Find a Research Collaborator: An Ontology-Based Solution to Find the Right Resources for Research Collaboration

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Abstract—Researchers in Higher Education (HE) institutions/academia and in industry are continuously engaged in generating new solutions and products for existing and emergent problems. Doing quality research and producing better scientific results depend greatly on solid research teams and scientific collaborators. Research output in HE institutions and industry can be optimized with appropriate resources in research teams and collaborations with suitable research partners. The main challenge in finding suitable resources for joint research projects and scientific collaborations pertains to the availability of data and metadata of researchers and their scientific work in traditional formats, for instance, websites, portals, documents, and traditional databases. However, these traditional data sources do not support intelligent and smart ways of finding and querying the right resources for joint research and scientific collaboration. A possible solution resides in the deployment of Semantic Web (SW) techniques and technologies for representing researcher and their research contribution data in a machine-understandable format, thus ultimately proving useful for smart and intelligent query-answering purposes. In pursuit of this, we present a general Methodology for Ontology Design and Development (MODD). We also describe the use of this methodology to design and develop Higher Education Ontology (HEO). This HEO can be used to automate various activities and processes in HE. In addition, we describe the use and adoption of the HEO through a case study on the topic of "finding the right resources for joint research and scientific collaboration". Finally, we provide an analysis and evaluation of our methodology for posing smart queries and evaluating the results based on machine reasoning.

Keywords—*Higher Education Ontology (HEO); Linked Open Data (LOD); Machine Reasoning; Semantic Web (SW); SPARQL Queries*

I. INTRODUCTION

As a semantic-based representation of shared conceptualization, ontologies make knowledge machine-readable and easy to share. They also help us in semantic-based smart search, easy integration, data analysis, exploration of new knowledge, as well as machine reasoning and inferencing [1]. With burgeoning research in the field of machine reasoning, researchers in the field of education predicted the existence of future opportunities for many participants [2]. Ontological reasoning can be helpful for inferring new knowledge in any domain, including Higher Education (HE). Through ontological inferencing, it is possible to answer questions such as: "finding instructor who best fits to teach a particular course", "predicting the possible cooperation between the faculty members", and "varying complexity of exams with varying level of

students". Transferring the data related to these activities from the original format (understood only by humans) to RDF/OWL format (understood by humans and machines alike) can help the machines to process and thus allow for inferencing or reasoning in response to smart queries.

Semantic Web (SW) technologies are being applied quite frequently in many problem domains nowadays. For instance, in [3], authors present a framework (i.e. ADOL) that can be used to construct and extend educational ontology automatically. The proposed 'ADOL' is an ontology learning framework that can transfer the domain of textbooks into a corresponding ontology automatically and efficiently. Besides this, authors in [2], present a case study for the derivation and implementation of ontology in the HE domain. The ontology covers key aspects of the university domain, including creating class hierarchy, instances for class, properties, and relations. In [4], the authors provide an in-depth curriculum and syllabus ontology and propose a classification and integration method to produce a semantically enriched syllabus model. An educational ontology of Palestine University is presented in [5]. The authors utilize the Unified Process for Building the Ontology (UPON) to provide a query retrieval process. In [6], the authors focused on the emergence of the Linked Open Data (LOD) platform of the South East European University curricula, progressing from experimental to open data hub. They utilized Linked Data principles to publish and access data on academic programs and courses offered by the university.

Despite these efforts to address educational domain problems, a semantic-based solution to automate processes in HE, especially in research collaboration, is needed. Moreover, the importance of ontological reasoning in extracting new knowledge from existing data in collaborative research has yet to be addressed. Further, the investigation and utilization of implicit or explicit data characteristics in educational data have not been investigated yet. This paper addresses the abovementioned limitations and challenges in extant research. It provides a Higher Education Ontology (HEO) that can automate various activities and processes in HE using academic analytics and ontological reasoning techniques. This paper makes several contributions. It provides:

- A Methodology for Ontology Design and Development (MODD).

- A Higher Education Ontology (HEO) that can be used to model and represent knowledge about different HE

processes and activities in a semantically enriched format based on LOD principles [7].

- We present a case study as a proof-of-concept of HEO on the topic "find the right resource for research collaboration".

- Finally, we also evaluate our proposed methodology by analyzing the results of our case study.

The remaining paper is organized such that related work is described and compared in Section II. Section III presents the Methodology for Ontology Design and Development (MODD) and discusses its implementation in designing and developing the HEO. Section IV describes the case study on the topic "find the right resource for research collaboration" and provides results analysis. Finally, we provide the conclusion and discussion of the future work in Section V.

II. RELATED WORK

The importance of developing an educational ontology has been highlighted in recent years. Many researchers have begun to design and implement ontologies to provide effective, web-based machine learning. The SW can help in solving the problem of information retrieval and facilitate the identification of accurate and useful resources. As an example, the research published by [8] creates the Ontology for Linked Open University Data (OLOUD). This ontology covers concepts and relations related to semesters, curriculum, courses, subjects, and personnel, in addition to events and buildings. In [9], the authors built the Bowlogna Ontology to improve the learning environment. The study also described practical applications of this ontology for university end-users, including a system for faceted searching and browsing for course information. Univ_Edu_Onto, which is another educational ontology, is described in [10]. This ontology contains two types of terms: general terms for university courses and specific terms for the Artificial Intelligence (AI) courses. Also, in [11], the authors introduced an educational ontology for the Indraprastha University, Delhi, India. The ontology presents a graph representing subclasses using TGViz.

In [12], a semantic-based university examination ontology was developed to provide enhanced support in examination systems, particularly for higher degrees. In [13], the authors present an educational ontology named Curriculum Course Syllabus Ontology (CCSO) to model entities, data, and concepts within an academic environment. Similarly, in [14], authors presented an ontology for Mosul University (OMU). The authors also implement different queries to show the inference processes. The Semantic Web for Research Communities (SWRC) ontology was presented in [15]. It describes the communities of the research and other related concepts. In [16], the authors presented Higher Education Reference Ontology (HERO). The work explains the process of building and developing the HERO ontology using the NeOn methodology from the specification of requirements stage to the ontology evaluation stage. In [17], the authors present an ontology of Ahlia University in which DL and SPARQL queries are used to retrieve explicit and implicit information employing ontological reasoning. In [18], the authors presented an ontology-based framework that facilitates semantic-based queries for postgraduate information queries at the Ministry of

Higher Education (MOHE) portal. In [19], the Massive Open Online Courses (MOOCs) ontology was presented to speed up the retrieval of educational data based on learners' requests from the Coursera platform.

In [20], the authors focus on designing and building university ontology methods. In [21], the authors presented an ontology that can be used for searching educational resources based on matching semantics. The proposed ontology was developed from real-life educational resources. In [22], the authors presented a semantically enriched system for e-learning. This system utilizes SPARQL queries and machine reasoning to provide smart question-answering methods. In [23], the authors presented a process of creating university datasets based on LOD. The generated datasets cover data items, vocabulary, and RDF entities related to the university, and the data is published based on LOD principles for query purposes. In [24], the authors present an ontology in the HE domain. This work's main limitation is that it was designed specifically for the engineering field, making it unsuitable for other HE activities. In [25], the authors created an ontology in the university domain that serves as an ontology searching hub. In [26], the authors also presented an educational ontology aiming to assist with the university internship assignment in an automated fashion. In [27], an e-campus ontology is proposed, which serves to stream various educational processes. This ontology is explicitly designed for learning activities and presents a semantic hierarchy that represents learning activities for programming languages such as C-Sharp. A fuzzy ontology-based framework has been presented in [28] to facilitate the organization of scientific research. In [29], the authors designed and presented a meta-model ontology. The work explains the methodology developed for ontological improvement by applying a semi-supervised learning method. In [30], the authors proposed an ontology-based e-learning system to identify the problems in the HES, such as the lack of connections between components and the poor structure of educational resources.

The solutions discussed above represent good efforts to address various challenges in HE. However, these proposed systems still need to effectively address the problems and issues related to automating the processes and activities in educational systems to maximize efficiency and accuracy. The following section addresses these limitations and presents our methodology for HE processes and activities automation by using ontologies and machine reasoning.

III. THE METHODOLOGY FOR ONTOLOGY DESIGN AND DEVELOPMENT (MODD)

Ontology design and development is a job that includes several tasks and activities for modeling an ontology in any domain. Even though different methods have been proposed and various tools have been developed to support these tasks and activities, there is still a dearth of a unified approach or methodology for ontology design and development. A lot of methodologies arrange tasks differently. However, the general approach does not vary widely. In this paper, we present our Methodology for Ontology Design and Development (MODD) (as illustrated in Fig. 1). In our proposed methodology, we follow two approaches presented in [31] and [32] as our baseline and present an upgraded approach that can support different

activities and tasks that are essential to ontology modeling. Here, we describe different phases of our Methodology for Ontology Design and Development (MODD). As a proof of concept, we also present the use of this methodology to create the Higher Education Ontology (HEO) which can ultimately be used to automate various activities and potential processes in research and development.
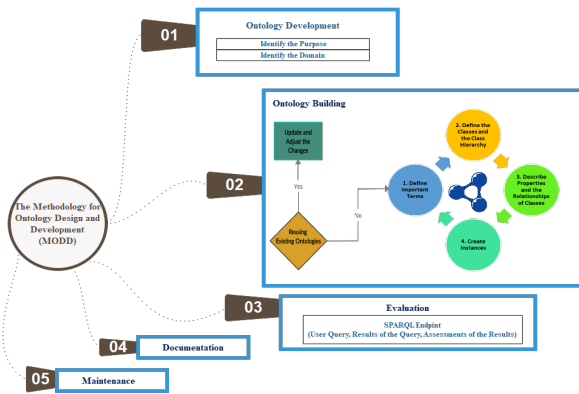

Fig. 1. The Methodology for Ontology Design and Development (MODD).

A. *Identify the Purpose and the Domain of the Ontology Development*

Before developing an ontology, there are several questions that knowledge engineers must answer:

- Do they have enough knowledge required to develop ontology in a particular domain?

- What are the benefits and purposes of using this ontology?

- What are the specific mechanisms and uses of the ontology?

Answering these questions furnishes a clear destination for making decisions and keeping the knowledge engineers on the right track. From the perspective of our case study, we developed an ontology in the education domain, especially in HE. The purpose was to automate the various HE processes and activities with special attention to the cooperation process between the researchers and faculty members. We identified the question "finding the right resources for joint research and scientific collaboration" as one of potential utility and a case study for our work. To empower our solution, we took real data from specific systems at King Abdulaziz University (KAU). Two of these main systems include OUDS PLUS and Accreditation Information Management System (AIMS). These systems provide all information related to the courses, syllabus, and faculty member data (e.g., publications, academic training, professional experience, and scientific research). After identifying the required data, we converted it into a machine-understandable format such as RDF. The resulting RDF data can be used to perform smart queries, inference, and machine reasoning. Also, to test the efficiency and quality of the ontology design, we defined a list of questions referred thereafter as

Competency Questions (CQs). CQs help us to determine and identify the knowledge that should be included in the ontology. Firstly, they can be used to answer the needs and requirements that the ontology must fulfill. Secondly, we can use it as a tool to evaluate the output of the ontology by examining the answers to the potential questions. We defined the following CQs:

1) Find all academic staff members who have the same research interests.
2) Find all academic staff members who have the same publication keywords.
3) Find specific academic staff members to collaborate with other academic staff members based on common research interests.
4) Find specific academic staff members to collaborate with other academic staff members based on common publication keywords.
5) Find all the academic staff members who can collaborate based on the four criteria.(research interests, certifications & trainings, publications and academic & professional experiences).

B. *Ontology Building*

In this phase, the knowledge engineers should define the most important terms, concepts, properties, and their relationship with each other. In addition, they should answer the following questions:

- How and whether to use ontologies that already exist?

The ontology-building phase is based on various principles and standards, as it requires a deep understanding of the domain. These principles are discussed below:

1) Reusing existing ontologies: At this stage, we must search and identify existing ontologies and decide which existing ontologies can be reused and to what extent they can be reused. Different factors can help us to decide about the reuse of existing ontologies. Some of these factors are missing classes, subclasses, relationships, and properties. Alternatively, we can build from the beginning by following a group of steps. The process of searching and exploring ontology is an essential phase of ontology development. Once we find an ontology that is suitable and compatible with our special needs, this will save time as well as extra effort. Additionally, if we do not find any ontology that is compatible with our domain and can be reused, a minimum use of such ontologies is that they can be used as a good source of guidance and inspiration. As we mentioned earlier, the scope of our work encompassed research and education, and we were able to find a lot of research and educational-related ontologies. Herein, we present some important criteria that should be considered while deciding about the reuse of existing ontology (as shown in Fig. 2):

1) The domain of the ontology. (From the perspective of our case study, it must be in the research and education domain).
2) The availability of the ontology. (The links must be work and available to download).
3) The format of the ontology (must be in RDF/OWL format).

TABLE I. AN OVERVIEW OF DIFFERENT EDUCATIONAL ONTOLOGIES

Ontology Name	Purpose	Year	Reference
E-campus ontology for the university of Zakho (UOZ)	Building an ontology wherein the classification of the developed ontology comprises the following (campus, deliverable, academic year, person, university).	2019	[27]
University ontology-based information retrieval system	Developing a university ontology that contains classes such as people, department, divisions, program, course, club, events and publications.	2019	[25]
Ontology for curriculum and syllabus	Building a Curriculum Course Syllabus Ontology (CCSO) which contains many classes (e.g., academic staff, administrative staff, assistant, bachelor, certificate, course and department).	2018	[13]
Massive Open Online Courses (MOOCs) Ontology for information retrieval through Coursera platform	Based on learner request, in the Coursera platform, building an ontology to retrieve educational resources such as classes related to assessment, certification, collaboration, course material and subjects.	2020	[19]
OntoSyllabus ontology	Developed an ontology for higher education institutions syllabus. The main concepts are topic, course, syllabus, instructor and concepts.	2019	[33]
University examination system ontology	Developed an ontology for the university examination system. The main concepts are student, faculty, subject and department.	2017	[12]
Academic Institution Internal Structure Ontology (AIISO)	Representing the internal organizational structure of academic institutes by using classes and properties described in the Academic Institution Internal Structure Ontology (AIISO). The main concepts are center, college, course, department, faculty and division.	2008	[34]

TABLE II. THE ONTOLOGIES FULFILLING THE DEFINED CRITERIA

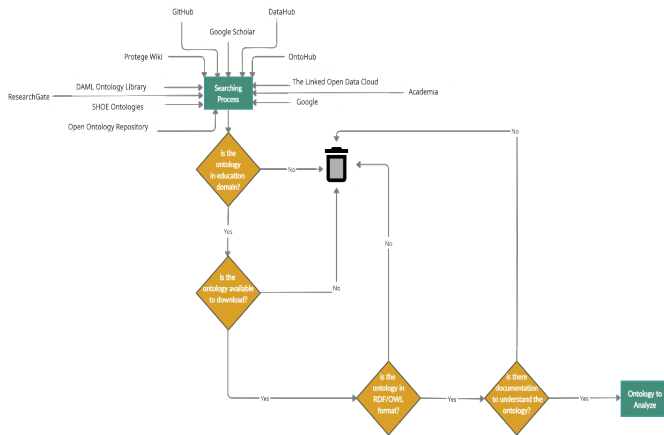| Prefix	Ontology Name	Reference	URI
AIISO	Academic Institution Internal Structure Ontology (AIISO)	[34]	vocab.org/aiiso/
CCSO	Curriculum Course Syllabus Ontology (CCSO)	[13]	w3id.org/ccso/ccso#
OS	Ontosyllabus	[33]	jachicaiza.github.io/ontologyDoc/
curriculum	BBC curriculum	[35]	www.bbc.co.uk/ontologies/curriculum

Fig. 2. The criteria for the search process.

4) Clear documentation available in the English language to understand the classes, relationships, and properties of the ontology.

Table I shows the most common educational ontologies that we came up with after searching different websites and portals. After analyzing the education ontologies from the previous table based on the defined criteria, we can say that the following four ontologies in Table II complement and resemble one another within the educational field. We benefited from these ontologies in terms of guidance and direction. So,

accordingly, we added our parts and built the HEO ontology.

2) Define important terms: Before creating the classes, and the properties, it is important to create a list of all the important terms for creating an ontology, whether for making statements about or describing it to users. We can identify and extract different terms that are used to describe classes, properties, and associations by exploring and understanding the source data. As mentioned earlier, in our case, we relied on two live systems at King Abdulaziz University (i.e., AIMS and OUDS PLUS) to obtain the data and create our ontology. Amongst others, two key documents we identified as our source of information are as below:

1) CVs of faculty members.
2) Course Syllabus.

Table III shows the most important terms extracted from these two files.

3) Defining ontology classes and their hierarchy: This is a core phase for organizing and introducing the structure to the captured terms in the previous phase. The phase of defining important terms can help us in designing the class hierarchy, wherein we can choose the most appropriate terms and define the independent existence for building super and subclasses. Classes are used to denote the collection of things that make up a concept. These classes can be linked to other classes through relationships when appropriate. In this phase, we define some classes that are used in the construction of HEO. Table IV illustrates some classes used in the domain that are identified to construct the ontology.

TABLE III. TERMS RELATED TO FACULTY MEMBERS' CVS AND COURSE SYLLABUS

CVs of faculty members	Course Syllabus
Academic Staff	Course
Assistant Professor	Syllabus
Associate Professor	Assessment Tool
Lecturer	Assignments
Professor	Exam
Teaching Assistant	Questions
Keywords	Lab Work
Academic and Professional Experiences	Project
Certifications and Trainings	Quiz
Publications Keywords	Class Activity
Research Interests	Learning Outcome
Publications	Course Learning Outcomes
Book	Student Outcome

4) Describe properties and relationships of classes: Super and subclasses alone do not provide us with sufficient information to answer CQs. After defining the main classes, we must describe the structure of these concepts. Also, we can use the rest of the terms that are already defined and represent them as properties. Entities that describe how individuals are related are called object properties. Also, properties can be structured in hierarchies. The permitted classes as values of properties are called the range of the property, while the actual classes that use the property are called the domain of the property. In this phase, we define some properties and relationships that are used in the development of HEO. The tables from V to IX explain the most important properties and how these properties are used to perform machine reasoning and to infer the new knowledge graphs.

5) Create instances: The final step in the ontology building phase is the creation of instances for defined classes. In semantic technologies, instances are also referred to as individuals. We can also think of them as objects of classes (to some extent). This involves selecting a class, creating its instance, and filling in the value of the property. These instances should meet the created questions and use cases. Ontologies can be better utilized with an enhanced number of instances (i.e., datasets). Instances have a vital role in the processes of semantic searches, data analysis, and exploration of new knowledge, in addition to evaluation processes. The answers that the ontology returns in the SPARQL queries of competency questions are based on instances. We enriched the scope of our ontology by extracting and populating our ontology with real-life data from the Faculty of Computing and Information Technology (FCIT) at King Abdulaziz University (KAU) (as a real case study).

C. Evaluation

The ontology must be evaluated to find any potential errors. Verifying the accuracy and fine-tuning of the ontology is the primary focus of this phase. Ultimately the target is to make sure of the domain coverage, quality of the development, and accuracy of the ontology design. We can verify the consistency, viability, and efficiency of the ontology by using the reasoners. The reasoners guarantee that there are no contradictory facts in the ontology. Also, this ascertains if the classes or properties can contain any type of individuals. In our case study, we use the Pallet reasoner at every stage of ontology development.

Fig. 3 shows the results of ontology consistency. Also, we used the Competency Questions (CQ) which we defined earlier in the ontology development Phase. The answers to the CQ are provided in Section IV which explains in detail the case study of the cooperation process between the faculty members.


```
INFO  21:11:18
INFO  21:11:22  ------------------------------ Running Reasoner ----------
INFO  21:11:22  Pre-computing inferences:
INFO  21:11:22      - class hierarchy
INFO  21:11:22      - object property hierarchy
INFO  21:11:22      - data property hierarchy
INFO  21:11:22      - class assertions
INFO  21:11:22      - object property assertions
INFO  21:11:22      - same individuals
INFO  21:11:23  Ontologies processed in 411 ms by Pellet
INFO  21:11:23
INFO  21:11:23  REASONER CHANGED
```

Fig. 3. Ontology consistency by pallet reasoner

D. Documentation

The last phase of MODD is documenting the ontology. It is a very important phase to understand the classes and the properties and their relationship with one another. The documentation phase is the creation of guidelines and instructions to clarify the domain and the purpose of the ontology. The lack of documentation may be one of the most significant obstacles preventing knowledge engineers from reusing the ontology. Documentation helps in understanding the ontology, reuse, and reviews. Each statement in the ontology must be explained in detail within the documentation. If there are no comments or explanations, this will make the ontology difficult to understand. So, we used both the "rdfs:comment" and "rdfs:label" properties to add descriptions and meaning for classes, object properties, and data properties.

E. Maintenance

Everything in the world is subject to change, and thus the ontology specifications may change to meet the requirements of the users and to suit other existing educational ontologies. It is very important to carry out periodic maintenance operations to organize the ontology by adding some classes, sub-classes, properties, and their relations with each other. Also, the documentation may be updated by adding meaning to unknown words and their logical description. Also, the availability of RDF/OWL links may be ensured to save time and facilitate the re-using phase for other researchers. Finally, mapping with LODC can be implemented so anyone can access, connect, and consume the data on an internet scale.

IV. CASE STUDY: FIND THE RIGHT RESOURCE FOR RESEARCH COLLABORATION

The cooperation process between researchers and faculty members starts with finding the right resources for joint research. Finding the right resources depends on matching different attributes such as faculty member or researcher publications, research interests, certifications and training, and academic as well as professional experiences. Further, applying machine reasoning on these attributes can play an important role in analyzing data consistency and extracting new knowledge and bigger knowledge graphs from an existing one. As an example, in our case study activity, the reasoning was

TABLE IV. Some Classes used in HEO

Class Name	Discerption
Academic_Staff	The academic staff of the university, college and department (e.g., assistant professor, associate professor, professor).
Professor	A professor can manage and coordinate most of the the activities within a course such as learning outcomes, design & implementation, topics, or be the instructor in some courses.
Associate_Professor	The associate professor can manage and coordinate most of the the activities within a course such as learning outcomes, design & implementation, topics, or be the instructor in some courses.
Assistant_Professor	The assistant professor can manage and coordinate most of the the activities within a course such as learning outcomes, design & implementation, topics, or be the instructor in some courses.
Lecturer	The lecturer is (teaching) assisting in a course. This is a person who holds a master's degree.
Teaching_Assistant	The teaching assistant is (teaching) assisting in a course. This is a person who holds a bachelor's degree.
Research_Interests	Summarizes the areas of expertise of a person.
Certification_and_Training	Certification and training attended by the academic staff member.
Academic_and_Professional_Experiences	The experience that a staff member has in Professional and Academic world to justify one or more areas.
Publications_ Keywords	Specific words that expose domain or topic of a research publication.
Class_Activity	The activities that are related to a class. It has two parts: in-class activity (Lectures, Class Exercises, Class Discussion/Participation, , Lab Sessions, Tutorial Sessions, Misc and Active Learning). out-class activity (Self-reading/Research, Teamwork & Group Discussion, Exercises, Lecture Summary, Design Problems, Case Study, Technical Writing).

TABLE V. *Related_to* Property

Object Property Name	Domain	Range	Property Type
Related_to	*Keywords*	*Course* *Research_Interests* *Academic_and_Professional_Experiences* *Publications_Keywords* *Certifications_and_Trainings*	Transitive

Logical Description

∀ Keywords ∈ Academic staff ∃ Keywords related to Course

Text Description

A course contents have implicit and/or explicit relation with the keywords of a publication, academic & professional experiences of a staff member, research interests, the certifications & training

Reasoning

Lets consider a Property (i.e., "Pr") that relates and individual "x" to individual "y", also an individual "y" to individual "z", then the ontology can infer that individual "x" is related to individual 'z' via property "Pr" (as the type of property "Pr" is transitive). Once we model the property "Related_to" as transitive property, ontological reasoning can be used to identify that which staff member is suitable for research collaboration based on various factors such as, professional experiences, research interests, publication, certifications & trainings and topic coverage.

TABLE VI. *can_work_with* Property

Object Property Name	Domain	Range	Property Type
Can_work_with	*Teaching_Assistant* *Professor* *Lecturer* *Associate_Professor* *Assistant_Professor* *Academic_Staff*	*Teaching_Assistant* *Professor* *Lecturer* *Associate_Professor* *Assistant_Professor* *Academic_Staff*	Symmetric

Logical Description

∀ Academic staff ∈ FCIT ⊆ KAU ∃ Academic staff can work with other Academic staff

Text Description

The academic staff members can work with other academic staff members based on their various matching factors and attributes such as certifications & trainings, research interests, academic & professional experiences and the keywords of their publications.

Reasoning

If a property "Pr" is symmetric, and this property relates individual "x" to individual "y" then the ontology can infer that individual "x" is also related to individual "y" via property "Pr". Once we design the characteristics of the property "can_work_with" as symmetric, the ontology can identify which academic staff can collaborate in publishing, teaching a course or starting joint research projects.

used to infer which faculty members or researchers could cooperate with in publishing, teaching a course, or starting joint research projects based on available data, research interests, publications, certifications and training, and academic and professional experiences.

Here, we describe how to find the right resource for research collaborations based on different contributing attributes and how machine reasoning is used to generate bigger knowledge graphs. A short description of these examples is as under:

- Example 1: Using research interest parameter to find

TABLE VII. *Experience_Since* PROPERTY

Object Property Name	Domain	Range	Property Type
Experience_Since	*Keywords*	*Experience_Since* *Academic_and_Professional_Experiences* *Publications_Keywords* *Certifications_and_Trainings* *Research_Interests*	Inverse Of

Logical Description

Experience since represents as S= {2011, 2012, 2016, 2019 ... etc.} ∀ Academic staff ∈ FCIT ⊆ KAU ∃ X ∈ S such that each Keywords connecting with the Academic staff in specific X

Text Description

All four criterias (i.e. academic & professional experiences, keywords of the publications, certifications and trainings, research interests, and the) adds a typical kind of experience for specific academic staff members.

Reasoning

If the property (pr) links individual "x" to individual "y" then it's inverse property will link individual "y" to individual "x". In our HEO, we modeled the properties Experience_Since and For_Keywords as inverse of each other. This helped us to connect a specific keyword to a specific year. So, the machine can infer that the specific year complies with a specific keyword.

TABLE VIII. *For_Keywords* PROPERTY

Object Property Name	Domain	Range	Property Type
For_Keywords	*Experience_Since*	*Keywords* *Academic_and_Professional_Experiences* *Publications_Keywords* *Certifications_and_Trainings* *Research_Interests*	Inverse Of

Logical Description

Experience since represents as S= {2011, 2012, 2016, 2019 ... etc.} ∀ Keywords ∈ Academic staff ∃ X ∈ S such that each Keywords connecting Academic staff within specific X

Text Description

The experience year which is related to a specific academic staff has a relationship with all the four identified criteria (academic and professional experiences, certifications and trainings, research interests and the keywords of the publications).

Reasoning

If a property (say "Pr") links an individual "x" to individual "y" then its inverse property will link individual "y" to individual "x". Two properties i.e., For_Keywords and Experience_Since are inverse of each other and these properties help for connecting a specific year to a specific keyword. So, the machine can infer that the specific keyword complies with a specific year.

TABLE IX. *related_to_person* PROPERTY

Object Property Name	Domain	Range	Property Type
related_to_person	*Experience_Since*	*Academic_Staff*	Symmetric

Logical Description

Experience since represents as S= {2011, 2012, 2016, 2019 ... etc.} ∀ Academic staff ∈ FCIT ⊆ KAU ∃ X ∈ S such that each X related to person

Text Description

Each academic staff member has experience years in four criteria, including academic & professional experiences, research interests, certifications & trainings, and the keywords of the publications.

Reasoning

Let's consider the property "Pr" as a symmetric property, and it relates an individual "x" to individual "y" then the machine can infer . that individual "y" is also related to individual "x" via property "Pr". Once we assign the characteristic symmetric to the property "*related_to_person*", the ontology can identify which experience year related to which academic staff

the best research collaborator.

- Example 2: Using scientific publications to find the best research collaborator.

- Example 2: Using multiple factors such as certification & trainings, research interests, academic & professional experiences, and publications, to find the best

research collaborator.

[Example 1: Research Interests]

By creating *has_research_interests* property, we can conduct some queries to identify all the faculty members and potential researchers who are suitable for research collaboration based on their research interests. This can also help to find

which faculty member has the most priority to start joint and collaborative research projects based on the research interest's data. *CQ: Find specific academic staff to collaborate with other academic staff based on common research interests.*

Fig. 4A shows all the academic staff with the same research interests:

By conducting the following query we find that Dr.Muhammad can work with Dr. Naif because both of them have "LOD" and "SW" as a research interest. (As shown in Fig. 4B).

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT DISTINCT ?Academic_Staff
?Academic_Staff1 ?Research_Interests
WHERE {
?Academic_Staff rdf:type KAU:Academic_Staff.
?Academic_Staff1 rdf:type KAU:Academic_Staff.
?Research_Interests rdf:type KAU:Research_Interests.
?Academic_Staff KAU:has_research_interests ?Research_Interests.
?Academic_Staff1 KAU:has_research_interests ?Research_Interests.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff1.
?Academic_Staff KAU:can_work_with ?Academic_Staff1.
FILTER(regex(str(?Academic_Staff),"Muhammad_Ahtisham_Aslam"))
}
ORDER BY ASC(?Research_Interests)
```

[Example 2: Publication's Keywords]
By creating *Has_Keywords property*, we can conduct some queries to identify all the faculty members who have the same publication keywords. Matching keywords guide us towards matching fields of interest and expertise which ultimately helps to infer the right resource for research collaboration. So, the results of such queries can help faculty members find potential researchers for joint research projects and scientific collaboration.

CQ: Find specific academic staff to collaborate with other academic staff based on common publication keywords.

Fig. 5A shows all the academic staff with the same publication's keywords:

By conducting the following query, we find all the academic staff members who can collaborate with Dr.Muhammad based on the publication keywords. (As shown in Fig. 5B.)

```
SELECT DISTINCT ?Academic_Staff ?Academic_Staff1 ?Publications_Keywords ?Publications
WHERE {
?Academic_Staff rdf:type KAU:Academic_Staff.
?Academic_Staff1 rdf:type KAU:Academic_Staff.
?Publications rdf:type KAU:Publications.
?Publications_Keywords rdf:type KAU:Publications_Keywords.
?Academic_Staff KAU:has_publication ?Publications.
?Academic_Staff1 KAU:has_publication ?Publications.
?Academic_Staff KAU:can_work_with ?Academic_Staff1.
?Publications KAU:Has_Keywords ?Publications_Keywords.
FILTER(regex(str(?Academic_Staff),"Muhammad_Ahtisham_Aslam"))
}
ORDER BY ASC(?Publications_Keywords)
```

[Example 3: Certifications & Trainings, Research Interests, Academic & Professional Experience and Publication's Keywords]

Example 3 shows all the academic staff that can collaborate based on all four criteria (Certifications & Training, Research Interests, Academic & Professional Experience, and Publications).

CQ: Find all the academic staff who can collaborate with other academic staff Certifications & Trainings, Re-search Interests, Academic & Professional Experience and Publications.

```
SELECT DISTINCT ?Academic_Staff ?Research_Interests
?Academic_and_Professional_Experiences ?Publications_Keywords
?Publications ?Certifications_and_Trainings
WHERE {
?Academic_Staff rdf:type KAU:Academic_Staff.
?Academic_Staff1 rdf:type KAU:Academic_Staff.
?Research_Interests rdf:type KAU:Research_Interests.
?Academic_and_Professional_Experiences rdf:type
KAU:Academic_and_Professional_Experiences.
?Academic_Staff KAU:has_research_interests ?Research_Interests.
?Academic_Staff1 KAU:has_research_interests ?Research_Interests.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff1.
?Academic_Staff KAU:Has_Academic_and_Professional_Experiences
?Academic_and_Professional_Experiences.
?Academic_Staff1 KAU:Has_Academic_and_Professional_Experiences
?Academic_and_Professional_Experiences.
?Academic_and_Professional_Experiences KAU:has_AcademicStaff
?Academic_Staff.
?Academic_and_Professional_Experiences KAU:has_AcademicStaff
?Academic_Staff1.
?Publications rdf:type KAU:Publications.
?Publications_Keywords rdf:type KAU:Publications_Keywords.
?Academic_Staff KAU:has_publication ?Publications.
?Academic_Staff1 KAU:has_publication ?Publications.
?Publications KAU:Has_Keywords ?Publications_Keywords.
?Certifications_and_Trainings rdf:type
KAU:Certifications_and_Trainings.
?Academic_Staff KAU:Has_Certifications_and_Trainings
?Certifications_and_Trainings.
?Academic_Staff1 KAU:Has_Certifications_and_Trainings
?Certifications_and_Trainings.
?Certifications_and_Trainings KAU:has_AcademicStaff
?Academic_Staff.
?Certifications_and_Trainings KAU:has_AcademicStaff
?Academic_Staff1.
?Academic_Staff KAU:can_work_with ?Academic_Staff1.
}
```

Fig. 6 shows the results of all the academic staff that can collaborate based on the four criteria.

In this section, we described selected CQs, their answers and the machine reasoning involved in answering each CQ. The rest of the CQs and answers to these extracted from real-life data are explained in the Higher Education Ontology (HEO) website[1].

V. CONCLUSION AND FUTURE WORK

One of the main activities in Higher Education (HE) institutions and research organizations is conducting high quality research. A key issue in conducting high quality research is to include the right resources in the research team as well as expert collaborators for joint research projects. Finding suitable and expert resources to conduct joint projects and research collaborations can be effectively addressed by applying semantic-based techniques and machine reasoning on research and researcher data. As an example, CVs of the researchers/faculty members and their scientific output can provide important data that can be used by machines to identify the right resources for research collaboration and joint research projects between the faculty members and researchers. In this paper, we presented a Methodology for Ontology Design and Development (MODD) and used this methodology to develop the Higher Education Ontology (HEO). This HEO can be used to automate various processes and activities in HE by using machine reasoning. As proof of concept, we presented a case study on "finding the right resources for joint research and scientific collaboration". In our case study, we answered various competency questions (CQ) enriching the HE data semantically and then applying reasoning on it by developing HEO. Finally, we evaluated and validated our approach by answering various CQs in the domain of HE. In future research, we plan to improve our ontology by applying as many higher education activities and

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[1]wo.kau.edu.sa/Pages-SPedia.aspx

(A)

(B)

Fig. 4. The research interests example results.

(A)

(B)

Fig. 5. The publication's keywords example results.

```
WHERE {
?Academic_Staff rdf:type KAU:Academic_Staff.
?Academic_Staff1 rdf:type KAU:Academic_Staff.
?Research_Interests rdf:type KAU:Research_Interests.
?Academic_and_Professional_Experiences rdf:type KAU:Academic_and_Professional_Experiences.
?Academic_Staff KAU:has_research_interests ?Research_Interests.
?Academic_Staff1 KAU:has_research_interests ?Research_Interests.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff.
?Research_Interests KAU:has_AcademicStaff ?Academic_Staff1.
?Academic_Staff KAU:Has_Academic_and_Professional_Experiences ?Academic_and_Professional_Experiences.
?Academic_Staff1 KAU:Has_Academic_and_Professional_Experiences ?Academic_and_Professional_Experiences.
?Academic_and_Professional_Experiences KAU:has_AcademicStaff ?Academic_Staff.
?Academic_and_Professional_Experiences KAU:has_AcademicStaff ?Academic_Staff1.
?Publications rdf:type KAU:Publications.
?Publications_Keywords rdf:type KAU:Publications_Keywords.
?Academic_Staff KAU:has_publication ?Publications.
?Academic_Staff1 KAU:has_publication ?Publications.
?Publications KAU:Has_Keywords ?Publications_Keywords.
?Certifications_and_Trainings rdf:type KAU:Certifications_and_Trainings.
?Academic_Staff KAU:Has_Certifications_and_Trainings ?Certifications_and_Trainings.
?Academic_Staff1 KAU:Has_Certifications_and_Trainings ?Certifications_and_Trainings.
?Certifications_and_Trainings KAU:has_AcademicStaff ?Academic_Staff.
?Certifications_and_Trainings KAU:has_AcademicStaff ?Academic_Staff1.
?Academic_Staff KAU:can_work_with ?Academic_Staff1.}
```

Academic_Staff	Research_Interests	Academic_and_Professional_Experiences	Publications_Keywords	Publications	Certifications_and_Trainings
Sachi_Arafat	Data_Science	Reviewer	machine_learning	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Sachi_Arafat	Data_Science	Reviewer	conditional_random_fields	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Sachi_Arafat	Data_Science	Reviewer	Urdu	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Sachi_Arafat	Data_Science	Reviewer	named_entity_recognition	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Sachi_Arafat	Data_Science	Reviewer	deep_recurrent_neural_network	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Fahd_S._Alotaibi	Data_Science	Reviewer	machine_learning	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Fahd_S._Alotaibi	Data_Science	Reviewer	conditional_random_fields	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Fahd_S._Alotaibi	Data_Science	Reviewer	Urdu	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Fahd_S._Alotaibi	Data_Science	Reviewer	named_entity_recognition	Deep_recurrent_neural_networks_with_wor	Visual_Basic
Fahd_S._Alotaibi	Data_Science	Reviewer	deep_recurrent_neural_network	Deep_recurrent_neural_networks_with_wor	Visual_Basic

Fig. 6. The academic staff with four criteria example.

processes as possible. We also aim to link our datasets with the scientific publications open datasets as this will help to produce bigger knowledge graphs which will ultimately be helpful for generating broader and improved results.

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