A Semantic Knowledge Graph Approach to Support Outcome-Based Education System

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Abstract— **The Outcome-Based Education (OBE) system is widely used to manage the learning process based on expected outcomes when students complete their studies. However, semantic web approaches have not been extensively utilized to support OBE implementations. This study introduces OBEOnto, an ontology for OBE curriculum implementation, comprising a general model (OBEOnto) and an extension model. The extension model accommodates specific requirements of institutions, illustrated through an example at Petra Christian University (PCU). The OBEOnto-based knowledge graph is then presented, showcasing its construction and use for data storage, retrieval, and analysis. Evaluation results demonstrate the justification and sufficiency of the OBEOnto-based knowledge graph, supporting the proper implementation of an OBE-based curriculum. This research contributes to the field by providing a foundation for incorporating semantic web approaches in OBE curriculum management.**

Keywords— outcome-based education, semantic web, ontology, knowledge graph

I. Introduction

Outcome-based Education (OBE) is a system that prioritizes on the results-oriented thinking. OBE is frequently compared to input-based education, wherein the focus lies on the educational process itself, and the outcome is accepted regardless of what it may be [1]. Since its introduction in pre-university education in the United States, OBE has garnered substantial support from higher education institutions worldwide. OBE has been adopted by a minimum of 30 countries, including the United States, United Kingdom, Australia, Canada, Singapore, New Zealand, Indonesia, and numerous others [2].

OBE has been found to be effective in realizing students' outcomes and improving teachers' approaches by encouraging learning and providing feedback [3]. Implementing OBE offers several advantages, including the adoption of more organized, innovative, and adaptable teaching methods. It encourages project-based learning, fostering the development of professional mindsets and competences. Additionally, educational institutions become more vigilant and attentive to the quality of graduates, ensuring their readiness for the market [4].

At the core of OBE are outcomes. Outcomes are evident results of students' learning experiences at the conclusion of the learning process [5]. Outcome-Based Education (OBE) involves directing and structuring an institution's programs and instructional initiatives based on clearly articulated outcomes that all students are expected to exhibit upon completing the institution. In the OBE paradigm, the emphasis lies on the significance of WHAT and WHETHER students learn, rather than the specifics of WHEN and HOW they acquire knowledge. Implementing OBE requires several steps [6]. First, determine the program's strategic vision, i.e., the primary purpose or goal of the program. Second, define the program education objectives that should align with the vision. Third, establish the program learning outcomes (PLO), which are declarations of the attitudes, knowledge, and abilities that students should possess upon completion of the program. Fourth, construct the curriculum by defining Course Learning Outcomes (CLOs), mapping CLOs into PLOs, and establishing assessments to measure CLOs. The last step is to map the outcomes to performance indicators.

Many institutions, including Petra Christian University (PCU), have implemented OBE-based curriculums. PCU adopts OBE to ensure its education aligns with graduate profiles based on industrial and societal needs. After several years of implementing an OBE-based curriculum at PCU, a major requirement has been identified: the implementation of OBE should be flexible enough to accommodate the different needs of each program while still utilizing a joint base to enable the monitoring and analysis of the curriculum.

Managing a curriculum is a complex task and can be supported by a model that captures interactions between curriculum components. The programs should not only define overall learning objectives but also consider learning strategies, evaluation procedures and methods, and continuous improvements. It involves recognizing the complex interactions between lecturers and students and adjusting learning resources and processes to evolving knowledge domains. To capture these interactions, a model capable to be adapted to different curriculum implementations can be proposed utilizing semantic web approaches.

Semantic approaches provide the advantage of expressing, organizing, and reasoning over multifaceted knowledge [7]. This capability facilitates the representation and understanding of interactions among objects in a specific domain. Furthermore, semantic technologies, which include languages supporting description logic and reasoners for articulating and evaluating axioms, can express and support diverse formalisms for these interactions [8]. Ontology-based knowledge graphs and the Semantic Web stack components can be used to implement the semantic approaches [9].

An ontology is specified as an 'explicit specification of a conceptualization' [10]. The conceptualization process describes entities and their relationships in a knowledge domain. Each entity is expressed through terms, and their meanings can be obtained through relationships. An ontology is often represented as a graph containing classes, individuals, and relationships, each identified by an internationalized resource identifier [11].

Many studies have mapped specific knowledge domains into learning curricula ontologies. Reference [12] mapped the learning concepts of various domains and their relationships to better integrate the curricula and prerequisite courses from different programs, such as biology, chemistry, physics, and computer science. Reference [13] proposed the integration of curriculum ontology, syllabus ontology containing the material, schedule, and instructur, and subject ontology discussing the main concepts of each subject domain.

Many of the current literature on curriculum implementation pays particular attention to utilizing ontologies. Reference [14] proposed e-LION, an integration ontology, to bridge learning-related data from various programs and courses. E-LION utilized states and requirements classes to capture the requirements of courses. However, it is not clear if the requirements can be classified as the required outcomes to be measured at the end of the courses. Reference [15] presented the VISION ontology to support the self evaluation processes in the vocational school. The VISION ontology captures the relationships between students, learning activities, infrastructure, and many data required by the academic information systems. However, the outcomes of the learning process are not captured in the ontology.

While other studies have addressed the mapping of subject domains and implementing curricula in various situations, no work has been done to address specifically how to support outcome-based education curriculum and its implementation utilizing semantic web approaches. This study aims to present a base OBE ontology, an extension ontology that support a specific OBE implementation, and a knowledge graph that implements both ontologies to capture instances required to implement the curriculum.

II. OBEOnto – An Ontology for Implementing OBE Curriculum

A. OBEOnto – the General OBE Curriculum Model

The purpose of OBEOnto modeling, as depicted in Fig. 1, is to encapsulate a general model of Outcome-Based Education (OBE) curriculum implementation, capturing Program Learning Outcomes (PLOs), Course Learning Outcomes (CLOs), courses, units, assessments, and their relationships. The model is designed based on the OBE-based curriculum model suggested by the Indonesian Association for Informatics and Computer Higher Education (APTIKOM) [16], which derives its guidelines from the OBE requirements of the Washington and Seoul Accords. Consequently, the model can be extended to support other OBE implementations.

At the core of OBEOnto are two outcome classes: ProgramLearningOutcome and CourseLearningOutcome. The ProgramLearningOutcome class captures the outcomes for a program (PLO). OBEOnto does not impose specific types for PLOs; each institution can define PLOs according to its educational objectives. For instance, institutions adhering to the Washington Accord's requirements may adopt twelve PLOs outlined in the Accord's guidelines, covering areas like engineering knowledge, problem analysis, investigation, and design/development of solutions [17]. Alternatively, institutions may align with government accreditation guidelines when formulating PLOs for a program.

A Department class represents a program that organizes the educational processes. The department plans curriculums, represented by the Curriculum class. Each instance of the Curriculum class can be linked (with 'hasOutcome' object property) to multiple instances of the ProgramLearningOutcome class.

The Course class represents each course provided by the program. It encompasses the GradedCourse and NonGradedCourse classes. These two subclasses offer an option to differentiate between courses that require assessment in the OBE system and those that do not. The NonGradedCourse class can be used to represent elective courses that provide additional skills but do not fulfill mandatory learning outcomes.

Course Learning Outcomes (CLOs) are encapsulated by the CourseLearningOutcome class, which is linked to the Course class to denote the outcomes (CLOs) for each course offered by the program.

The Unit class represents an implementation of a course in a program. For instance, a course such as 'Machine Learning' may have several units to accommodate a number of students interested in taking the course. Each unit is associated with a specific period, consisting of the year and semester the unit is offered to students.

Each unit will have its set of assessments, represented by the Assessment class. The set of assessments for each unit is not restricted, meaning that each unit of the same course may have a different set of assessments. This setting enables each unit's lecturer to select the most appropriate assessments for the students. The results of these assessments are recorded as instances of the AssessmentResult class and contribute to the achievement of CLOs (instances of the CourseLearningOutcome class).

The Student class represents students enrolled in a unit. It is linked to the AssessmentResult class, assuming that only students taking assessments need to be captured by OBEOnto's implementation. If a program decides that all students should be included in the model, the Student class can also be linked to the Unit class when extending OBEOnto.

B. An Extension of OBEOnto

As OBEOnto provides a general model for implementing OBE curriculum, in this section we describe some ways to extend OBEOnto. Extending an ontology has a goal to fit the general model into more specific requirements by adding new classes and properties or replacing some parts of the general model.

Figure 2 shows an extension of OBEOnto to implement a curriculum at Petra Christian University (PCU). PCU does not only define PLOs to represent the expected students' competencies, but also the indicators of each of the PLOs. The PLO indicators enable the educators to ensure all necessary characteristics are to be evaluated during the learning process.

The implementation of OBEOnto at PCU requires the addition of several new classes, namely ProgramLOIndicator, CourseContribution, and StudentLOResult. Some new datatype properties are also introduced, namely, to store the year and semester period of a unit (hasPeriodYear and hasPeriodSemester), the student's ID and year of intake

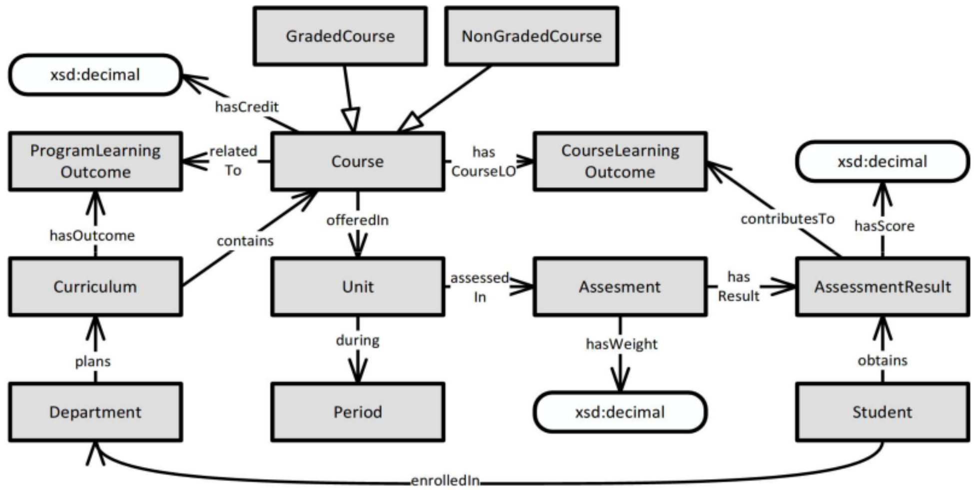

Fig. 1. Outcome-Based Education Ontology (OBEOnto)

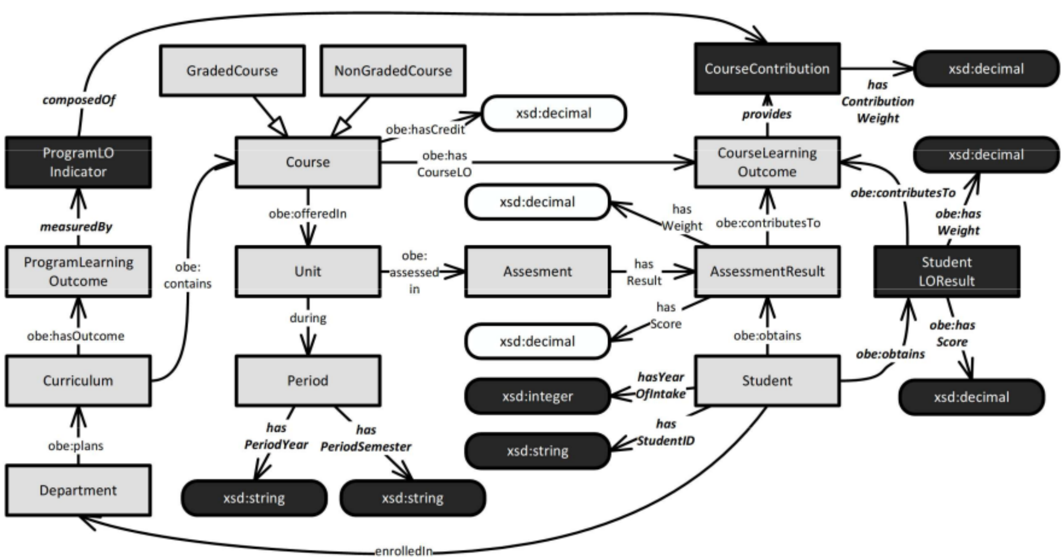

Fig. 2. Extension of OBEOnto to Implement the Curriculum of Petra Christian University

(hasYearOfIntake and hasStudentID), the weight of CLO contribution to ProgramLOIndicator (hasContributionWeight), and the weight and grade of the StudentLOResult class (hasWeight and hasScore).

The StudentLOResult class aggregates the scores acquired by a student for assessments taken in a specific unit. This class is used to store the scores of students without the necessity to calculate all assessment results, which are typically captured by the AssessmentResult class.

ProgramLOIndicator class represents the indicators to be measured to evaluate the accomplishment of the program learning outcomes (PLOs). The value of ProgramLOIndicator instance is calculated based on the values and weights of the StudentLOResult instances, and the contribution weights of related CourseContribution instances.

III. OBEOnto-based Knowledge Graph

A knowledge graph (KG) based on the PCU's extension of OBEOnto has been constructed to capture data to support various queries and analyses at PCU. The data of Informatics Department, extracted from PCU's internal OBE management system, was converted into RDF and OWL statements. The KG stores instances of students, departments, curriculums, Program Learning Outcomes (PLOs), Course Learning Outcomes (CLOs), courses, units, periods, assessments for each unit, and the corresponding results for students who took the assessments, spanning from the year 2019 to 2023. The KG comprises 1,889,204 RDF and OWL statements capturing 106 PLOs, 455 courses, 1337 units, 2995 CLOs, 3299 assessments, 197,258 assessment results, and other instances. Every statement is stored in a GraphDB 10.3.3 database server with an allocated 4GB heap memory, facilitating the execution of the queries directly within the memory space.

To populate the KG with data from PCU's OBE management system, several namespaces and prefixes are used to construct the RDF and OWL statements. Each unique instance, class, or relationship is identified by a specific internationalized resource identifier (IRI) [18]. To conserve space, these IRIs can be abbreviated using a namespace prefix. A namespace, represented by a non-empty string, serves the purpose of preventing naming conflicts among various resources that share the same identifier within a repository. The namespace prefix, on the other hand, operates as an alias for the namespace. The complete namespaces and prefixes are shown in Table 1.

Figure 3 illustrates a subset of the KG in the form of a graph, depicting a course labeled 'TF4514 Machine Learning' and its related nodes. The course is associated with three units labeled 'TF4514 (A) 2021_2022_2,' 'TF4514 (A) 2022_2023_1,' and 'TF4514 (B) 2022_2023_1.' For brevity, only two units are shown with linked nodes. Each unit is associated with two CLOs labeled 'CPMK-1' and 'CPMK-2' and is assessed through four exams: 'UTS' (Midterm Exam), 'Q&A,' 'Presentasi Paper' (Paper Presentation), and 'Proyek Akhir' (Final Project). It's important to note that assessment nodes with the same label represent different instances of

TABLE I. NAMESPACES AND PREFIXES USED BY THE ONTOLOGIES AND KNOWLEDGE GRAPH

Prefix		Namespace
:	(the prefix used by all instances in the KG)	<http://www.kmrg.org/kgobepcu#>
obe:	(the prefix used by classes and relationships in OBEOnto)	<http://www.kmrg.org/obeonto#>
pcu:	(the prefix used by classes and relationships in the extension of OBEOnto)	<http://www.kmrg.org/pcuobeonto#>

assessment implementations while sharing the same node types.

IV. EVALUATION OF THE OBEONTO-BASED KNOWLEDGE GRAPH

To evaluate the KG, several approaches were used to ensure the validity of the KG. First, several reasoners were used to check the consistencies of all the RDF and OWL statements constructed during the population of the KG. Employing reasoners serves as an internal validation approach since it relies solely on data already contained within the KG. In this approach, GraphDB 10.3.3 reasoner, HermiT 1.4.3.456, and Pellet were employed as reasoners. HermiT and Pellet were integrated as plugins for Protégé 5.5. The GraphDB reasoner had been utilized during the KG population process to identify and address inconsistencies in the KG statements.

The outcomes of the validation process indicated the absence of contradictions or inconsistencies in KG. This lack of issues might be attributed to the straightforward RDF or OWL semantics implemented in OBEOnto, its extension, and the KG. Instead of declaring complex class statements, the

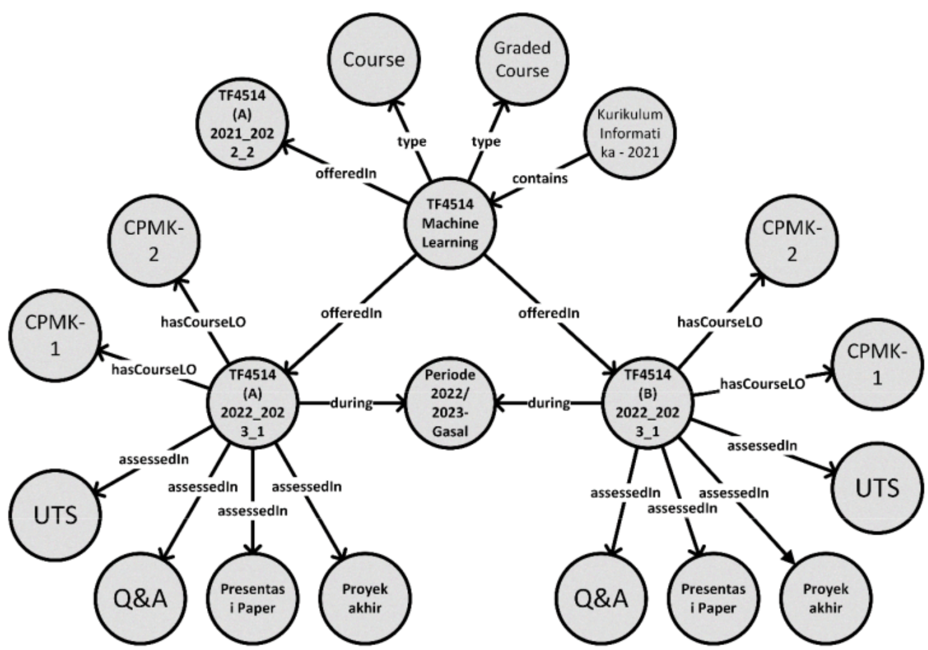

Fig. 3. A Graph Depicting Part of OBE Knowledge Graph at PCU

relationships in the KG are mainly made up of type-assertion statements.

The second evaluation method involved employing queries to extract data and validate the accuracy of results against the original data source. Since this approach utilized external data, it can be classified as an external validation method. The queries are used to evaluate whether OBEOnto can be used to fulfill various use cases required for the implementation of the OBE curriculum. Only three queries are described in this paper for brevity. The first query aimed to retrieve the scores of assessments attained by a student with ID 'student_60b648dfbbe28257dc1' for the 'TF4205 (C) 2020_2021_1' unit. The complete SPARQL query is presented below, and its results are shown in Table 2.

```
PREFIX : <http://www.kmrg.org/kgobepcu#>
PREFIX obe: <http://www.kmrg.org/obeonto#>
PREFIX pcu: <http://www.kmrg.org/pcuobeonto#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-
schema#>
Select ?unit ?exam ?clo ((?percentage/100*?score)
as ?result) where {
    ?s a obe:Student .
    ?s obe:obtains ?ar .
    ?ar obe:hasWeight ?percentage.
    ?ar obe:hasScore ?score.
    ?ar obe:contributesTo ?clo_i .
    ?clo_i rdfs:label ?clo .
    ?unit_i obe:assessedIn ?exam_i .
    ?exam_i rdfs:label ?exam .
    ?exam_i obe:hasResult ?ar.
    ?unit_i rdfs:label ?unit .
    filter (?s=:student_60b648dfbbe28257dc1)
    filter (?unit_i = :unit_664)
} order by ?unit ?exam
```

The second query aims to identify all courses taken by a student with ID 'student_60b648dfbbe28257dc1'. The query utilizes GraphDB's graph path search functionality [19], employing the 'all path' algorithm to find all possible courses within a specific distance from the student. The SPARQL query is presented below, and a segment of the results is shown in Table 3.

```
PREFIX : <http://www.kmrg.org/kgobepcu#>
PREFIX obe: <http://www.kmrg.org/obeonto#>
PREFIX pcu: <http://www.kmrg.org/pcuobeonto#>
PREFIX path: <http://www.ontotext.com/path#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-
schema#>
select distinct ?mk where {
  ?dst a ?type . ?dst rdfs:label ?mk .
  bind (:student_60b648dfbbe28257dc1 as ?src)
  filter (?type = obe:Course)
  filter (?prop = obe:obtains)
  SERVICE path:search {
    [] path:findPath path:allPaths ;
       path:sourceNode ?src ;
       path:destinationNode ?dst ;
       path:pathIndex ?pathIndex ;
       path:propertyBinding ?prop ;
       path:resultBindingIndex ?edgeIndex ;
       path:resultBinding ?edge ;
       path:bidirectional true;
       path:maxPathLength 4 ; . }}
```

The third query finds the courses offered by two departments, namely Business Information System, and Informatics. The query is shown below and part of the results are shown in Table 4.

```
PREFIX : <http://www.kmrg.org/kgobepcu#>
PREFIX obe: <http://www.kmrg.org/obeonto#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-
schema#>
select ?dept_label ?course where {
  ?dept obe:plans ?curr .
  ?dept rdfs:label ?dept_label .
       ?curr obe:contains ?course .
  ?course a obe:GradedCourse .
  filter (?curr = :curr_126 || ?curr = :curr_127)
}
```

The results of executing several queries indicate that the knowledge graph has been implemented properly. There was no data error while examining the results. Executing various queries also shows that the selection of classes in OBEOnto and the extension of OBEOnto are justified and sufficient to capture all the entities needed for implementing the OBE-based curriculum.

TABLE II. QUERY RESULTS SHOWING THE EXAMS' SCORES ATTAINED BY A STUDENT

Unit	Exam	CLO	Result
"TF4205 (C) 2020_2021_1"	"Tes 1"	"CPMK-1"	"75.00"^^xsd:decimal
"TF4205 (C) 2020_2021_1"	"Tes 2"	"CPMK-1"	"87.52"^^xsd:decimal
"TF4205 (C) 2020_2021_1"	"UTS"	"CPMK-2"	"84.00"^^xsd:decimal
"TF4205 (C) 2020_2021_1"	"UAS"	"CPMK-1"	"88.66"^^xsd:decimal

TABLE III. QUERY RESULTS SHOWING COURSES TAKEN BY A STUDENT UTILIZING GRAPH TRAVERSAL

Student	Course
:student_60b648d fbbe28257dc1	"TF4424 Customer Relationship Management"
:student_60b648d fbbe28257dc1	"TF4429 Risk Management"
:student_60b648d fbbe28257dc1	"TF4448 Enterprise Architecture"
:student_60b648d fbbe28257dc1	"TF4521 IT Governance"
:student_60b648d fbbe28257dc1	"TF4526 Knowledge Management"
:student_60b648d fbbe28257dc1	"TF4529 Human Resource Management IS"

TABLE IV. QUERY RESULTS SHOWING SOME COURSES OFFERED BY TWO DEPARTMENTS

Program	Course
“Business Information System”	"TF4273 Advanced Database"
“Business Information System”	"TF4414 Enterprise Resource Planning"
“Business Information System”	"TF4521 IT Governance"
“Informatics”	"TF4514 Machine Learning"
“Informatics”	"TF4409 Artificial Intelligence"
“Informatics”	“TF4255 Software Engineering"

V. CONCLUSION

The Outcome-Based Education system is widely used to implement a curriculum that emphasizes what students will demonstrate at the end of their study. This study proposes two ontologies to support the implementation of outcome-based education curriculums. The base ontology, OBEOnto, provides general classes and relationships to capture required entities such as program learning outcomes, courses, course learning outcomes, assessment process artifacts, and their relationships. The extension ontology includes additional classes and relationships to implement OBE specifically at PCU. A knowledge graph has also been constructed, and its evaluation using queries demonstrates the feasibility of OBEOnto to support various use cases for OBE implementations.

REFERENCES

[1] M. H. Davis, "Outcome-Based Education," *J. Vet. Med. Educ.*, vol. 30, no. 3, pp. 258–263, 2003, doi: https://doi.org/10.3138/jvme.30.3.258.

[2] International Engineering Alliance, "Washington Accord Signatories," 2024. https://www.ieagreements.org/accords/washington/signatories/ (accessed Jan. 10, 2024).

[3] M. Z. Zamir, M. I. Abid, M. R. Fazal, M. A. A. R. Qazi, and M. Kamran, "Switching to Outcome-Based Education (OBE) System, a Paradigm Shift in Engineering Education," *IEEE Trans. Educ.*, vol. 65, no. 4, pp. 695–702, 2022, doi: 10.1109/TE.2022.3169184.

[4] H. M. Asim, A. Vaz, A. Ahmed, and S. Sadiq, "A Review on Outcome Based Education and Factors That Impact Student Learning Outcomes in Tertiary Education System," *Int. Educ. Stud.*, vol. 14, no. 2, p. 1, 2021, doi: 10.5539/ies.v14n2p1.

[5] W. G. Spady, Outcome-Based Education: Critical Issues and Answers. 1994.

[6] J. Qadir et al., "Outcome-based (engineering) education (OBE): International accreditation practices," in *ASEE Annual Conference and Exposition, Conference Proceedings*, Jun. 2020, doi: 10.18260/1-2--35020.

[7] G. Dobson and P. Sawyer, "Revisiting Ontology-Based Requirements Engineering in the age of the Semantic Web," *Proc. Int. Semin. Dependable Requir. Eng. Comput. Syst. NPPs*, pp. 27–29, Nov. 2006.

[8] B. Motik, B. Cuenca Grau, and U. Sattler, "Structured Objects in Owl: Representation and Reasoning," in *Proceedings of the 17th International Conference on World Wide Web*, 2008, pp. 555–564. doi: 10.1145/1367497.1367573.

[9] World Wide Web Consortium, "OWL 2 Web Ontology Language Direct Semantics (Second Edition)," 2012. https://www.w3.org/TR/2012/REC-owl2-direct-semantics-20121211/

[10] T. R. Gruber, "A translation approach to portable ontology specifications," *Knowl. Acquis.*, vol. 5, pp. 199–220, Jun. 1993, doi: 10.1006/knac.1993.1008.

[11] World Wide Web Consortium, "OWL 2 Web Ontology Language Primer (Second Edition)," 2012. https://www.w3.org/TR/2012/REC-owl2-primer-20121211/ (accessed Mar. 22, 2019).

[12] P. R. Aldrich, "The curriculum prerequisite network: Modeling the curriculum as a complex system," *Biochem. Mol. Biol. Educ.*, vol. 43, no. 3, pp. 168–180, 2015, doi: 10.1002/bmb.20861.

[13] H. S. Chung and J. M. Kim, "Ontology design for creating adaptive learning path in e-learning environment," *Lect. Notes Eng. Comput. Sci.*, vol. 2195, pp. 585–588, Mar. 2012.

[14] M. Paneque, M. del M. Roldán-García, and J. García-Nieto, "e-LION: Data integration semantic model to enhance predictive analytics in e-Learning," *Expert Syst. Appl.*, vol. 213, no. PA, p. 118892, 2023, doi: 10.1016/j.eswa.2022.118892.

[15] M. Ali and F. M. Falakh, "Semantic Web Ontology for Vocational Education Self-Evaluation System," Proceeding - 2020 3rd Int. Conf. Vocat. Educ. Electr. Eng. Strength. Framew. Soc. 5.0 through Innov. Educ. Electr. Eng. Informatics Eng. ICVEE 2020, pp. 2–7, 2020, doi: 10.1109/ICVEE50212.2020.9243278.

[16] Panduan Kurikulum Bidang INFOKOM Berbasis OBE/KKNI/SKKNI Tahun 2022. APTIKOM, 2022.

[17] International Engineering Alliance, IEA Graduate Attributes and Professional Competency Profiles Graduate Attributes and Professional Competencies Executive Summary. 2013. [Online]. Available: http://www.ieagreements.org.

[18] T. Berners-Lee, R. Fielding, and L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax, RFC 3986." [Online]. Available: https://www.ietf.org/rfc/rfc3986.txt

[19] Ontotext, "Graph path search." https://graphdb.ontotext.com/documentation/10.0/graph-path-search.html (accessed Mar. 20, 2024).

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