Ontology-based representation and design of subject domains for Computer Science education

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Abstract

This paper presents an ontological approach for representing and designing subject domains in computer science education. An ontology schema is proposed to formally describe the key concepts, relationships, and competencies within a discipline. Criteria for selecting computer ontology systems are established, and a methodology for designing subject domain ontologies using the web-based Protégé environment is outlined. An algorithm is provided to guide future IT specialists in constructing ontologies based on the schema. Experimental results demonstrate improved speed, reduced defects, and faster integration when using the proposed ontology-based approach compared to traditional methods. The findings highlight the effectiveness of ontologies as a means to systematize knowledge and enhance the training of aspiring IT professionals.

Keywords

ontology, knowledge representation, computer science education, subject domain modeling, competency-based learning

1. Introduction

1.1. Problem statement

The development of ontology-driven information systems is a key trend in modern computing [1, 2]. Ontologies enable the formal specification of domain concepts and relationships, providing a foundation for knowledge sharing and machine processing [3, 4]. In the context of computer science education, ontologies can play a vital role in representing subject domains and supporting competency-based learning [5, 6].

However, constructing ontologies is a complex and time-consuming process that requires expertise in knowledge representation languages and techniques [7]. Computer ontology systems (COS) have emerged as tools to facilitate ontology development by providing intuitive interfaces and features [8]. Integrating COS into the training of future IT specialists is crucial for equipping them with the skills to model and reason about subject domains.

1.2. Related work

Foundational work on ontologies and their application in computer systems has been conducted by Gruber [9, 10], Lapshyn [11]. The use of ontologies to support knowledge sharing and reuse has been explored by Gruber [12], Noy and McGuinness [7]. Ovdei and Proskudina [8] provide an overview of ontology engineering tools and their capabilities.

In the educational context, Yevseeva [5], Liubchenko [13], Tsidylo [6] have investigated the use of ontologies for modeling subject domains and integrating knowledge. Tsidylo and Kozibroda [14] examine the role of COS in developing design competencies among engineering educators.

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While these works highlight the potential of ontologies in education, there is a need for a comprehensive approach that guides future IT specialists in constructing subject domain ontologies using COS.

1.3. Objectives

The objectives of this paper are:

1. To propose an ontology schema for representing subject domains in computer science education.
2. To establish criteria for selecting COS and identify a suitable environment for ontology design.
3. To develop a methodology for constructing subject domain ontologies using the selected COS.
4. To experimentally evaluate the effectiveness of the proposed approach in terms of ontology construction speed, defect reduction, and integration efficiency.

2. Ontology schema for subject domains

Figure 1 presents the proposed ontology schema for representing subject domains. The schema defines a set of core concepts (C_{DD}) and relationships (R_{DD}) to capture the key elements and associations within a discipline:

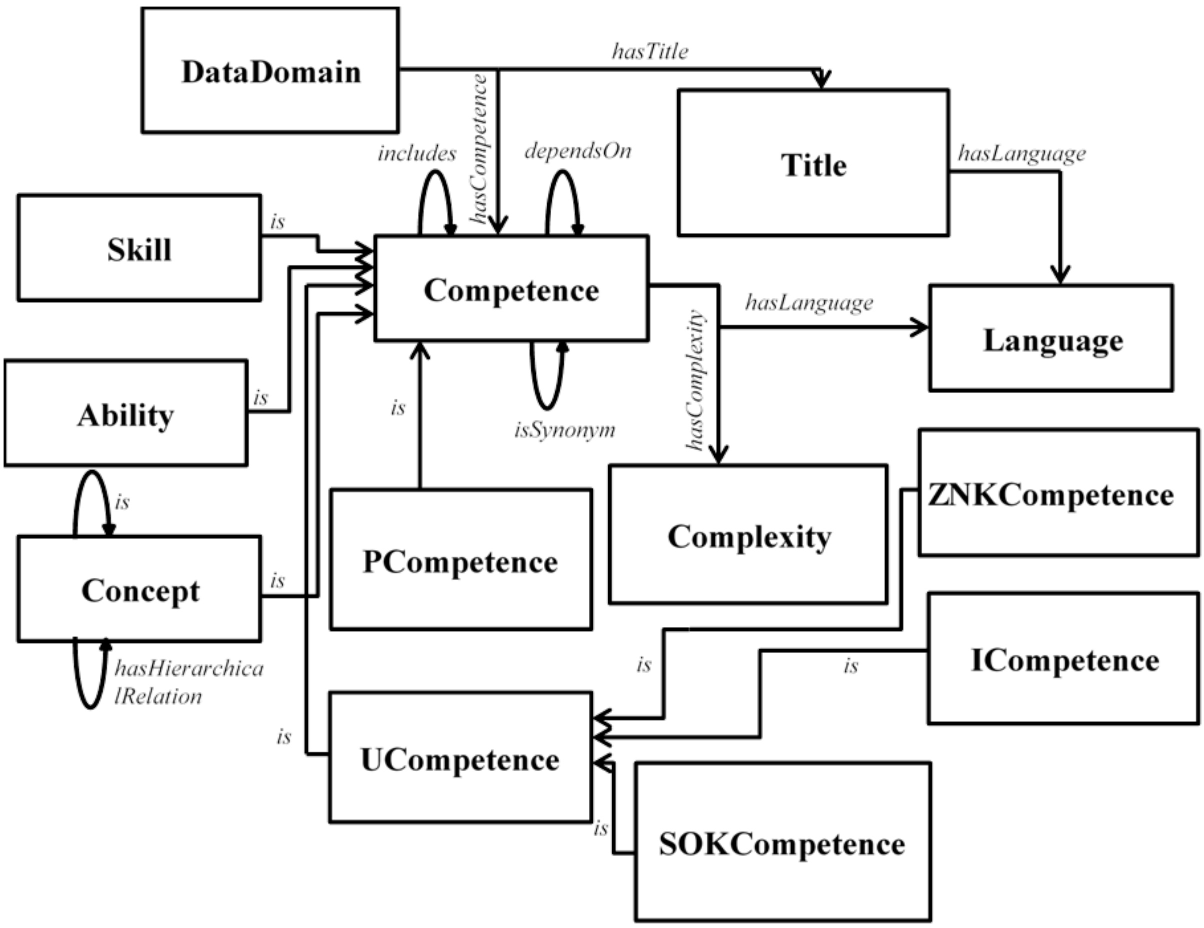

Figure 1: Ontology schema for subject domains.

The set of concepts C_{DD} includes:

- `DataDomain`: The subject domain of the discipline.
- `Competence`: The competencies associated with the discipline.

- `Concept`: The key concepts or terms within the subject domain.
- `UCompetence`, `PCompetence`, `ZNKCompetence`, `ICompetence`, `SOKCompetence`: Different types of competencies (universal, professional, general scientific, instrumental, socio-personal/cultural).
- `Skill` and `Ability`: The skills and abilities acquired within the subject domain.
- `Language`: The language used to represent the subject domain knowledge.

The set of relationships R_{DD} includes:

- `hasLanguage`: Specifies the language of the ontology.
- `hasComplexity`: Defines the level of competency development.
- `includes`: Represents the inclusion of competencies, concepts, skills, and abilities.
- `dependsOn`: Captures dependencies between competencies, concepts, skills, and abilities.
- `isSynonym`: Indicates synonymy between subject domain concepts and competencies.
- `is`: Expresses an "is-a" relationship between subject domain concepts.
- `hasHierarchicalRelation`: Represents hierarchical relationships between concepts.
- `hasTitle`: Specifies the natural language description of a competency.
- `hasCompetence`: Links a subject domain to its associated competencies.

This schema provides a foundation for formally representing the structure and elements of a subject domain in computer science education.

3. Criteria for selecting computer ontology systems

To support the design and development of subject domain ontologies, it is crucial to select an appropriate COS. The following criteria should be considered [15]:

1. Software architecture and development tools: The COS should have a robust architecture and provide tools for ontology editing, visualization, and reasoning.
2. Functional compatibility: The COS should support interoperability with other ontology languages and tools, enabling seamless integration and knowledge sharing.
3. Intuitive interface: The COS should offer a user-friendly interface that facilitates collaborative ontology development and provides access to ontology libraries.

Based on these criteria, the web-based Protégé environment [16] is identified as a suitable COS for ontology design in computer science education. Protégé offers a rich set of features, including an intuitive graphical interface, support for multiple ontology languages (e.g., OWL, RDF), and extensive reasoning capabilities.

4. Methodology for ontology design

To guide future IT specialists in constructing subject domain ontologies using Protégé, the following methodology is proposed, adapted from [17]:

1. Define the domain and scope of the ontology.
2. Reuse existing ontologies if applicable.
3. Enumerate important terms in the ontology.
4. Define classes and class hierarchy.
5. Define class properties and attributes.
6. Define facets of properties.
7. Create instances of classes.

Applying this methodology in the context of the proposed ontology schema (Section 2), the following algorithm is suggested for ontology construction:

1. Identify and describe first-level competencies (`UCompetence`, `PCompetence`, `ZNKCompetence`, `ICompetence`, `SOKCompetence`) based on the discipline's curriculum and competency matrix.
2. Identify and describe second-level competencies (`Concept`, `Skill`, `Ability`) by analyzing the acquired knowledge, skills, and abilities.
3. Identify and describe third-level competencies associated with each module of the curriculum.
4. Identify and describe lower-level competencies based on the subject domain knowledge and available educational resources.
5. Define relationships between competencies using the R_{DD} set, considering inclusion (`includes`), dependency (`dependsOn`), synonymy (`isSynonym`), and hierarchical relations (`hasHierarchicalRelation`).

Figure 2 illustrates an example of a subject domain ontology constructed using this algorithm in Protégé.

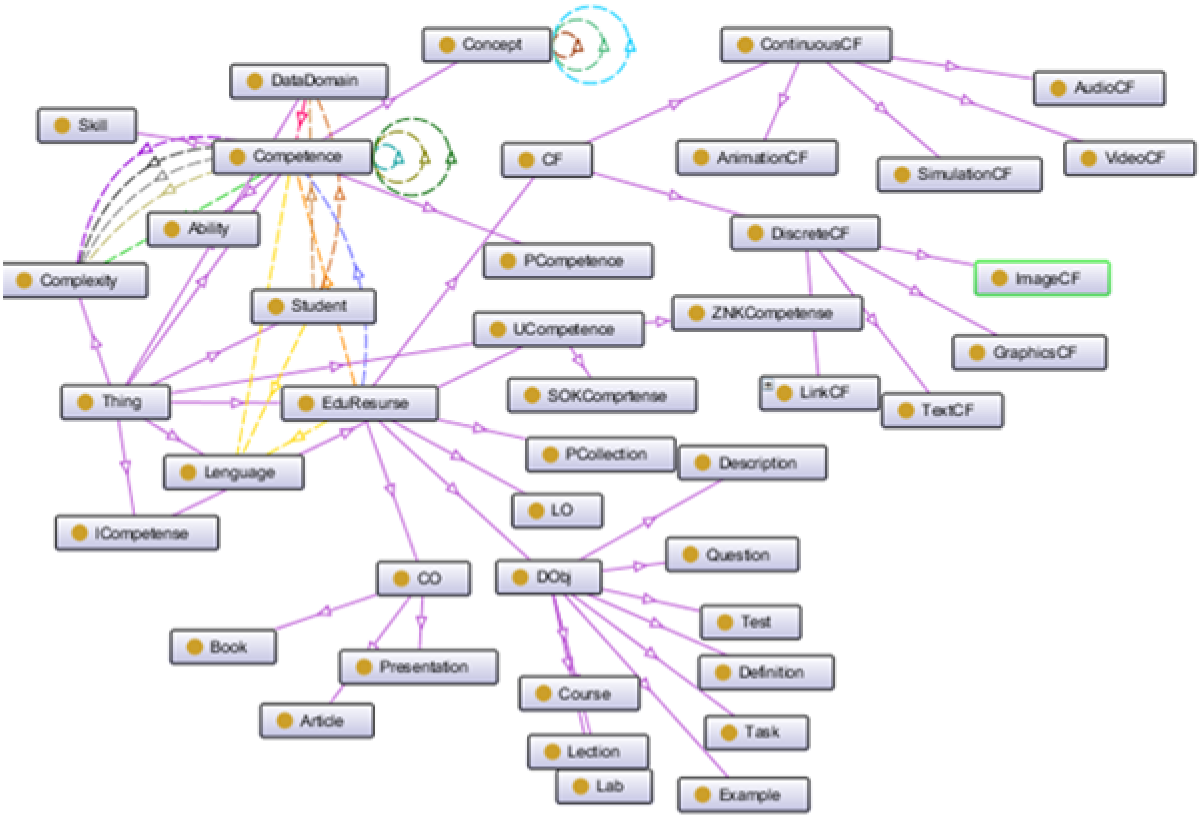

Figure 2: Example of a subject domain ontology in Protégé.

5. Experimental evaluation

To assess the effectiveness of the proposed ontology-based approach, an experiment was conducted with 40 future IT specialists divided into control and experimental groups. The experimental group used the ontology schema and methodology with Protégé, while the control group used traditional methods without COS.

The following metrics were evaluated:

1. Ontology construction speed: The experimental group completed ontology construction 2.5 times faster than the control group (figure 3).
2. Number of defects: The experimental group's ontologies had significantly fewer defects (almost 2 times) compared to the control group (figure 4).

3. Integration speed: The experimental group integrated their ontologies into a larger university ontology 3 times faster than the control group (figure 5).

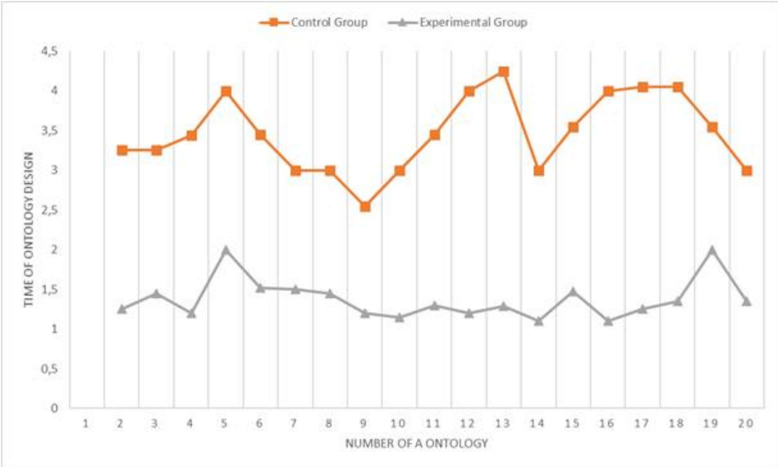

Figure 3: Comparison of ontology construction speed.

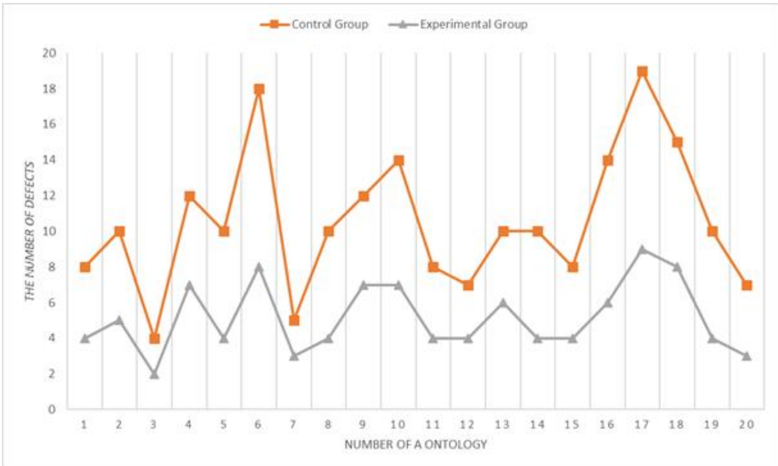

Figure 4: Comparison of ontology defects.

These results demonstrate the significant benefits of using the proposed ontology-based approach and COS in terms of efficiency, quality, and integration capabilities.

6. Conclusions

This paper presented an ontological approach for representing and designing subject domains in computer science education. The proposed ontology schema provides a formal structure for describing key concepts, relationships, and competencies within a discipline. Criteria for selecting COS were established, and the web-based Protégé environment was identified as a suitable tool for ontology design.

A methodology and algorithm were developed to guide future IT specialists in constructing subject domain ontologies using the schema and Protégé. Experimental evaluation demonstrated significant improvements in ontology construction speed, defect reduction, and integration efficiency compared to traditional methods.

The findings highlight the effectiveness of ontologies as a means to systematize knowledge and enhance the training of aspiring IT professionals. Future research directions include exploring the

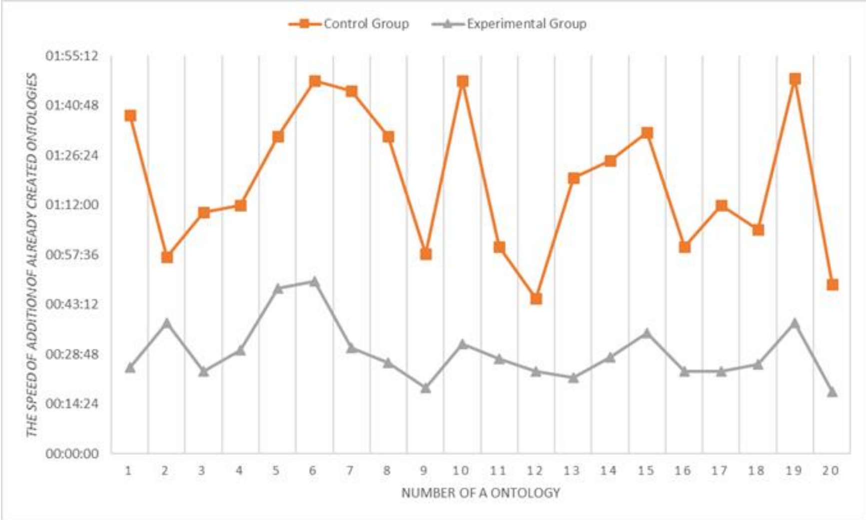

Figure 5: Comparison of ontology integration speed.

integration of constructed ontologies into intelligent tutoring systems and investigating the impact on student learning outcomes.

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