Bridging education and labor skills by a novel competency-based course linked-data model

Safia Nahhas¹, Omaimah Bamasag², Maher Khemakhem³, Nada Bajnaid⁴
¹,²,³ Faculty of Computing and Information Technology, King Abdulaziz University, 21577 Jeddah, Saudi Arabia
Corresponding author: Safia Nahhas (e-mail: snahhas0003@stu.kau.edu.sa).

ABSTRACT Competency-based education (CBE) aligns with current requirements by providing students with competencies needed in real life. Emerging new styles of education, such as open courseware (OCW), massive open online course (MOOC) and open educational resources (OERs), play a role in renewing CBE by offering the required open materials. In this paper, we propose a novel competency-based course model (CBC model) that was developed with two aims. The first aim was to represent the fundamental concepts of CBE courses by exploiting the expressivity of ontologies. The second aim was to design a CBC model to act as a bridge between the existing ontologies that represent education and open materials and the ontologies that represent competencies from labor knowledge bases by exploiting linked-data interoperability. The model was designed to provide materials at the competency level in addition to the course level in order to allow students who fail one competency to repeat its materials rather than the whole course. Though the dynamic nature of labor knowledge bases, the integrated competencies from labor linked-data repositories will be automatically updated based on linked-data features. The use of W3C standards and linked-data ontology engineering principles to design the CBC model make it reusable and expandable. A proof of concept application was used to show the possibility of using the model in real life by applying the model to educational systems, such as LMS. Applying the model can increase a university’s appearance on the web, thus enhancing its reputation. Additionally, the model can increase the links between education and labor that form a substantial contribution from the linked-data science perspective.

INDEX TERMS Competency-based education, linked-data, OCW, ontology.

I. INTRODUCTION

Recently, a renewed form of competency-based education (CBE) has arisen concurrently with other new emerging education paradigms. For example, open courseware (OCW), massive open online course (MOOC) and open educational resources (OERs) are recent styles of education that can support CBE by offering educational resources and materials. CBE can be a compromise solution by providing both the benefits of education and certificates on the one hand and the competencies and skills needed by labor fields on the other hand. In [1], the authors outlined the main principles of CBE: “i) The degree reflects robust and valid competencies. ii) Students are able to learn at a variable pace and are supported in their learning. iii) Effective learning resources are available any time and are reusable. iv) Assessments are secure and reliable”. According to these principles, we investigated the vital role that linked-data technology can play in facilitating the modeling of the CBE fundamentals and making integration with the new emerging paradigms of education to offer the required materials. Furthermore, linking competencies of education courses with real-world fields, such as labor, is one of the core goals of CBE [1], [2]. Linked-data potentials can meet these goals by offering interoperability, shareability and accessibility among linked datasets [3], [4], [5].

Using shared ontologies is one of the linked-data technologies that enable the interoperability between the different datasets and offer common understanding. By making the mappings and integration processes, it is possible for sources of data to be diverse from multiple places. The basic LD principles that are supposed to be satisfied in linked datasets are summarized as follows: “i) Use URIs as names for things; ii) Use HTTP URIs so that
people can look up those names; iii) When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL); iv) Include links to other URIs, so that they can discover more things” [3]. Utilizing linked-data abilities, such as interoperability to link both education courses and labor competencies in addition to open education materials, can help guide course designers as they build and refine their courses based on CBE.

In this paper, we propose a novel competency-based course model (CBC model) by developing and implementing linked-data ontology. The model aims to help course designers to build competency-based courses that provide students with competencies kept up with the real labor’s demands. This satisfies the current orientation of many companies that become seeking skills beside certificates. To realize this aim, the model is designed with the ability to integrate open learning resource models and labor’s competencies knowledge bases by exploiting linked-data interoperability. Integrating with open learning resources models helps offer educational materials, and integrating with labor’s competencies knowledge bases helps reach the current labor’s competencies. In addition, the CBC model exploits the expressivity of linked-data ontologies to represent the fundamental concepts of CBE courses. However, at the same time, the model maintains the regular structure of typical courses to keep the model consistent with the course designer’s experience. By following the linked-data ontologies methodology to build the model, it becomes more practical and applicable than having just theoretical ontology.

Exploring procedures are introduced to enable course designers to explore competencies obtained from real labor repositories and easily include them in the courses. These procedures also allow exploring the furthest depth of competencies related to a particular occupation’s knowledge and their related competencies and so on. In fact, these exploring processes act as a bridge between the academic side and the industry/labor side in order to facilitate the discovery of the knowledge and skills that learners will need in real life. Another exploring procedure is provided to enable the course designers to find appropriate materials from open education resource repositories in order to enrich the course with the needed materials at the competency level as well as at the course level. This strategy enables the student who does not master any competency to return to this competency’s specific material rather than repeat the whole course materials. Additionally, enabling multiple levels of exploring materials can lead to the discovery of the interdisciplinary topics related to the course. Essentially, these exploring features can reduce the efforts and time needed by university teams, as [13] indicates, “Scholars familiar with CBE learning models recognize the significant aspects of identifying competencies. Faculty and curriculum developers draw upon several resources in order to identify the knowledge, skills, and abilities expected of graduates in a particular field or discipline”. The algorithm that illustrates these procedures is implemented through the application that has been built based on the model to demonstrate its potential uses and its validation. Moreover, one of the main characteristics of the labor market is that it is dynamic and constantly changing. Therefore, when the providers of labors’ linked datasets update their repositories, the applications based on the CBC model will be able to reflect these updates and give a chance for course designers to choose the updated competencies and include them in the competency-based course. Multiple approaches of evaluation were conducted to validate and assess the model. Since the CBC model is built based on linked-data ontology, reasoning abilities can be applied to it.

From the linked-data science point of view, this work can contribute towards increasing the links between various education linked datasets with labor knowledge bases. That agrees with the linked-data view as [6] indicates, “Generating connections is at the core of linked-data, and connecting bits of information in new ways has the potential to create unanticipated opportunities for data navigation, discovery, and use”. Additionally, by following the linked-data ontology methodology, the datasets that are produced will contain links to other datasets that can help increase the university’s appearance on the web and, therefore, enhance its ranking and reputation. Finally, the CBC model was built using W3C standards, such as RDFs and OWL, in order to facilitate its reuse and application in different scenarios and to make it readable by machines.

The rest of the paper is organized into the following sections. The related work is presented in Section II. Section III outlines the modeling issues of the proposed ontology, including the modeling methodology and the modeling phases that are comprised of the specification phase with explanation of the knowledge acquisition and formalization issues, the vocabulary selection and reuse phase, the core conceptual model phase that includes modeling the core concepts of CBE courses, the integration and mapping phase and, finally, the generation and exploitation phase that is embodied in Section IV. Hence, Section IV discusses the evaluation of the CBC model by several approaches, including verification, validation and assessment of the CBC model. Lastly, Section V concludes the paper and outlines the potential practical uses of the model and future work.

II. RELATED WORK

Basically, CBE focuses on what the student can do besides what he knows [13]. The authors in [29] describe CBE as a bridge between the traditional paradigm and learning revolution. In this era, recent open education paradigms such as OER, OCW and MOOC can play an important role to augment CBE by enriching the students with the open education materials that they need to perfect real-life
competencies. Additionally, teachers and course designers can benefit from these paradigms’ materials and reproduce them to make their courses more adaptive with CBE orientation. OER is any educational resource that is open and free to use, re-purpose or share with a license that does not require payment or permission [30]. OCW is a specific structured type of OER that is organized as courses. MOOCs arise from the need to have a more interactive and dynamic paradigm than the case of OCW. However, the following mentioned works that provided ontological models for CBE did not provide integration with open educational linked-data models such as LOCDW which is introduced in [31].

The IEEE LOM model that was introduced in [24] provided a competency application profile that can be used to tag educational resources. CBE can be augmented by having educational resources that are tagged with competencies. A recent study [25] examined the difference between the objectives in traditional models and CBE models. The authors concluded that the trend is moving towards CBE, especially in health-related education. On the other hand, the authors in [26] introduced a prototype of a competency-based management system with learning paths. The core of ontology that the system was built upon focuses on the employee, the job, the skills and the learning object. The authors provided a scenario that can provide a skill gap report for an employee. Another competency management work based on ontologies was presented in [33]. It discussed the relationship between learning concepts’ description and competency management. Along the same line, the article [27] studied the collaboration between education and the labor market based on using semantic ontologies. The authors in [34] provided a conceptual model that presented mapping between competencies and learning resources in 'a process-oriented framework'. They provided a use case applied on the aeronautic field to explain their work. Additionally, in [28], the authors provided a model to identify and classify competencies and learning outcomes in higher education, teaching technology and web information management. In [32], the authors developed a competency-based search system by using ontologies. They built competency ontology, content ontology and domain ontology to develop this search system. Competency clustering is applied in this work to improve the search results ranking.

Our model differs from the above works in many ways as elaborated in the following points:

- None of the previously mentioned models has provided a particular model for the ‘competency-based course’ attributes. Our model worked on modeling several new concepts of CBE courses based on the domain field references and with the help of the domain experts that were not modeled in the previous works.
- The CBC model also forms a bridged model, since it integrates ontologies from both formal and recent open education models, such as OCW, MOOC and OER, in addition to real-world labor competency ontologies. Some of the models with which we integrated, such as LOCWD, emerged after the above-mentioned models.
- Our methodology of building the ontology is based on the specification and features of linked-data ontologies, which is not the case for the above-mentioned models. Following this methodology enabled us to integrate competency’s knowledge bases from real life with the corresponding material from open education repositories.
- Additionally, one important thing to mention is that the target users of our work are mainly course designers and teachers rather than employees or employers, as is the case with mere competency models.
- Finally, we propose keeping the model close to the form of the traditional course structure with anchor proprieties to enhance discovery and linking, which is an issue that could not be considered at the same level in other works.

The next section tackles the modeling issue of the proposed model.

III. MODELING

A. MODELING METHODOLOGY

The main methodology that we followed in designing the CBC model considered the specifications of engineering ‘linked-data ontology’ as detailed in [6], [7], [8], [9], [10] and [23] (the term CBC model or CBC ontology is used interchangeably in this research). Adopting this methodology helped make the model more practical and usable and leveraged many features of linked-data technology. Additionally, the guidelines and technical issues that are mentioned in [11] and [12] were taken into account. For example, [11] provided practical guidelines to determine the ontology’s classes, the ontology’s taxonomy and the ontology’s properties while describing their allowed values and their constraints. Also, it guided us to determine the domain and scope of the ontology as we will see in the following sections. The model was established based on references to many articles and fundamentals that were mentioned in the literature and based on mentoring from the domain field experts as detailed in the following sections.

This modeling methodology has the following phases: i) the specification phase including knowledge acquisition and formalization, ii) the vocabulary selection and reuse phase, iii) the core modeling phase including the addition of new concepts to match the CBE fundamentals and the attributes of the ontology, iv) the integration and mapping phase and, lastly, v) the generation and exploitation phase that is embodied in the implementation and evaluation section. Before discussing each phase, we indicate that we took into consideration the main guidelines of reusing
existing ontologies unless there was no existing model or representation of the concepts that we needed, in which case we created new terms and concepts. By following these guidelines and linked-data guidelines in [3] and [5], we had the opportunity to map and link the ontology terms with other vocabularies and, therefore, prepare the ontology to be extendable, which is one of the important features of linked-data ontologies. Additionally, we worked to balance the use of domain-specific vocabularies and popular vocabularies in order to have a clear structure model, but at the same time making the ontology easy to consume. In the next sections, we illustrate how we developed the CBC model through the above-mentioned phases.

B. MODELING PHASES

SPECIFICATION PHASE

In the beginning, we needed to specify the purpose and scope of the CBC model and answer the questions that were introduced in [11] regarding the determination of the specification, such as “what are we going to use the ontology?, Who will use and maintain the ontology?”. In fact, the CBC model aims to provide a representation of the competency-based course concepts and structure to have an ontology that provides real modeling of the CBE course fundamentals and principles. Additionally, the aim of the CBC model is to provide possibilities of integration with the new emerging educational models, such as OCW, MOOC and OER, and also to exhibit the ability to integrate with the competency’s knowledge bases and ontologies that are extracted from the real labor world. This model offers a bridge between the existing educational ontologies that we reused. Mainly course designers, teachers and academic staff will benefit from this model as they build or refine courses according to competency-based education. The scope of the ontology is the concepts of CBE that are related to the ‘course’ concepts and structure and does not include all other various aspects of the CBE.

Knowledge Acquisition: The nature of knowledge acquisition in linked-data ontologies mostly concentrates on finding appropriate vocabularies to reuse the needed concepts and terms. The following section tackles a wide survey we conducted to identify such vocabularies and analyze them. Additionally, in Section (core of CBC conceptual modeling phase), we show how we added the new concepts that were extracted based on the competency-based course requirements.

Formalization: Since we were developing linked-data ontology, our modeling decisions mostly focused on having a model that could be reused and integrated and is easy to maintain more than implementing many constraints in order to generate complex reasoning processes. Therefore, we decided to make the ontology lightweight and relatively small with low formal constraints and well documented as recommended in [7] and [8].

VOCABULARY SELECTION AND REUSING PHASE

One of the main challenges in modeling ontologies is the process of discovering and analyzing which vocabularies should be reused, as [15], [16] indicate. Since the reuse process is at the core of linked-data ontology development and has a substantial impact on giving the model commonly agreed upon understanding and making it more interoperable, a considerable part of this research was spent on finding and investigating the best approaches for reuse.

Basically, the main steps suggested in [16] were considered to achieve this phase as follows:

1) Discovering which vocabularies were candidates for reuse: For this issue, we conducted a wide survey as in [19] in which we extracted the most commonly used vocabularies in the education field.

2) Selecting the most relevant vocabularies and terms: In this step, we analyzed the vocabularies we obtained in the previous step and determined the vocabularies that are most relevant to our domain and our intended applications, and we also considered the following criteria from [5]:

   Usage: In addition to conducting a survey to assess the usage of vocabulary in the domain field, we relied on LOV service. LOV shows the number of datasets that use a particular vocabulary. Additionally, LOV has an efficient ranking algorithm that shows the frequency and popularity of the terms of the vocabulary [18]. Also, the authors in [18] provided Protégé LOV plugin that facilitated accessing LOV service and making the appropriate reusing action.

   Maintenance and governance: When the vocabulary is registered in LOV service, it meets the LOV criteria. LOV has many criteria that support the maintenance of the vocabulary. Examples of such criteria are that the vocabulary should be well documented, follow standard formats, have stable URLs and be published based on best practices and by trusted entities with respect to version policies. Most of the vocabularies that we reused exist in LOV registries such as Teach, courseware, AIISO, FOAF, DC, CCO, CC REL and SKOS.

   Coverage and expressivity: We worked to use multiple complementary vocabularies to ensure that we included as much of the needed concepts from the existing vocabularies as possible. As the authors of [4] indicated in the metrics section that they presented regarding interoperability, an increase in the usage and coverage of relevant vocabularies can increase the interoperability, which is demanded in our work.

   3) Customizing and integrating the reused vocabularies: This step will be more detailed in the final phases of modeling section, but for now, we clarify that as [3] recommended, we reused vocabularies that are described as well-known RDF vocabularies and widely used as anchors and hubs. For example, we reused terms from FOAF, SKOS, Dublin Core and DBpedia ontologies to facilitate other applications and ontologies’ use and linkage with our model. Additionally, this act makes the datasets that will be
generated from our model interoperable and have the ability to be integrated. The final set of ontologies that we reused are listed in Table 1.

By following the guidelines from [15], we created a balance between reusing domain-specific vocabularies, such as TEACH, COURSEWARE, AIISO, LOCWD and ESCO, and the popular vocabularies, such as FOAF, DC and SKOS. On the one hand, reusing domain-specific vocabularies led to having a clear structure model; on the other hand, reusing popular vocabularies facilitated consuming the resulting datasets. This mixing of vocabularies helped make the model more extendable.

### Table 1

<table>
<thead>
<tr>
<th>Vocabulary name</th>
<th>Description of the reused vocabularies and concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEACH, COURSEWARE, AIISO</td>
<td>To represent formal education aspects.</td>
</tr>
<tr>
<td>LOCWD, LOE RD</td>
<td>To represent open education aspects such as open resources, open courses and open repositories.</td>
</tr>
<tr>
<td>ESCO</td>
<td>To represent competencies and occupation aspects. ESCO is built based on ESCO (International Standard Classification of Occupations).</td>
</tr>
<tr>
<td>CC REL</td>
<td>To represent copyright licenses.</td>
</tr>
<tr>
<td>Cognitive Characteristics Ontology (CCO)</td>
<td>To represent competences proprieties.</td>
</tr>
<tr>
<td>DBpedia ontology</td>
<td>To represent skills propriety.</td>
</tr>
<tr>
<td>DC ontology</td>
<td>To represent title and description proprieties of the CBC model.</td>
</tr>
<tr>
<td>FOAF</td>
<td>To represent persons and organizations such as “facilitator” in the CBC model.</td>
</tr>
<tr>
<td>SKOS</td>
<td>To represent the relationship between concepts such as “broadMatch”.</td>
</tr>
</tbody>
</table>

In most cases, we practiced direct reuse as the authors in [15] recommended, “The main findings of our work are that reusing vocabularies directly is considered significantly better”. We downloaded and referenced each one of the reused vocabularies, examined every concept mentioned in them (especially domain-specific ones) and reused what was suitable for our purpose. When the required terms were missing, we added the required terms and tried to link them to the related terms from external vocabularies, as will be seen in the next section. During this task, we faced some challenges and difficulties, such as the lack of ease in finding many vocabularies by referring to the given documentation website, especially the domain-specific vocabularies. Instead, we accessed these vocabularies by reaching their carbon versions or using tools, such as Protégé. The authors in [17] tackled this issue and emphasized on the importance of following the recommendations of publishing vocabularies to facilitate the access and reuse of the vocabulary. Additionally, they recommended providing user-friendly websites for the ontologies and their documentation.

### Core of CBC Conceptual Modeling Phase

Now that we have identified which vocabularies and concepts will be reused, we can complete the modeling process by the following:

1) Determining the model structure by defining the final set of classes and organizing them in a taxonomic hierarchy and defining the properties and their allowed values. This step includes reusing the selected terms from the previous phase and adding the new concepts that are needed to model the CBE course fundamentals and principles as detailed in Table 2.

2) Adding any required restrictions. Basically, the model needs to use the following existential restriction to ensure that any competency-based course instance has at least one competency:

\[ \exists \text{hasCompetence} \text{Competency} \]  

Equation (1) means that in order for the course to be a ‘CompetencyBasedCourse’, it is necessary for it to have at least one ‘Competency’.

3) Integration and mapping between the various reused ontologies, which is further detailed in the next section.

Table 2 shows modeling of the CBE course concepts that are needed to be part of the CBC model based on [1], [2], [13], [14], as well as based on mentoring from the domain field experts.

### Table 2

**Matching between the CBE course principles and the attributes of CBC ontology**

<table>
<thead>
<tr>
<th>CBE course fundamentals and principles</th>
<th>CBC model</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the issues that various CBE sources emphasize is having clear, explicit, robust and valid competencies. For instance, the authors in [1] stated that one of the main CBE principles is “The degree reflects robust and valid competencies”.</td>
<td>We reused the “Skill” concept from the ESCO ontology and integrated it into the CBC model to make it possible to have a standard source of clear, explicit, robust and valid competencies.</td>
</tr>
<tr>
<td>Learning resources should be available any time and be reusable [1]. Furthermore, as [13] states, “Free or open educational resources are normally utilized as course materials in an effort to make these programs more affordable”</td>
<td>We reused OCW and OER concepts from LOCWD vocabulary and integrated them to facilitate the provision of open materials from open educational repositories at any time. Additionally, we created a new property “competencyArchivedExperience” as a type of material. This property aims to accumulate the experience that the</td>
</tr>
</tbody>
</table>

1 http://linkedscience.org/teach/hs/
2 http://courseware.rkbexplorer.com/ontologies/courseware
3 http://purl.org/vocab/aiiso/
4 http://purl.org/locwd/
5 http://data.europa.eu/escouserco/ontology
6 http://creativecommons.org/ns/
7 http://purl.org/ontology/cco/
8 http://dbpedia.org/ontology/
9 http://purl.org/dc/terms/
10 http://xmlns.com/foaf/
11 http://www.w3.org/2004/02/skos/
The CBC model is implemented using W3C standards, basically RDFS and OWL. The use of such standards helps augment the model’s reusability and maintainability. We also used Protégé to facilitate the implementation by following the guidelines from [12]. The whole model is depicted in Figure 1 by using OWLGrEd to provide visualization version of the OWL file. The figure shows the CBC ontology, its classes, data properties inside the classes box, object properties as relationships between classes, super-subclasses relationships, equivalent relationships, restrictions and the reused ontologies that are surrounded by brackets. To reduce the occurrence of isolated resources, every resource produced from the CBC model will be associated with one of CBC ontology’s classes (types) or linked to other resources from other datasets by the “sameAs” property. Using the “sameAs” property can help augment the appearance of a university on the web, which can play a vital role in enhancing the ranking and reputation of the university and make it more discoverable; as the authors of [6] said, “discoverability depends on being linked”. The next section discusses other actions that help make the model and datasets produced from it not isolated.

INTEGRATION AND MAPPING PHASE

Many integration and mapping processes have already been mentioned in the previous sections; however, here we will summarize the most used approaches detected by examining the research and giving examples of each one from the CBC model. See Table 3. Mainly, these integration processes have been done at the schema level.

Stating equivalent relationships helps infer new semantics and facilitate the integration process. As we will see in the next section, the CBC model acts as a backbone model to make integration and enrichment among data from multiple datasets, such as competencies, occupation knowledge bases, OER and open universities repositories, to facilitate the development of an effective competency-based course.

The authors of [6] indicated that, “The data enrichment offered by mashing up datasets will open up unanticipated possibilities for information discovery and analysis”. In fact, that has happened during the implantation of an application based on this model. As we will see in the next section, we were able to explore the deepest competencies related to particular occupation’s knowledge, and the possibility of exploring interdisciplinary topics related to the course.

<table>
<thead>
<tr>
<th>Connectors</th>
<th>Example from CBC model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subclass</td>
<td>“Facilitator” as subclass from “foaf:Person”</td>
</tr>
<tr>
<td>Subproperty</td>
<td>“hasCompetence” as Sub-Property from “cco:competence”</td>
</tr>
<tr>
<td>owl:equivalentClass &amp; owl:equivalentProperty</td>
<td>-Make “Course” from AIIOS and COURSEWARE equivalent -Also make “StudyProgramme” from TEACH equivalent to “Programme” from AIIOS</td>
</tr>
<tr>
<td>skos:closeMatch, skos:exactMatch, skos:relatedMatch, skos:broadMatch, so on.</td>
<td>-“skos:related” relationship between “Teacher” and “Facilitator” -“skos:broadMatch” relationship between “Subject” and “Topic”</td>
</tr>
<tr>
<td>owl:sameAs &amp; rdf:seeAlso</td>
<td>sameAs property is usually used more at the instance level. We will see in the next section sameAs entries for the various instances produced by the CBC model</td>
</tr>
</tbody>
</table>
FIGURE 1. Visualized overview of the whole CBC model.
IV. EVALUATING THE CBC MODEL

We examined the approaches presented in [20], [21], [22], [10], [11] to evaluate the CBC model. Most articles agreed on the possibility of evaluating the ontology by using it in applications or discussing it with experts or both when it is needed; as [11] mentioned, “After we define an initial version of the ontology, we can evaluate and debug it by using it in applications or problem-solving methods or by discussing it with experts in the field, or both”. However, as Figure 2 shows, in addition to using the ontology in applications and consulting human experts, we used several other tools and approaches that were discussed in these articles to evaluate the CBC model. The evaluation of the CBC model by each approach is detailed in the following subsections.

![Diagram of Approaches used in evaluating the CBC model.]

Since the CBC model is linked-data ontology, our aim was to meet the six dimensions that were mentioned in [21] in addition to the linking dimension that was mentioned in [10]. We aimed to meet this additional dimension and evaluated CBC model based on the five-star rating approach that [10] provided, due to CBC is a linked-data ontology and this approach was developed to rate linked-data vocabularies. The authors in [20] indicated that “there is no single best or preferred approach to ontology evaluation; instead, the choice of a suitable approach must depend on the purpose of evaluation, the application in which the ontology is to be used, and on what aspect of the ontology we are trying to evaluate”. Hence, as Table 4 shows, we were able to meet each dimension by at least one approach. Thus, we did not aim to meet each dimension by each approach even though it was sometimes possible to do so; instead, we chose to use the approach that was most suitable and most regularly followed for each dimension.

A. VALIDATION AND VERIFICATION OF THE CBC MODEL

BY OOPS TOOL

By using the OOPS tool to evaluate CBC ontology, the results showed that the ontology successfully passed most of the pitfalls (approximately 40 pitfalls). For example, the model covers the human understanding issue, since it provides comprehensive documentation, annotations for all classes and properties and clear names for the various new concepts as well as reusing existing concepts.

![Table 4: Seven dimensions across 5 approaches used to evaluate the CBC model.]

Some issues did appear, such as OOPS, suggesting that ‘Subject’ and ‘Topic’ were equivalent. However, after referring to domain experts and related domain references, it turned out that there is a slight difference between the two concepts, since a subject is broader than a topic, so we used ‘skos:broadMatch’ to make a more accurate relationship between these terms. Additionally, the tool indicated that there was a minor pitfall of “Using different naming conventions in the ontology”. This happened because we integrated various ontologies that use different naming conventions. In fact, the authors mentioned the following in [21]: “It is worth mentioning that OOPS! output points to ontology elements identified as potential errors, but they are not always factual errors as sometimes something can be considered a factual error depending on different perspectives”.

BY USING PROTEGÉ

We used Protégé to validate the CBC model. The ontology language specifications were evaluated, and the syntax correctness was confirmed. Additionally, by running a Hermit reasoner through Protégé, we evaluated the consistency. Protégé did not give any indications of
inconsistent cases. Another validation we performed on the datasets that resulted from the application builder will be presented in the next approach.

BY PLUGGING THE MODEL INTO AN APPLICATION

As part of the evaluation stage, we provided a proof of concept application that was built based on the CBC model. Additionally, through this application we demonstrated the generation and exploitation phase by creating build functions that generated RDF triples based on the model. To implement this application, Jena framework including RDF API, Ontology, ARQ and TDB stores and Eclipse including its KOMMA plugin were used. Also, real open linked-data repertoires were used from both of the educational repositories and labor repositories. This application was built to be an explorer, builder and linker at the same time, as the following algorithm shows.

Algorithm: CBC Explorer, Builder and Linker

Function exploreCompetencies/Occupations (keywords) begin  
Data: keywords of the course topics  
Result: List of related competencies, occupations and its deep/narrow knowledge’s competencies

Find competencies from competencies/occupations repositories  
Foreach selected competency
Find
- narrower and broader competencies
- essential and optional knowledge
- essential and optional occupations
- Foreach occupation’s knowledge
  repeat
  Find narrower competencies
  until no further narrow competencies

end
  Function exploreMaterials (keywords) begin  
Data: keywords of the course topics  
Result: List of materials and related courses and OERs

Find materials from universities/OERs repositories  
Foreach material
  find
  - publications
  - OERs such as podcasts, tutorials, presentations
    related courses
    Foreach course
      exploreMaterials();
  end

  Function buildComptencyBasedCourse() begin  
Data: user’s entries based on the CBC model and selections from previous functions
  Result: storing all entries in TDB
  exploreCompetencies/Occupations (keywords);
  exploreMaterials (keywords);
  For each entry based on the CBC model
  provide optional SameAs entry
  store data in TDB
  end

In addition to providing generation functionality, it offers a linking mechanism that realizes the linked-data vision. The algorithm has three main functions. The first function is the ‘exploreCompetencies/Occupations’ function that allows the user (e.g., course designer) to enter a keyword of the course topics that is intended to be built or refined (e.g., “brand”). See Figure 3, step 1. The output of the function will be a list of related competencies, occupations and its deep/narrow knowledge’s competencies as Figure 3, step 2a shows. For each occupation, when the user goes over it, the function can get the narrowest/deepest knowledge’s competencies related to this occupation. For example, as Figure 3, step 2a shows, when the user goes over the “brand manager” occupation, a pop-up tab appears with the knowledge the occupation needs and its narrower competencies until there are no further narrow competencies. The user can select one or more of the resulting competencies to be part of the course.

On the same page, the output of running the second function ‘exploreMaterials’ with the keyword that the user entered in step 1 will be presented as shown in Figure 3, step 2b. The output includes a list of materials and its related courses and OERs. Each material will be retrieved with its related courses. Then, the recursive function will run to retrieve the related materials for each course and so on. This functionality can lead one to reach the interdisciplinary material that is related to this course. Additionally, the user can select one or more of the materials to be included in the ‘buildComptencyBasedCourse’ function. Therefore, the user will have already selected some competencies and materials that the ‘buildComptencyBasedCourse’ function will store in the TDB repository in addition to the other course information that the user entered as shown in Figure 3, step 3.

Optional ‘sameAs’ entries are provided with course information boxes. The input of these entries is supposed to be dereferenceable links, such as the professor’s page from DBpedia or his university website. Such links could be considered as a starting point to discover other related information and to navigate between datasets starting from this point to other chains of ‘sameAs’ links that can also be gathered by software agents. Further comprehensive information can be obtained through using SPARQL queries with these resulting datasets. Last, the user can enter the course code to retrieve the overall course information as shown in Figure 3, step 4. Figure 3, step 5 shows the validation of the resulting RDF triples by using the Protégé tool based on the CBC model.

This application helps evaluate and validate the correctness of the ontology language specification, since Jena was able to load the model and deal with it successfully. We also tested the ability to link with other knowledge bases, such as ESCO and open OER repositories, based on the CBC model through this application. The real-world representation and the semantics are the main points that have been assessed by implementing these applications.
FIGURE 3. Competency-based course explorer, builder and linker application based on the CBC model.
B. Assessment of the CBC model
BY CONSULTING HUMAN EXPERTS

Throughout the development of the model, we consulted human experts in both ontology engineering and the domain field of competency-based education. The main issues that have been discussed with considering linked-data ontologies’ specification and the criteria that were mentioned in [22] are as follows:

- Completeness: the model provides real representation of the competency-based courses’ domain as much as possible and covers most concepts of the domain. Mainly the content of Table 2 was discussed to ensure this point.
- Structure: the fitness of the model’s taxonomy and its relationships such as the relationship between ‘teacher’ and ‘facilitator’ concepts and the relationship between ‘topic’ and ‘subject’ concepts have been discussed.
- Clarity: whether the model provides clear concepts and descriptions without unnecessary redundant concepts has been discussed. For example, here the necessity of adding the ‘Goal’ concept beside the ‘Objective’ concept in the CBC model has been considered.
- Expandability: building the model in a way that makes it has the ability to add new concepts without affecting existing ontologies has been tackled. For this point, reusing terms from the available vocabularies was considered to facilitate any future needed expansion. For example, since we reused the ‘Material’ concept from ‘teach’ vocabulary, any new emerging material concepts could be considered as a subclass from the ‘Material’ concept as we did when we made ‘OER’ as a subclass from ‘Material’.

The experts at the end stages described the model as applicable, realistic and compatible with current education requirements. Since the structure of the CBC model corresponds with the structure of the traditional courses, experts found it adaptable with existing university systems and able to help academic staff. One of the experts suggested adding a ‘Goal’ concept at one level above the ‘Objective’ concept in the ontology taxonomy. Since the model already had these (Objective, Outcome, Competency) concepts, it appeared that keeping the taxonomy simple was more prioritizing to keep following the guidelines of [7] regarding engineering linked-data ontologies; as the authors mentioned, “Lightweight ontologies are those that are mostly defined with concept and property definitions, as well as simple concept taxonomies supporting simple taxonomic inferences”. In addition, this helps avoid synonym classes since ‘Goal’ and ‘Objective’ are very close to each other.

Finally, evaluation with five-star rating: The CBC model meets four stars out of five that were detailed in [10], since the model is dereferenceable with human-readable information (first star) available as an OWL file, is machine-readable (second star), is linked to other vocabularies (third star) and is provided with metadata (fourth star).

V. CONCLUSION AND FUTURE WORK

The results that we obtained from the implementation and evaluation section of this work show many potential uses of linked-data technology to serve the purposes of CBE courses. Based on the CBC model that has been achieved and realized in this work according to linked-data ontologies methodology, it turned out the role that the model can play to do integration among various vocabularies to fulfill the main principles of CBE courses. More clearly, this work shows that the CBC linked-data model can act as a bridge between the materials that a CBE course could need from open education repositories and the robust and valid competencies extracted from labor knowledge bases. Based on the CBC model, the materials could be offered at the competency level in addition to the course level; thus, when a student fails any competency, this modeling style enables him to return to this specific competency material rather than repeat the whole course materials.

By evaluating the CBC model through using it in proof of concept applications, we deduced the possibility of leveraging the model in the real world in ways such as adding it to education systems, like LMS or blackboards. Additionally, the application that has been built based on this model showed that by integrating with labor knowledge bases, we were able to explore the furthest depth of the knowledge’s competencies related to a particular occupation as well as explore multiple levels of the materials related to the course topics. Experts’ feedback indicated that they think this model will facilitate the work of course designers and academic staff to go towards the CBE and minimize the effort and time needed to interact with the industry, especially that the model maintains the regular structure of the traditional courses. The technical issues of the model have been tested by several tools, such as OOPS and Protégé, and a visual form of the model has been provided to give an overview of it. The model gained four stars out of five in the five-star rating method that leads to a more reusable, extendable and linkable model. To support the reusability of the model, we used W3C standards and respected the systematic methodology that was detailed in the modeling section. We also examined the most reliable reusing methods to reuse existing models and integrate with them. The appearance of the university’s courses and its related information and people on the web could increase by following this method, which could enhance the reputation and ranking of the university. Additionally, applying this model will contribute to increasing the links between education and labor, which is very vital from the linked-data community perspective.

For future work, there is an opportunity to create some indicators based on the CBC model and its integrating
This page appears to contain a list of references, possibly from a scientific or academic paper. The references are numbered and likely follow a specific citation style. Without the ability to view the entire document, it's challenging to provide a comprehensive transcription or analysis. The references cover various topics, including educational technologies, ontologies, and linked data, among others. Given the nature of the content, the text is likely to be discussing methodologies and findings relevant to these fields.