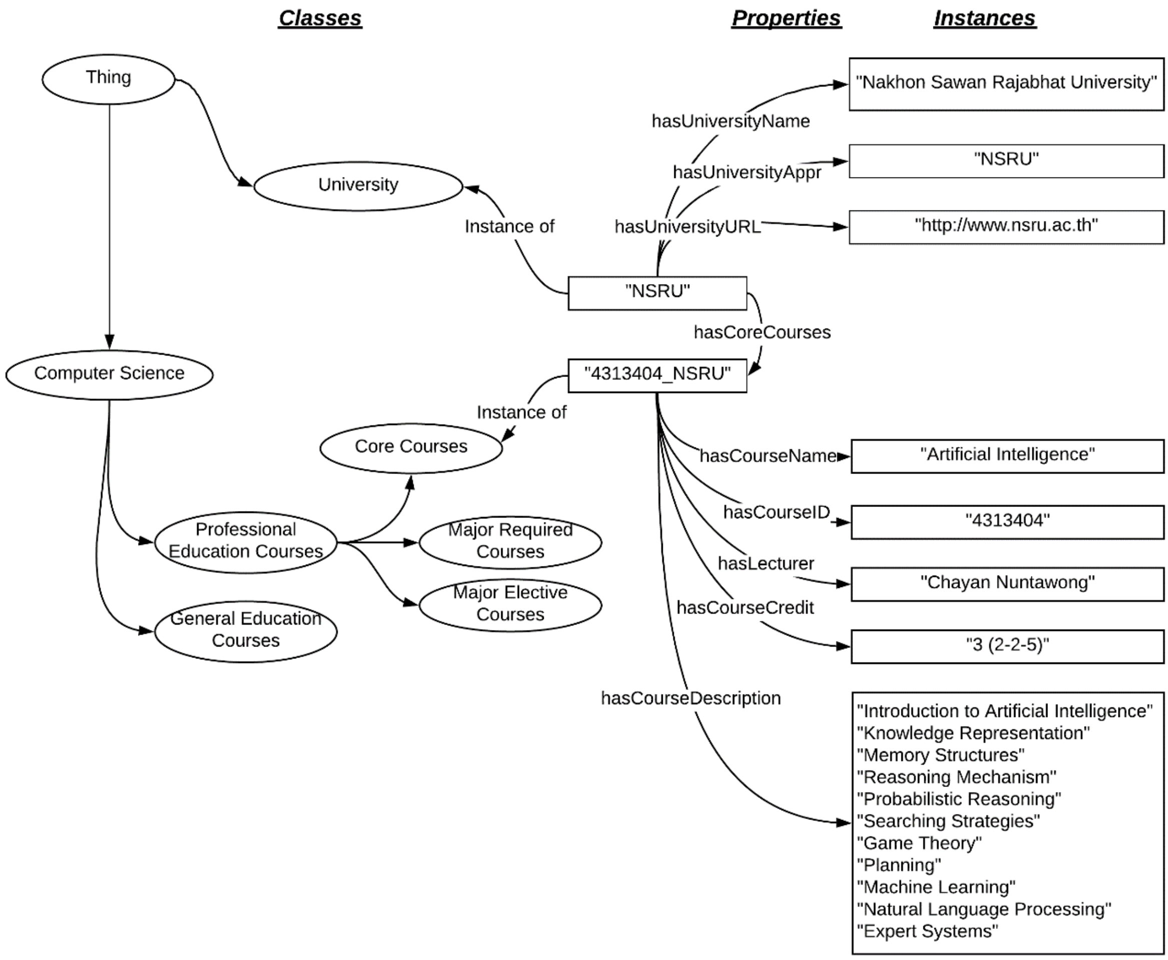

Fig. 4. Class, Property and Instance of AI subject in O_{CC}

Fig. 5 shows the design of O_{TQF}, which illustrates the class "TQF: HEd Computer Science" with subclasses representing all 14 knowledge domains. It references all 14 knowledge domains and presents an example of the knowledge entities within the knowledge domain of the 3 knowledge areas, namely:

1. Knowledge entities under the "Intelligent Systems" knowledge domain in the form of three classes: "Fundamental Issues," "Basic Search Strategies," and "Knowledge-Based Reasoning," all of which are subclasses of the "Intelligent Systems" class.
2. Knowledge entities under the "Software Engineering" knowledge domain in the form of eight classes: "Software Design," "Using APIs," "Tools and Environments," "Software Processes," "Requirements Specifications," "Software Validations," "Software Evolution," and "Software Project Management."
3. Knowledge entities under the "Information Management" knowledge domain in the form of three classes: "Information Models," "Database Systems," and "Data Modeling."

However, O_{TQF} only has subclasses at the level of knowledge entities, lacking detailed topics under them. It is not specified how these knowledge entities should be composed of topics for instructional purposes.

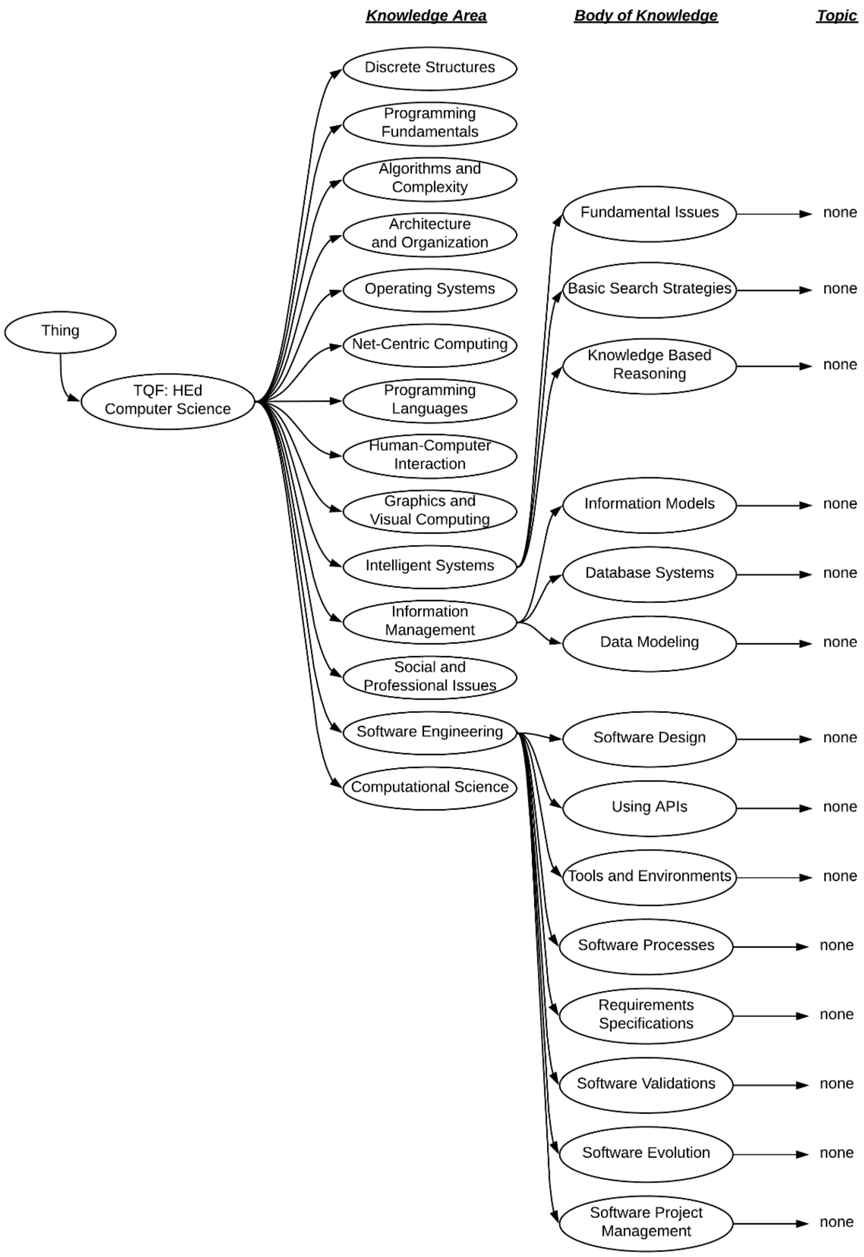

Fig. 5. Design example of O_{TQF} with classes for the knowledge domains in Intelligent Systems, Software Engineering, and Information Management.

The example results of course detail matching relevance to the curriculum standard using PIC hybrid algorithm are shown in Table 1.

Table 1: Results of consistency matching between each topic from Artificial Intelligence course and knowledge under the Intelligent Systems knowledge area.

Topic from course description (Occ)	Consistent knowledge area (OntoCS)	Type of Consistent
Problem Solving	Basic search strategies	PIC hybrid
Memory Structure	-	Mismatch
Reasoning mechanisms	-	Mismatch
Searching strategies	Basic search strategies	PIC hybrid

Topic from course description (Occ)	Consistent knowledge area (OntoCS)	Type of Consistent
Machine Learning	Basic machine learning	PIC hybrid
Sensor performance	-	Mismatch

Table 1 shows the results of correspondence matching between the Artificial Intelligence course description/topic from the computer science course in a University (Occ) and the standard Intelligent Systems knowledge area from OntoCS. The results show that there are three topics mismatched, such as memory structure, Reasoning mechanisms and Sensor performance. This leads to the conclusion that concluded that these three topics must be revised and updated to be consistent with course standards.

DISCUSSION

Conclusion and Future Directions

In this research, the researchers developed a tool to assess the alignment of a curriculum with knowledge standards at the national tertiary education level. The tool was implemented as a Web Application using PHP and RAP for development, incorporating a combination of five linking technology techniques: Instance-based, Constraint-based, Property relation-based, Semantic-based, and Structure-based. The goal was to find alignment between course descriptions imported and stored as instances from the curriculum technology and knowledge stored as classes from the standard computer science curriculum knowledge base.

Summary of Research Results: The development of the tool for assessing curriculum alignment with knowledge standards at the national tertiary education level using linking technology was divided into three main components:

Data:

Design and development of three new technologies: Curriculum Technology, Standard Curriculum Framework Technology (referenced in the Ministry of Education's announcement), and Standard Computer Science Curriculum Knowledge Base (referenced in ACM and IEEE standards 2023). These technologies were designed and stored in OWL and SKOS file formats.

Methodology:

Introduction of a new technique for assessing alignment, including testing to find alignment between the Standard Curriculum Framework Technology and the Standard Computer Science Curriculum Knowledge Base. The study found that data from the standard curriculum knowledge base was more up-to-date and detailed compared to data from the national standard curriculum framework. Therefore, the researchers chose to assess alignment between the curriculum technology and the standard computer science curriculum knowledge base for more relevant and up-to-date results.

Results:

The study revealed the alignment between the curriculum technology and the knowledge base of the standard computer science curriculum. The data from the standard computer science curriculum knowledge base was found to be more contemporary and detailed than the data from the national standard curriculum framework. The content was updated to be more current, making the results of the alignment assessment more appropriate and up-to-date.

Regarding future directions, the rapid development of generally available Artificial Intelligence (AI) tools may lead to prospective new processes in the realm of ontology alignment. Promising aspects are

- **Streamline resource discovery:** AI can sift through vast educational resources, pinpointing materials that align with specific learning objectives and standards.
- **Automate tedious tasks:** AI can analyze curriculum documents and resources, highlighting gaps or redundancies in learning goals.
- **Facilitate adaptation:** AI can suggest adjustments to existing curricula to better suit diverse learning styles or regional contexts.

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