USING DOMAIN ONTOLOGY UNCERTAINTY OR ONTOLOGY MAPPING UNCERTAINTY TO IMPROVE LEARNING

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ABSTRACT

A grand amount of research, related to the application of ontologies in education has been done in recent years. Hot topics are personalization of tutoring and learning and knowledge modeling. Most of ontologies are mainly implemented in software systems (i.e. personalized e-learning environments) and are rarely used directly by learners or teachers. This is because of the needs of specific knowledge and skills. We think that in our days some teachers and learners mainly in higher education have all the knowledge and skills for using ontologically represented knowledge directly in learning and tutoring. Knowledge uncertainty exists in all real domains, but it is rarely discussed in e-learning courses. Most of semantic technologies are based on crisp logics and cannot deal with uncertain knowledge. In this research we analyze the specifics and sources of uncertain knowledge and technologies for its semantic modeling. We also discuss strategies for direct use of uncertainty both in domain knowledge and ontological models to improve learning. In such a way we search possibilities for direct usage of methods of one of the most important artificial intelligence fields, as knowledge modeling for improving learning and tutoring.
We propose a model of interactive ontology and ontology alignment evaluation environment, aimed at involving users in solving uncertainty problems during learning. We discuss strategies for application of domain and ontological models uncertainty for e-learning purposes and situations of its practical usage.

Keywords: *Ontology, Uncertainty, E-Learning, Ontology Evaluation, Ontology Mapping*

1. INTRODUCTION

There are huge amount of information and learning content on every scientific topic in our days. Sources, related to the same topic, differ from each other in scientific quality, correctness and presentation. It is difficult for students to find the most appropriate sources for its learning, and also for teachers to recommend the best learning content for every student. Many researchers propose suitable ontology-based semantic models and tools for better learning and teaching. This paper does not discuss usage of ontologies for building personalized learning systems, adaptive or intelligent tutoring systems. There are grand amount of successful or not so successful research on these topics. The aim of our research is to explore direct usage of ontologies in e-learning and find ways for deeper understanding of learning content and enhancing critical thinking skills, using semantic models. Related knowledge on the same topic from different sources can cover close, but not identic contexts, interpretations, or contain contradictory elements. One of the main goals of higher education is to teach students to use incomplete, contextual or conflicting knowledge. Our hypothesis is that some ontologies in DIFFERENT DOMAINS can be used directly in tutoring to develop skills for working with incomplete or conflicting information and correctly integrating information. Traditional Semantic web knowledge modeling technologies as OWL or RDFs are modeling languages for crisp knowledge and are not suitable for representation of fuzzy, interpretation dependent or contradictory knowledge. Some types of uncertain knowledge can be modelled by fuzzy, modal, probabilistic or possibilistic extensions of logics and semantic technologies. In our research we will seek ways to teach students how to work with some of above-mentioned types of knowledge by usage of semantic models, based both on classical and modern logics.

Every scientific domain contains some uncertain (probabilistic, vague, imprecise, partial or subjective) knowledge. Having in mind uncertainty is very important for many domain tacks. In some learning contexts learners should be aware about the uncertainty degree of the learning content and ways to deal with uncertainty, specific for this domain. So, it is important both for accurate semantic representation of domain knowledge and high quality learning to be able to capture and manage uncertainty. As traditional ontologies are based on crisp logics, as classical description logics [1], they can represent only certain knowledge and have no capabilities for modeling uncertainty. In this work we will discuss types and specifics of the uncertain knowledge, ways for its representation in semantic models and usage of uncertainty in education. We will pay attention on detecting and managing of ontology-related uncertainty, as well as usage of this process in the learning context to improve learning.

Working with unclear, incomplete or vague information usually is more difficult and requires deeper understanding of domain knowledge. Interesting questions are frequently raised for clearing facts, understanding dependencies, defining boundaries, etc. Discussing such questions can be very helpful during learning for better understanding of the content.

We will discuss specific techniques for usage of some of knowledge uncertainty elements for achieving deeper understanding of the learning content.

Other interesting aspect of uncertainty in ontology and ontology mapping is related to possible logical or modeling errors, imprecision or contradictions. We will discuss causes of logical problems, arose during ontology development, usage and mapping, and possible usage of its solution approaches for increasing learning quality.

Our main research questions are:

- Find main types of semantics – based knowledge models managing uncertainty that should be preferable in e-learning domain;
- Understand and classify uncertainty in real domains and semantic models;
- Find ways of usage of domain knowledge uncertainty for achieving better understanding of learning domain specifics;
- How domain knowledge uncertainty can be used in semantics-based models for making them useful for improving learning?
- How problems (including errors, vagueness or multisemy) in ontological models can be used to improve learning?
- What ontology evaluation, debugging or mapping methodology should be followed when its main goal is improving learning?

Our research is explanatory with some experimental design elements. Our aim is to find aspects of usage of ontologies in e-learning, different from usual ones, and suitable for developing skills to work with uncertain knowledge. Our research methods are based on analysis of latest scientific publications in several scientific areas, found by well-defined search queries, sending to Google scholar, ACM or IEEE. We also use Scopus Analytics to evaluate latest trends, related to relevance and importance of the research on uncertainty in semantic modeling and education. Then we use software system design methods, knowledge modeling and maintenance methods and our pedagogical knowledge and experience to find ways for direct usage of knowledge models and related uncertainty for improving learning and tutoring.

We propose a model of interactive ontology and ontology alignment evaluation, making them usable for e-learning purposes. The main goal of our model is to propose easy-to-use for learners, having semantic web-related skills and knowledge environments to stimulate participation in ontology mapping and evaluation process. We believe the activities, related to searching incomplete or contradictory definitions in ontological models. Rethinking and discussing differences, incompleteness or errors will be interesting and very useful in the learning process. We also propose a methodology for dealing with uncertainty in ontology and ontology alignment in e-learning environments and discuss strategies for using ontology uncertainty to improve learning. As the mapping process, which needs to be applied on different domains or sub-domains always has some degree of uncertainty we analyze approaches for modeling uncertainty in ontology mapping, including languages and tools. In our proposal we discuss statistical and fuzzy models for representing uncertainty and its usefulness in the learning process.

2. UNCERTAINTY IN REAL DOMAINS AND ONTOLOGIES – ANALYSIS AND CLASSIFICATION

Before selecting or finding appropriate semantic modelling technologies for uncertainty in

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

real domains we will analyze and classify uncertainty – related problems.

2.1. Classifications of Uncertainty in Real Domains

Researchers have discussed various types and sources of uncertainty. There are two main aspects of uncertainty, related to semantics-based knowledge models:

- Knowledge – related uncertainty;
- Model - related uncertainty.

Knowledge – related uncertainty refers to the uncertainty of some elements of the knowledge in the modeled domain.

There are five main uncertainty sources:

- Lack of knowledge, insufficient information, incomplete knowledge (for example of healthcare professionals);
- Semantic mismatch or a lack of semantic precision;
- Lack of machine precision, including imprecision and ambiguity in machine sensors;
- Unreliable sources of knowledge;
- Contradictory knowledge.

The frequency or type of uncertainty depends on the scientific domain. Uncertainty is very frequent in the medicine, but it is also usual in many other real life domains as weather forecasting, reports, accidents in aero and vehicle traffic, etc. Intelligent agents and automated reasoning should deal with uncertainty, so it is important to include uncertainty theory in ontology languages.

2.2. Importance of Uncertainty in E-Learning Domain

To evaluate the relevance and importance of the research on uncertainty in education and its ontological representation, we sent queries to Scopus database. Results show rapidly growing number of publications, containing words “knowledge” and “uncertainty” and “education” in abstract, title and keywords during the last 30 years (see Figure 1).

Results also show some publications, containing words “ontology” and “uncertainty” and “education” in abstract, title and keywords during the last 20 years (see Figure 2).

There are only a few such publications, but its number is slightly grooving in the last ten years. So, there are only a few researches on usage of uncertainty for educational purposes, but almost of them are performed during last ten years.

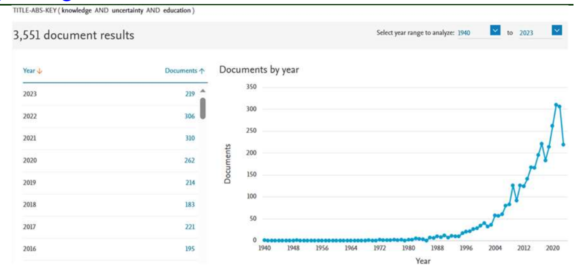

Figure 1. The number of publications, containing words “knowledge” and “uncertainty” and “education”

Figure 2. The number of publications, containing words “ontology” and “uncertainty” and “education”

2.3. Uncertainty and Semantic Models

Knowledge models, dealing with uncertainty are used in scenarios related to the lack of knowledge, vague or imprecise knowledge. Probabilistic and fuzzy logical models are well-known formalisms including dealing on uncertainty. There are ontology representation formalisms for development of such models. A probabilistic ontology is an ontology where some of the axioms are labeled with a truth value in the interval [0,1] [2]. The ground of probabilistic ontology languages lies in the family Bayesian DLs[3]. PR-OWL language (https://www.pr-owl.org/) is Bayesian extension to the OWL. In fuzzy logics, axioms can be satisfied to some degree of truth between 0 and 1. Examples of applications of fuzzy DLs are in image interpretation, recommendation systems, medical diagnosis and robotics. A Protege plug-in for creating Fuzzy OWL 2 ontologies (http://www.umbertostraccia.it/cs/software/fuzzyDL/download.html) that allows also submitting queries to the fuzzyDL reasoner can be used for Fuzzy ontology development.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Model - related uncertainty includes possible errors, incompleteness, inconsistencies or contradictions in the ontological models of certain, complete and logically correct domain knowledge.

Ontologies are used as crisp knowledge source, but in fact, they contain some (more or little) uncertain elements. Factors which influence the ontology uncertainty are:

- It claims to represent true and widely accepted knowledge, but in fact it contains only developer's knowledge of the subject;
- Every ontology is incomplete domain model;
- Term duplication (Synonymous and non – strict synonym repetition);
- Ageing of ontology versions and changes in the information over time;
- Possible inclusion of knowledge, inadequate to the usage context;
- Inclusion of information from numerous sources;
- Inclusion of inconsistent information;
- Inclusion of redundant information;
- Inclusion of inaccurate information (Vague information).

So, in real situations eliminating uncertainty is very difficult and in many cases -impossible. That is why explicit inclusion of some types of uncertainty in ontological models have become more and more important.

Semantic models having different complexity (including concept maps, folksonomies, or ontologies) are significant tool for knowledge management, because they allow explicit knowledge to be captured and represented both in machine-processable and human-usable way. Ontologies can be used for representing of knowledge, having various complexity levels. The main restriction of description logic or other classic logics–based ontologies is the impossibility to represent and handle uncertain or incomplete knowledge. We will shortly discuss the most important knowledge uncertainty types and extensions of classical semantic models for its representation and management.

2.3.1 Ontology-related uncertainty

Most ontologies claim that they represent true and crisp knowledge, but in practice its usage can lead to wrong or contradictory results. This is because of the fact that the ontology is only partial description of the corresponding domain and results of its usage depend from the context. Uncertain information may explicitly be modeled in ontology, or not, but every ontology is related to some uncertainty coming from incompleteness of the model, contextual dependence, possible errors, etc. The measurement of ontology uncertainty is difficult because of it depends from the usage context or assumptions. We will analyze sources and types of *Ontology-related uncertainty.*

2.3.1.1. Analysis and classification of ontology-related uncertainty.

According to its origins *ontology-related uncertainty* can be classified as*:*

- *Intra-ontology-related uncertainty;*
- *Inter-ontology-related uncertainty;*
- *External ontology-related uncertainty.*

Intra-ontology-related uncertainty is the uncertainty within the same ontology with respect to the specific structural components of ontology.

There are three levels intra-ontology uncertainty of knowledge in ontology:

- Concept Level;
- Property Level Uncertainty;
- Instance Level Uncertainty.

Concept Level *Uncertainty exists when there are concepts that have several different meanings. For example, Java can mean programming language, or coffee. This is the linguistic ambiguity.* Property Level Uncertainty is related to unclear domain, range, or ambiguous semantic properties.

Typical Instance Level Uncertainty problem arises when ontology contain information that an instance belongs to two disjoint classes. Example:

- Instance of Human: "Mis. P".
- Subclasses of Human : Men, Women.
- Disjoint Classes: Men, Women.
- "Mis. P" is inherited instance of both classes Men and Women, but these classes are Disjoint (contradiction).

Inter-ontology representation refers to the results of alignment of two or more ontologies (ontological networks). After alignment ontological components and relationships from different ontologies have become inter-related and semantic integration is achieved. This may lead to logical problems or contradictions. Inter-ontology-*related uncertainty* refers to the uncertainty in combination of two or more ontologies (as a result of ontology mapping). After the alignment some similar piece of knowledge can be stored in two or more places in the resulting ontology network. This is the redundancy problem in ontology mapping and it can lead to the inconsistency and lower the confidence level in ontology mapping. Uncertainty may exist for example when two or more mapped ontologies contain the same concept, having the same or similar name but its position is different in different ontologies. Uncertainty also may happen when two or more mapped ontologies contain uncertain concept, having several meanings and in different ontologies it has different meanings. This is called ambiguous kind of uncertainty.

External ontology-related *uncertainty* refers to every types of uncertainty that comes from the usage of external ontologies. Usage of external ontologies includes its inter-ontology uncertainties, and also can lead to additional inter-ontology ambiguities if they are aligned to internal ontologies.

2.3.1.2. Ontology-based modeling of knowledge - related uncertainty

Knowledge – related uncertainty occurs in some domains, where real world knowledge is inaccurate, imprecise or vague. Incomplete knowledge also is a source of uncertainty.

Three main approaches are used for modeling uncertainty using Ontological models (Figure 3):

- Fuzzy approach [4];
- Probabilistic theories;
- Dempster-Shafer Approaches.

Fuzzy uncertainty is when it is difficult to make clear cut boundaries between some concepts of a domain [5]. Classical knowledge models based on crisp logic are not capable of handling fuzzy knowledge. Fuzzy models were proposed to tackle such problems. Fuzzy models are mathematical tool for representing vague or imprecise information.

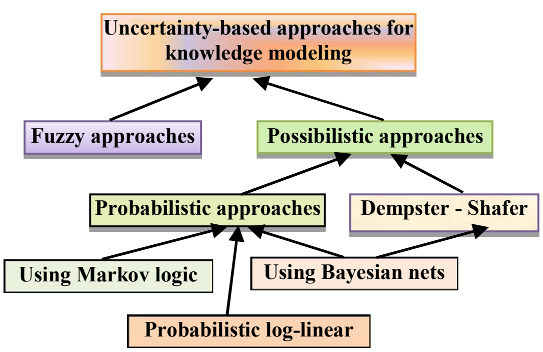

Figure 3. Classification of uncertainty-based approaches for knowledge modeling

Fuzzy models usually use fuzzy sets. They use gradual assessment of truth about vague information and fuzzy rules to handle the uncertainty of the Learner learning Styles prediction [6].

Probabilistic approach is based on probabilistic theory. It is the most frequently used mathematical theory dealing with uncertainty. Probabilistic theory provides a formal calculus for rational degrees of belief.

Probability theory is the most frequently used mathematical and logical approach for modeling and handling uncertainty in ontologies. The main idea of probabilistic ontologies is to model and handle uncertainty by adding a probabilistic interpretation to the constraints forming the ontology, and adapt reasoning methods to handle these probabilities. Several probabilistic ontology languages have been proposed in recent researches, as PR-OWL and Dynamic Bayesian Ontology Languages [7]. Systems and reasoners for reasoning with probabilistic OWL also have been proposed [8]. Probabilistic extensions to Description Logics (DL) are an alternative to Bayesian approaches. Some of them use OWL axiom annotations to associate probability intervals with uncertain OWL axioms.

Dempster–Shafer theory [9] of evidence or belief functions is a generalization of the probability theory. A hypothesis Beliefs are calculated in this theory as the sum of the masses of all sets it encloses. It allows combining evidence from different sources and calculating the degree of belief (represented by a belief function) that takes into account all the available evidence. This theory is the most useful for inconsistency handling in OWL ontologies and ontology mapping ([2] and [10]). PR-OWL is an ontology that can be used as a framework for developing probabilistic ontologies that are expressive enough to represent even the most complex probabilistic models [11].

Log-linear description logics (LLDL) integrate description logics with probabilistic log-linear models. LLDL use the syntax of description logics and propose possibilities to assign real-valued weights to axioms [12].

2.3.2. Ontology mapping uncertainty

Ontology mapping is a process of finding alignments (or mappings) between concepts, properties, relations or instances of two ontologies. Ontology alignment is a set of mapping relations. An alignment between ontologies O_1 and O_2 can be defined as a set of correspondences between entities of these ontologies [13]. There are several definitions and representations of mapping relations. The correspondences (or links, or mappings) can be one – directional or bi-directional. The ontology entities can be mapped by hierarchical, part-of-whole or other semantic links. So, wrong mappings can result from incorrect relation types, incorrect directions or insufficient similarity of linked entities.

Important characteristics of the alignment are its consistency, completeness and correctness. By definition, an ontology or ontological network is inconsistent if it has no interpretation. Informally, the inconsistency can be a result of T-box problem (as the pretense of unsatisfable classes) or of A-box problem (the same instance belongs to two disjoint classes for example). A network of ontologies can be made as a result of integration of mapped ontologies. A network of ontologies consists of a finite set of ontologies and a set of alignments between these ontologies [14].

Ontology mapping increases ontology uncertainty by leading to the inconsistency of the resulting ontological network. The simple ontological network $O_1 \cup O_2 \cup M$, resulting from the integration of the input ontologies O_1 and O_2 via the alignment M may be inconsistent because of the wrong mapping relations, or because of the significant differences in knowledge models (as in Figure 4), expressed by O_1 and O_2. Reasoning techniques are needed to detect and repair such inconsistencies.

Widely used statistical measures for alignment quality (as precision, recall or f-measure) have only statistical importance and are not useful for finding semantic errors or for checking consistency of the integrated ontology network. Reasoning-sensitive applications need consistent alignments and can work well only when the used ontology network is consistent. Real Matching systems in many cases generate incorrect or logically contradictory (incoherent) mappings. According to OAEI, for example up to 50% of all generated correspondences have to be removed until a coherent subset can be found. So, there are increasing needs in finding and repairing mappings that lead to inconsistency in ontology networks. Coherence and consistency are two main concepts that are used in evaluation of the quality of ontological networks from logical point of view.

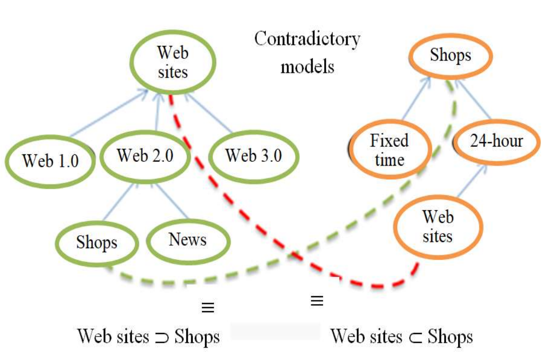

Figure 4. Example of significant differences in knowledge models

A network of ontologies is consistent if it has a model (as a merged ontology). Inconstancies occur in many cases in relation with disjointness statements. In some ontologies these statements are often missing. In this case a completely incorrect mapping can look as consistent.

To check logical correctness of mappings between ontologies, we have to check consistency of the resulting ontology network. Generally, an ontology network is a set of ontologies and sets of mappings between those ontologies. In the simplest case, when we map two ontologies, the resulting ontology network consists of these two ontologies and mappings between entities of these ontologies.

Logically correct mappings are semantic relations between ontologies that do not cause inconsistencies in resulting ontological system. Consistency can't guarantee the correctness of the mapping relation. Mappings can be logically correct, but wrong as semantic relations between ontological entities. This case occurs mainly when mapping small lightweight ontologies.

Main sources of complexity that make checking of the mapping correctness hard (especially when mappings are generated automatically) are:

- The correctness of mappings depends on the semantics of the ontologies that in many cases is only partially expressed explicitly;
- In some cases systems of mapped ontologies are very big or have high logical complexity and checking consistency is hard and slow.
- The correctness of some mappings in some cases can be subjective, or context-dependent. It for example can depend on the application tack, in which ontologies are used.
- The correctness of a given semantic mapping relation can have an influence on the previously accepted mappings, or on the possible future mappings;
- Manual mapping acceptance or rejections even by experts in some cases can be subjective, or context-dependent (including application-dependent).

Consistency and correctness of mappings are two different concepts and are important in different usage contexts. Mappings can be incorrect without leading to inconsistencies in ontologies. This type of incorrect mapping cannot be found by reasoning or debugging, but it can lead to semantically incorrect conclusions. In many cases mapping relations contain some uncertain

Journal of Theoretical and Applied Information Technology
31st December 2023. Vol.101. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

knowledge about relatedness of entities of different ontologies. This uncertainty may be related to possible errors in automated mappings, subjective view of knowledge experts or the specifics of the mapping context.

Mapping coherence is important mainly for the Data Transformation and Query Processing tacks. An incoherent mapping can lead to errors in data translation and query processing. Inconsistency is undesirable in the ontological networks when they are used in the applications that use logical reasoning. Inconsistency makes the ontological network unusable by applications for meaningful reasoning.

2.3.3. Classification of mapping problems

We can classify mapping problems according to several different criteria. According to the type of wrong mapping relations mapping problems are:

- Related to wrong hierarchical (is-a) relations;
- Related to incorrect equivalence relations;
- Related to incorrect part-of relations;
- Related to semantic relations having incorrect meaning.

According to the type of ontology entity causing mapping problems mapping problems can be categorized as T-box mapping problems and A-box mapping problems.

T-box mapping problems arise when:

- Detecting unsatisfable classes;
- Detecting contradictions in mapping properties (e.g. differences in domains or ranges of possibly mapped properties).

Solution of T-box mapping problems ensures coherence of integrated ontological networks.

A-box mapping problems are related to:

- Detecting inconsistency of Assertions about individuals, e.g., an individual is asserted to belong to two classes that are mapped by equivalence relation to the corresponding disjoint classes in the other ontology.
- Detecting defects in Class Axioms Involving Nominals (individuals mentioned in owl:oneOf and owl:hasValue constructs)

Its solution ensures consistency of integrated ontological networks.

According to the effects of the uncertainty problematic alignments can be classified as:

- Incoherent;
- Inconsistent;
- Incoherent and Inconsistent
- Incorrect;

2.3.4. Managing Model - related uncertainty.

Model - related uncertainty can be decreased by increasing the ontology quality. The first step for improving ontology is diagnosis of problems, causing uncertainty. There are three main ways for diagnosis of model-related problems in ontology:

- Ontology evaluation;
- Ontology debugging;
- Reasoning with ontologies.

2.3.4.1. Ontology evaluation

A universal goal of ontology evaluation is to find ways for decreasing in some aspect ontology uncertainty. The evaluation gives information about how to improve ontology. Evaluation can be performed manually (by experts) or using some software tools or algorithms.

As ontologies are complex objects, usable in many different contexts, many ontology quality criteria can be defined and ontologies can be evaluated in various aspects. Most frequently used evaluation dimensions are [15]:

- Accuracy;
- Adaptability;
- Completeness;
- Computational efficiency;
- Conciseness;
- Consistency;
- Organizational fitness;
- Vocabulary;
- Syntax;
- Structure;
- Semantics;
- Representation;
- Context dependence;
- Mappablity to upper level or other ontologies
- reusability for wider purposes;
- Coherence;
- Clarity.

Ontologies can be evaluated in several different levels:

- Within some context (context-based ontology evaluation);
- Within an application (application based ontology evaluation);
- In the context of an application and a task.

Evaluation methods describe evaluation procedures or specify the expected results of the procedures for extracting information about ontology during evaluation

Traditional ontology evaluation methods can be classified in four main categories [5]:

- Gold Standard-based;
- Corpus-based (Data-driven);
- Task-based (Application);
- Criteria based.

Some new ontology evaluation methods are:

- Schema validation;
- Pattern discovery using SPARQL;
- Normalization;
- Metric stability;
- Representational misfit;
- Unit testing.

According to the main evaluation goals Evaluating Domain Ontologies process can be classified as [16]:

- Error Checking;
- Domain/Task Fit;
- Metric Based evaluation (precision, recall, F-measure);
- Evaluation for placing into Ontology Libraries (BioPortal, COLORE Linked Open Vocabularies, OntoHub, ROMULUS).

Errors can be classified as syntactic and semantic. Examples of syntactic errors are: Using different naming criteria in the ontology, missing inverse relationships, using a recursive definition). Examples of Semantic errors are Merging different concepts in the same class Semantic errors Missing equivalent properties; Missing disjointness relationships; Creating synonyms as new classes; Swapping intersection and union.

Latter we will discuss which evaluation criteria, methods and levels can be useful for better learning or tutoring. Reasoning capabilities are embedded within the ontology and can be executed by starting general purpose reasoning engines such as Pellet (https://github.com/stardog-union/pellet), RacerPro (https://franz.com/agraph/racer/), HermiT (http://www.hermit-reasoner.com/). During ontology development or ontology visualization in integrated development environments (such as Protégé) reasoners can be used for checking logical correctness of the ontology elements.

2.3.4.2. Ontology debugging

Logically incorrect elements of ontologies can be detected by reasoning and tracing logical consequences or by Debugging ontologies. All these approaches are tightly related to the underlined logic of the mapped ontologies and reasoning capabilities of used reasoners or debuggers. Main goal of ontology debugging is to detect incorrect logical descriptions and to explain causes of inconsistency of an ontology or unsatisfablity of its classes.

There are two main fault localization methods:

- Glass-box methods;
- Black-box methods;

Glass-box methods use modifications of general-purpose description logic reasoners for faster computation of diagnoses. Black-box approaches do not use description logic reasoning algorithms, implemented in reasoners. They use reasoners to check if some set of axioms is consistent and/or coherent. Glass-box approaches have better performance in comparison to black-box ones.

Reasoners' main goal is to derive information from a knowledge base. Reasoners can detect inconsistent ontologies but are not optimized or specialized for diagnosis and resolution of the bugs. Interactive ontology debuggers allow iteratively stating queries in the form of axioms or in the form of the questions. Interactive debuggers also provide a repair interface to help in correction of the localized bugs.

Model - related uncertainty should be detected and eliminated, reduced or managed. This is made by using of reasoners, ontology debugging or ontology evaluation. We will discuss later how some of these activities can benefit learning and tutoring.

3. RELATED WORK

There is some research about the usage of ontologies directly in the learning process. Quality of visualization tools is very important as graphical representation of relationships between entities is very useful for rapid knowledge acquisition. Research results show that ontological models are useful for knowledge understanding, but they cannot be sufficient for finding solutions of problems, related to fuzzy, contradictory, erroneous or unclear knowledge. We could not find any research on direct use of uncertainty of ontology mapping in e-learning process. Similarity metrics calculated for mapped elements during the mapping process can be seen as statistical information about the level of certainty of proposed mappings. Some of the resource recommender systems in e-learning use ontology mapping and calculation of various similarity metrics [17]. In this sense, recommendation systems, using metric-based ontology mapping can explicitly show some level of uncertainty to learners and can be discussed as a related works. In such systems ontology mapping uncertainty can have important role for recommendation of external resources, and in such a way influence learning. Intelligent tutoring systems [18] also can use ontology mapping and its correctness is important for conducting the tutoring process. Short analysis of the approaches for modeling ontology uncertainty and the ways for detecting inconsistent mappings in e-learning context is proposed [19]. Almost all of them report by importance of ontology uncertainty in e-learning, but not propose ways for its direct usage by teachers or learners. A Framework of recommendation system for teachers and designers, that recommends MOOCs according to their profiles Linked Data from OLDC, ontologies and their mappings is proposed in [20]. Concept-based structural and semantic similarity measures have been used.

So, the focus of these researches is slightly different from ours. Main goal of them is rather to find ways for increasing the quality of ontologies or automatically proposed mappings than using ontology or ontology mapping uncertainty to increase the quality of learning. Our main idea is to find visual tools and ways for interactive ontology evaluation, evolution and/or mapping that can support visualization of knowledge models and stimulate learner's cognitive activities. We will analyze existing ontology development, evaluation and mapping tools and environments and search ones, suitable for our goal.

4. INTERACTIVE ONTOLOGY AND ONTOLOGY ALIGNMENT EVALUATION AND LEARNERS' SUCCESS.

The evaluation is the main activity, aimed to decrease ontology and ontology mapping uncertainty. Ontology and ontology mapping evaluation can be attractive, interesting and engaged tutoring activities for some type learners. Involving learners in such activities can increase both comprehension of the tutoring content and learners satisfaction. It also can lead to more active searching and use of additional learning resources that also will increase learner's success. Teachers and content developers also can benefit from ontology evaluation. During evaluation they can take a big picture of the learning content, understand important relations between learning objects, view at a glance possible ambiguity problems that can arise during tutoring and learning.

So, thinking about uncertainty will give many benefits both for learners and teachers. On the other hand, ontology evaluation requires specific knowledge and skills and in many cases is difficult even for knowledge management experts. So, it is important to find ways and tools for simplifying the otology evaluation process and representing them in more friendly and understandable way for non-professionals in this area. Interactive ontology evaluation, supported by sophisticated evaluation tools on the background is the most encouraging approach. It can involve learners and teachers in the evaluation of semantic models and stimulates rethinking of learning content and adequacy of learning objects to the tutoring goals in natural way.

4.1. Ontology Evaluation and Friendly for Non-Professionals Tools

Two main approaches of ontology evaluation were discussed in the literature: "glass box" "black box" evaluation. "Black box" or "task-based" evaluation is employed when ontology is tightly integrated into an application. In this context the evaluation measures the ontology's overall performance on a specific task. Teachers can perform black box evaluation estimating ontology quality during e-learning content retrieval tack or learning resource recommendation tack during personalized learning and tutoring.

"Glass box" or "component" evaluation, examines ontology components, evaluating its individual characteristics. "Component" evaluation is the most useful in learning (for learners) and in resource development (for tutors or resource developers). Criteria – based evaluation means that ontology is evaluated according to previously specified criteria. Criteria – based evaluation is most frequently glass- box evaluation. It is mainly directed for finding some type errors or pitfalls in ontologies and is related to discussing concrete pieces of knowledge. These evaluation approaches also can be useful during learning. Metrics and statistics-based evaluation are less informative for specific knowledge modeling problems and are less useful for learners. Some of these evaluation approaches can be used by teachers and domain ontology developers to estimate the usefulness of external ontologies or usability of freely available domain ontologies.

There are only a few tools, developed for ontology evaluation. Only eight tools are found and compared in [21]. Most of them are intended for knowledge engineers and are difficult for use by non-professionals. OntoVal [22] is a ontology evaluation tool for domain specialists. OntoKeeper [23] is a web-based ontology evaluation tool for ontology developers that can calculate important metrics and statistics for ontology quality scoring.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Most of the metrics are difficult to be understood by non-expert users, as teachers or learners. Ontology metrics and statistics are not useful for learners to understand the learning domain knowledge. The improvement of the ontology quality is the main purpose of most of the ontology evaluation tools. Every ontology evaluation tools has focused on a specific area (topic, level or method) in ontology evaluation and no one is related to the education.

Ontology evaluation by students should be performed in collaboration with teachers, and easy-to use communication interfaces should be developed to this purpose.

Reasoning engines, as Pellet, or RacerPro also can be used for ontology evaluation, but they can detect only a few types logical errors. Reasoners are intended mainly for ontologydevelopers, its interfaces are not suitable for learners.

Reasoning engines are easy to use by higher education students in knowledge modeling courses, as most of them are integrated in ontology development environments as Protégé, or NeOn toolkit. All the problems, reported by reasoners are very interesting and useful for deep understanding of the learning content. Reasoning engines have restricted evaluation capabilities, as they can find only logical errors and can't be used for detection of semantic modeling errors.

Ontology Debuggers help in discovery and identification of axioms that are responsible for the inconsistency or incoherency in ontologies. These tools are very useful for ontology developers and are directly used by professionals in semantic modeling. They can be used in the background in interactive ontology evaluation environments for finding and reporting logical errors and in such a way can stimulate learners to rethink some definitions, statements or relationships in the learning domain. Most of debuggers were developed as standardized elements of component – based architectures and can be easily implemented in other ontology development or evaluation frameworks. OntoDebug [24] for example is a plug-in for the popular open-source ontology development environment Protégé It implements an interactive approach to ontology debugging.

4.2. Ontology Alignment Evaluation and Mapping Problems

Ontology mapping evaluation is the process of estimating ontology mapping algorithms. Reference relationship based approaches evaluate the matching algorithms by applying them to test ontologies and comparing the results with some reference mappings. Precision recall and F-measure are statistical measures, coming from information retrieval and used to estimate degree of correctness and completeness of mapping results. Other important semantic measure is incoherence measure. It is closely – related to the reasoning with mappings and estimates relative number of incoherent concepts, that unsatisfablity is a result from the proposed mappings. Measuring inconsistency degree of an ontology w.r.t. a model, atomic individual assertions divided by the amount of all possible atomic individual assertions of O. The inconsistency value is in [0;1]. Both incoherence and inconsistency measures give some quantified estimation of the mapping problems, but are not very useful for the concrete solutions. They are mainly useful in comparing of the degree of coherence or consistency problems.

The Ontology Alignment Evaluation Initiative (http://oaei.ontologymatching.org/) is web-based ontology mapping evaluation approach, aiming to assess strengths and weaknesses of ontology alignment algorithms and systems. It proposes tools and datasets for testing and comparison of developed mapping systems or algorithms. All the tools are only aimed to evaluate new mapping tools and algorithms, and only generate evaluation results without proposing any possibilities for interactive participation in the evaluation process. So, they are not suitable for any learning goals.

5. FUNCTIONAL MODEL OF INTERACTIVE ONTOLOGY AND ONTOLOGY ALIGNMENT EVALUATION FRAMEWORK, ENCOURAGING USAGE OF UNCERTAINTY FOR E-LEARNING PURPOSES

Querying Scopus and using Scopus analytics we concluded that ontologies are now widely used in almost all scientific and application domains (see Figure 5). So, specialists in almost all domains should have some knowledge about ontological modeling of knowledge and many branches of higher education should include ontology – related courses. And easy-to use interfaces for ontology development, visualization and evaluation for students attending such courses and non-professionals in knowledge engineering should be proposed.

Our analysis of knowledge uncertainty and uncertainty in ontologies leads to the conclusion that finding logical errors, pitfalls and other types of uncertainty reveals important specifics of domain knowledge and its ontological models. These

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

properties can be useful during learning. Unfortunately, we do not found high quality tools that can support usage of ontology uncertainty during learning. We will first discuss requirements to such tools, and then propose a model of interactive ontology and ontology alignment, suitable for e-learning purposes.

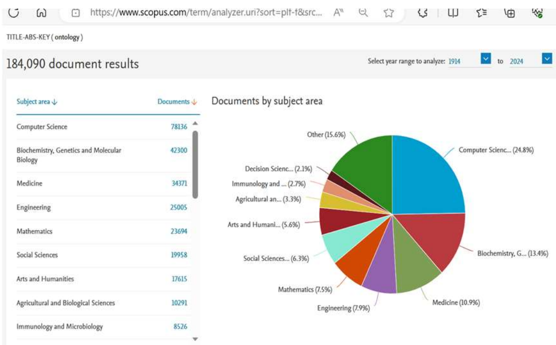

Figure 5. Distribution of the number of documents, containing "ontology" in the abstract, title or keywords by subject areas.

5.1. Requirements to the Model

We briefly specify main requirements, that will make ontology uncertainty and its' decreasing by ontology evaluation useful for learners or teachers in e-learning environments. Main requirements are:

- Easy to use for non-professionals in knowledge modeling. Different interfaces are needed for teachers and learners;
- Graphical ontology development capabilities (mainly for teachers);
- Graphical ontology evaluation capabilities;
- Ontology evaluation capabilities, adapted to the e-learning purpose;
- Systematized storing of the developed and evaluated ontologies;
- Searching, comparison and evaluation of external ontologies;
- Supporting ontology-based tacks in personalized learning (both for tack-based evaluation and usage).

5.2. Description of the Proposed Model

The recently published findings about uncertainty in real domains and ontological models and ideas for its usage in e-learning context are summarized through proposed model, outlining the main functions that should provide educational platforms with integrated tools and strategies for uncertainty management and usage for better learning. The functional model is layered and each layer presents different aspect of uncertainty management and usage (Figure 6). This model can be used for development of components that can be integrated in e-learning environments. Main purpose of components, based on the proposed model is interactive ontology and ontology alignment evaluation in the e-learning context. The functional model consists of five interconnected layers (see Figure 6):

- User interface layer;
- Layer, supporting ontology usage;
- Ontology evaluation algorithms and tools layer;
- Ontology modeling, mapping layer;
- Data, resources and ontology storing layer;

User interface layer includes Graphical User Interface (GUI). GUI proposes different interfaces for learners and teachers, and different customizable and adaptable interfaces for learners, having different knowledge management skills. Hierarchical ontology-based structures for example can be useful for learners, having some knowledge about ontologies, concept map oriented structures can be useful for visual learners, and other learners can prefer interactive voice or text message – based communication. Web technologies as JavaScript-based ones combined with intelligent technologies can be used for development of these interfaces**.**

Layer, supporting ontology usage contains tools and algorithms for analysis of ontologies and recommendations about its potential usage. These tools can use metrics and analytics, generated from ontology evaluation tools to compare requirements to ontologies for supporting various tacks, including resource recommendation, personalization, ontology development, or direct use in learning and tutoring process.

Ontology evaluation methods and tools layer

We first classify ontology evaluation tools and algorithms in two main categories: useful mainly for direct usage by learners, and intended mainly for teachers.

We carefully analyze the work [25] and on this ground systematize ontology evaluation techniques, useful mainly for learners in two main categories: For overall understanding of the learning domain and for understanding of specific relations or facts.

Understanding of specific relations or facts can be increased by finding and discussing errors, related to:

- Polysemy or synonymy, related to class names;
- Wrong type relations (is – a; part of, semantic);
- Missing connections between elements;

- Wrong relation type (object property, datatype property);
- Missing or wrong Domain or Range in Properties;
- Disjointness and instance problems;
- Missing Equivalent Properties;
- Wrong or missing relation property (inverse, functional, Symmetric, Transitive)

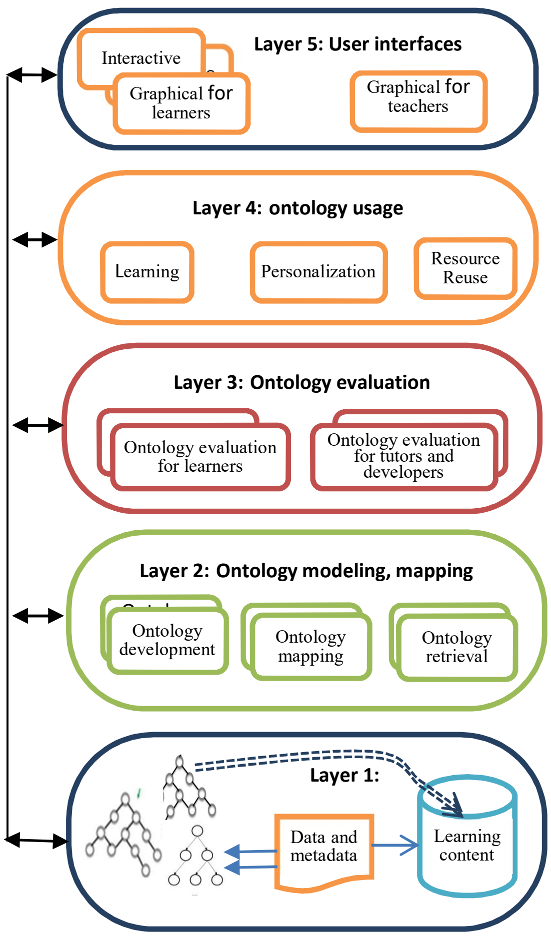

Figure 6. The functional ontology and ontology alignment evaluation model

Overall understanding of the learning domain can be increased after visualization of the hierarchical structure, represented in the ontology and attempts of the learners to estimate how close the ontology is to the learning content.

Ontology modeling and mapping layer

Every e-learning system needs from continuous actualization of its content and the corresponding semantic (ontological description). So, tools for ontology development (including searching of available ontologies, ontology learning, manual ontology development and actualization) and ontology mapping are needed for supporting actual ontological models. Easy-to use ontology development and mapping tools, having graphical interface should be implemented, as these tools will be used mainly by non-professionals in knowledge modeling area.

Data and ontology storing layer

Ontologies, used in e-learning environment are stored in this layer. All these ontologies should be described with metadata about its usability properties for successful use. Domain ontologies describe e-learning content, stored also in this layer. These possibly mapped ontologies can be used by higher layer components for supporting various tacks.

Strategies and tools for searching semantic problems in metadata, learning content, or possibilities of its interpretation are implemented in layer 1 or layer 3 and work in the background during the learning process.

Online independent of any ontology development platform and available online tools as OOPS! (Ontology Pitfall Scanner!, https://oops.linkeddata.es/) can be also integrated and used to detect ontology building errors or logical problems in ontologies and targeted learners, teachers or e-learning content developers unfamiliar with description logics and ontology implementation languages about problems in metadata, learning content, or possibilities of its interpretation.

5.3. Evaluation

We performed some initial evaluation of the proposed model by development of prototype component and testing it in several typical working scenarios.

We used JavaScript programming language, HTML and CSS for development of flexible and adaptable graphical interfaces. JavaScript is the leading scripting language widely used for client-side programming and it is essential for the development of modern web applications.

We used Protégé ontology development environment for ontology development and built-in reasoners as Pellet and HermiT for finding logical inconsistencies. We also used OntoDebug (a free and open-source plugin for Protégé 5, http://isbi.aau.at/ontodebug/) for ontology debugging and Prompt protégé plugin (https://github.com/protegeproject/ protege-plugin-examples/blob/master/README.md) for ontology mapping and merging. A new Protege plugin

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

RepOSE-CTab for extending ontologies [26], which guides users through the addition of new concepts, instances and axioms is also very useful, as it can lead learners or teachers in finding related terms (concepts, instances, properties, etc.) .

Graphical visualization of concepts and relations in ontologies makes them more understandable than in the text form. A multilingual ontology visualization plug-in MLGrafViz [27] is very useful, as it has sufficient graphical capabilities for controlled visualization of ontologies in different natural languages (multilingual ontologies). This is very important for Bulgarian learners, as most of the developed ontologies use English language terminology, but all the tutoring content is the most usable in Bulgarian. In the same time, it is important for Bulgarian learners to know and use scientific terminology in two, three or more languages.

The usefulness of our prototype system was evaluated during the course of Social and Semantic Web Technologies at Technical University of Sofia, College of Energy and electronics. 32 students attending the course were participated in development and evaluation of domain ontology, representing course terminology. We have carefully tracked student's learning in the context of development, evolution and evaluation process.

We currently are working on implementation of our prototype system in Moodle.

During testing of our prototype system we also have established a methodology for dealing with uncertainty in ontology and ontology alignment in e-learning environments.

5.4. Methodology for Dealing with Uncertainty in Ontology and Ontology Alignment in E-Learning Environments.

Uncertainty in real domains should be presented in adequate way to different learners in every course. Usage and presentation if uncertainty depends from learning goals and learners' specifics, as his knowledge, interests, logical thinking level, performance, etc. Ontologies are good tool both for explicit representation of uncertainty and for raising questions and provoking discussions about uncertain knowledge. Main steps for using ontologies in clarification of domain uncertainty problems are as follow:

- Ontology delivery or development;
- Ontology visualization or evaluation;
- Ontology usage for learning content retrieval, curriculum map generation, or test generation;
- Ontology mapping;
- Ontology mapping evaluation;
- Usage of ontology network for learning content retrieval, curriculum map generation, or test generation.

Ontology development requires excellent knowledge of the modeled subject area and knowledge modeling capabilities. Ontologies are explicit specification of shared conceptualization of the domains. So, they are important tools for explicit and clear specification of the exact learning content that will be shared between learners and teachers during the course. Only a few learners can independently develop good ontologies, but ontology development in collaboration with teachers can be very useful. As ontology is explicit specification of shared conceptualization, learners should clearly and explicitly present his knowledge and discuss learning domain knowledge with colleagues and the teacher. Discussing polysemous elements, homonymy, various types of relations and concepts' definition is of great importance for successful learning.

Linked Data cloud (LDC) proposes free ontologies that can be used for enriching the published in the web data or local data with semantics and help their integration. LDC contains free ontologies in many scientific domains, that can be used as initial versions in ontology development process. Evaluating the relatedness and closeness of available ontologies and course content is engaging and interesting tack and can help both learners and teachers in deeply understanding the domain. It can be effectively performed by ontology visualization.

Ontology evaluation is the main way for minimizing uncertainty in knowledge representation. Evaluating domain ontologies is very complex and context-dependent problem. In the e-learning context evaluation usually is tightly-related to the goals of ontology usage. So, it should be performed in collaboration with teachers, or by teachers. Learners are other possible participants in ontology evaluation. As we have mentioned above, learning and ontology evaluation can benefit each-other.

Ontology evaluation approaches were classified as syntactic and semantic [28]. Syntactic ontology quality evaluation approaches evaluate structural elements, as metrics (including precision or recall) and also search common pitfalls. Semantic evaluation approaches mainly include semantic validity of concepts and relationships and are made by experts. Syntactic evaluation can gives quick overall view on the ontology, whereas semantic evaluation can be a basis for discussing concrete concepts or relations, related to the learning content.

Ontology usage for learning content retrieval in personalized e-learning systems usually can lead to some uncertainty, related to the adequacy of the retrieved resources to the sent queries. Semantically correct and unambiguous ontological models can be good ground for expectation of useful returned content. Automatically-generated curriculum maps should be evaluated by learners or teachers. Interesting questions about the learning content can arise during evaluation and its answers can act as a good interactive initial presentation of the learning content. Logical inconsistencies can be automatically detected and then displayed to the learners.

Ontology mapping can be done interactive using visual graphical tools. Automated mapping algorithms can work in the background and suggest similar thinks. Mapping process requires comparison of elements of two ontologies and in such a way can stimulate learning, recalling and logical thinking. Most of mapping relations have some uncertainty level, as mapped elements in two different ontologies rarely are identical. So, acceptance of mapping proposals can be done after ensuring acceptable certainty level.

Some global LDC ontologies can be used in the process of ontology mapping. Some logical or terminological problems can be arisen during such mappings and learners can be informed about them by usage of learner-friendly graphical interface. Learners participation in solution of such problems stimulate them to participate in solving interesting problems by searching additional information, discussions with colleagues and teachers, rethinking, and so on. In this way ontology mapping can be used to stimulate active participation of learners, and enhance his thinking and problem solving skills.

Ontology mapping evaluation is the most complex evaluation procedure, as logical problems in systems of mapped ontologies can arise even after correct mappings. They can results from differences in modeling the same thinks in the mapped ontologies. Interactive ontology debugging [29] can be useful for solving logical problems in ontology networks.

6. SEMANTIC MODELS WITH UNCERTAINTY FOR IMPROVING LEARNING – DISCUSSION AND USE CASES

In our days artifical intelligence is more and more widely used for improving learning. Knowledge representation is a sub-branch of Artifical Intelligence, concerned with understanding, reasoning, and interpreting data/information [30]. All these activities are also in the base of successful learning. So, all the research on semantic modeling and management is closely related to e-learning and most of the results can be used to improve learning quality.

Domain ontologies are one of the most frequently-used type ontologies in personalized e-learning systems. These ontologies are machine – processable and human-readable models of the tutoring knowledge. Every bugs, logical problems, inaccuracy or incompleteness can be used during learning for showing and discussing possible learning problems, related to understanding of the learning content. Ontology evaluation and debugging tools can be used for automated diagnosis of knowledge representation problems in automatically learned or freely available ontologies, as well as in learner or teacher-developed ones. Many of logical problems are closely- related to the difficult for learning and understanding peaces of knowledge and its localization is very important for learning and organization of tutoring.

So, detection of Ontology uncertainty problems can be used for improving learning both by teachers (during resource development and organization of tutoring) and by learners during learning.

6.1. Ontology Uncertainty and Learning

Finding ontology uncertainty problems by teachers can:

- Give teachers ideas about interesting test questions;
- Give teachers ideas about deeper explanations of the learning content;
- Rice interesting questions during tutoring;
- Give teachers ideas for development of new learning content;
- Help in evaluation of the learner’s success;

Finding ontology uncertainty problems by learners can:

- Show explicitly important relationships and components of the learning content;
- Rice interesting questions during learning;
- Stimulate logical thinking;

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

- Stimulate deep understanding of the learning content.

Ontologies can be very complex knowledge models and grand variety evaluation techniques and quality characteristics have been used. Only some of them can be useful during learning. Important for e-learning ontology evaluation characteristics are:

- Internal consistency(inconsistent elements);
- External inconsistency(resulting from mapping);
- Misused disjointness;
- Omitted disjointness;
- Low precision;
- Inappropriate Inheritance;
- Explicit redundancies;
- Inconsistent axioms;
- Implicit redundancies. A is a subclass of B, B is a subclass of C and A is a subclass of C. When considering these definitions, “A is a subclass of C” is a definition that can be inferred from the first two definitions.
- Identical formal definition of some classes: this occurs when two or more classes exist in ontology with the same formal definition, however, with different class names (synonymy).
- Completeness from a course content. Metric is not so important, as finding and filling gaps (icompletness);
- Correct Object property characteristics (functional, inverse-functional, Transitive, Symmetric, Asymmetric, And Reflexive.

6.2. Ontology Mapping Uncertainty and Learning.

Reasoning-based approaches for discovering logical inconsistencies caused by erroneous mappings (or mapping of contradictory models) and repairing erroneous alignments can use one or more of the following reasoning models:

- Description Logic reasoning [31], [32];
- Rule-based logical models for reasoning with mappings;
- Probabilistic models for reasoning with mappings;
- Using Ontology Design Patterns (ODPs) [33];
- Graph-based approach [34]
- Interactive, involving the user, visualization;

Reasoning-based approaches can be very useful in learning, as they are glass-box technique and all the reasoning steps can be easily displayed in his order. This sequence of conclusions can be very helpful in domain understanding and development of logical thinking skills. Reasoning with mappings helps in logical problem detection [19]. A pattern-based reasoning and classical glass-box approaches can be used. DL reasoners can detect unsatisfable concepts, in ontology networks, but determining what mapping exactly causes it can be more difficult. Reasoning procedures, leading to contradictions can be visualized. Following these procedures, learners can participate in ontology mapping evaluation. Such evaluation can help learners in understanding domain knowledge and at the same time, learners can help in finding causes, leading to inconsistency of ontological networks.

6.3. Strategies for Usage of Ontology and Ontology Mapping Uncertainty. Use Cases

Strategies for usage of uncertainty by learners depend from the type of uncertainty and learning goals. There are two main sources of knowledge uncertainty according to the needed methods for uncertainty management: natural intra-domain uncertainty and uncertainty, caused by missing, wrong or deceptive knowledge. It is very important for learners to make clear distinction between the two types. Understanding sources of uncertainty and successful application of methods for working with uncertain knowledge by discussions and collaboration with experts are main strategies for managing first type uncertainty. Using information from several different sources and information integration is the main strategy for managing second type uncertainty. Ontological representation of knowledge is explicit, clear and easy for understanding. So, ontologies are important knowledge source for knowledge integration. Explicit representation of uncertainty levels helps in its understanding and stimulates critical thinking during learning.

General strategies for usage of ontology and ontology mapping uncertainty by teachers are mainly related to organization of personalized learning and development of personalized learning content. Teachers can use ontological models that make domain uncertainty explicit (as fuzzy or probabilistic models), or use classical ontologies, containing incomplete, vague, or even contradictory elements to provoke student’s mental activity. The best approach for modeling mapping uncertainty in e-learning domain depends from the tutoring domain. Fuzzy approach is better for example for medical knowledge modeling, and probabilistic approach should be preferable for modeling knowledge in probabilistic branches of

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mathematics. Teachers should pay special attention to the fuzzy or probabilistic properties of knowledge in the tutoring domain. The understanding of knowledge uncertainty and application of domain-dependent approaches for managing the knowledge uncertainty is extremely important in higher education. Ontological models are very useful for explicit modeling of uncertainty and showing probabilistic or fuzzy nature of knowledge.

Interesting observation is that the most of the research on ontologies, representing uncertain knowledge is classified as computer science and mathematics research, where only a small piece of knowledge can be classified as uncertain. At the same time uncertainty is not discussed in the most of the huge amount of research on ontologies in medicine and biology (see Scopus analytics on Figure 7, Figure 8). This leads to the conclusion, that most of the research on uncertainty in ontologies is not intended for practical modeling uncertain knowledge, but for theoretical research on possibilities for ontological modeling of uncertain knowledge. So, the application of the strategy of making uncertainty explicit by usage of uncertain models is very restricted because of the low availability of such ontologies in almost all practical domains.

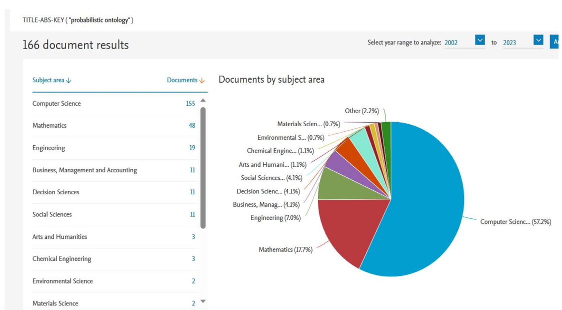

Figure7. Inter domain distribution of the research on probabilistic ontologies in Scopus

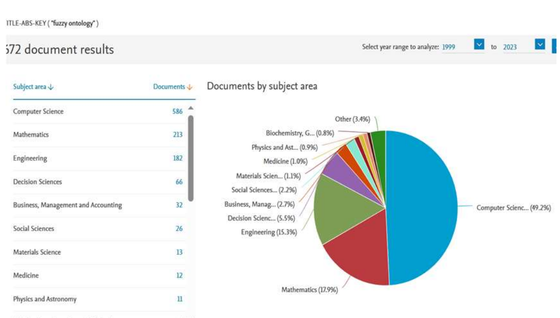

Figure 8. Inter domain distribution of the research on fuzzy ontologies in Scopus

Our main strategy is ontology evolution – based strategy. It includes the use incomplete domain ontologies to provoke students mental and doing activity. We developed small ontological models of learning object's content and ask students to add newly learned concepts or relations to these models. This is the evolution step of the ontology development process. Then student were asked to check ontology consistency by reasoners. After correction of logical errors every student asked his colleague to evaluate extended ontology and discussions about needed corrections were performed in groups. Finally the teacher evaluated ontologies, extended by students and errors or incompleteness were discussed in the group.

After development of ontological models of two related learning objects students were asked to align these ontologies and evaluate proposed alignments, using similar strategy.

Other ontology uncertainty-based tutoring strategy is usage of fuzzy or probabilistic ontological models for modeling and explicit representation of uncertainty in real domains, as medicine or history, where uncertain knowledge is widely used.

Uncertainty in ontology mapping can also be used when teachers evaluate ontologically described learning resources in different courses.

Use case 1: Usage of probabilistic or fuzzy semantic models in mathematical courses on probability or fuzzy logic.

Real world examples and graphical representation of mathematical domain terminology (including concepts, relationships, and strict mathematical definitions) can be very useful for understanding complex mathematical theories and possibilities of its practical application.

The medicine is one of typical domains where uncertainty is commonly found. There are some uncertainty level in almost all medical diagnoses and cures, and this is good ground for demonstrating practical application of mathematical theories (as probability and statistics theories), dealing with uncertainty in practice. Medical examples are very useful for discussing application of probabilistic or fuzzy mathematical theories in real application domains. Shared ontological conceptualization can decrease vagueness and uncertainty, related to context-dependency or differences in experts' conceptualization in medical domain. Usage of fuzzy or probabilistic models in artificial intelligence-based reasoning systems for disease diagnosis and cure in medicine can show strengths and practical applicability of related mathematical theories and in such a way increase student' s motivation for learning.

Ontological models of mathematical domain terminology are very useful for understanding important relationships and memorizing complex definitions. These graphical representations of mathematical domain knowledge can make easier the application of axioms or theorems in mathematical proofs or solving complex problems. There are well-developed and freely available ontologies, modeling mathematical domain knowledge, including for branches of mathematical theories about uncertain knowledge. The ProbOnto ontology (https://www.ebi.ac.uk/ols/ontologies/probonto) is a freely available ontology-based knowledge base of probability distributions. It is very useful in probability courses both for learners and teachers, as it features distributions with their clear and explicit defining functions, characteristics, relationships and reparameterization formulas. Visualization of all the relationships between distributions and its properties by usage of good ontology visualization tools is very helpful for understanding basics of the probability theory. [35] proposes good probabilistic ontology that can give clear view about the possibility for some things to be true. Learners can compare truth values of the different things and reason about its possible (or realistic) truth values.

Use case 2: usage of ontology uncertainty in Inquiry-based learning (IBL). IBL is an educational strategy including usage of scientific methods and practices for constructing knowledge, as formulating hypotheses and testing them by making observations or conducting experiments. This learning approach stimulates learner's active participation in learning, including discovering new causal relations, participation in discussions and experiments.

Inquiry-based learning engages students by making interesting connections through exploration and high-level questioning. Our strategy of usage of ontology uncertainty in inquiry learning includes assigning tacks, related to ontology evolution, evaluation ad ontology mapping evaluation to the advanced learners, understanding ontological models. Reasoning engines, ontology and ontology network evaluation tools report contradictions or inconsistencies, resulting from ontology mapping and teacher should ask questions about causes of these problems. In this way ontology mapping encourages students to engage in solving of problems, related to finding interesting learning content. It also helps to make explicit persistence of different viewpoints or contradictory information in many scientific domains and stimulate students in searching truth by discussions or logical thinking.

Five general phases of inquiry learning are identified in [36]: Orientation, Conceptualization (including Questioning and Hypothesis Generation), Investigation (including Exploration, Experimentation and Data Interpretation), Discussion (including communication and reflection) and Conclusion. Conceptualization is one of the main steps in almost all ontology development or evolution methodologies. Checking correctness of semantic models (ontology evaluation) also is based on some conceptualization and learners, seeking errors in ontology should first understand underlying conceptualization. When learner does not understand some ontology elements, he should solve some uncertainty problem. This stimulates him to explore some learning materials, or discuss vague elements with colleagues or teacher. Final conclusions lead to change or acceptance of some things in the ontology. So, main steps of ontology evaluation process are very similar to inquiry learning phases and consequently, ontology evaluation is good inquiry learning tack for students, familiar with ontologies.

Automatically generated mappings are good base for discussion. Good visualization tools [37], [38], [39] can be used for visualizing mappings, its correctness probability or raised questions, related to proposed mappings.

There are four levels of inquiry [40]: confirmation, structured, guided, and open. In confirmation inquiry uncertainty is a base for asking questions, participating in discussions and following solution procedures to verify a previously learned concepts or relations. For more advanced learners teacher can use structured inquiry by providing problems related to ontology evolution or mapping, as well as needed materials, and procedures for doing these tacks. The teacher also directs students to use reasoners or debuggers to find logical problems. When students guided some experience, inquiry approach will be sufficient (the teacher then can give only problems and materials, and the students work on ontologies and arising uncertainty in well-known environments). During ontology evolution or mapping many unexpected questions, related to manipulated knowledge models and uncertainty levels can arose. In such situations, the students generate problems, search materials, and solutions by themselves (this is the Open inquiry level).

Ontology mapping task proposes possibilities for deepening of knowledge and understanding of the subject and teachers should apply tutoring strategies, based on creation of mappings or evaluating alignments. Strategies for usage of ontology mapping in learning include visualization of the structure of mapped ontologies around the elements of mapping proposals and asking questions about structural or semantic similarity of components, used in the alignment, as well as its similarity according to the learner's knowledge. Strategies for usage of ontology mapping evaluation in learning include visualization of the structure of resulting ontology network around the elements of arisen logical conflicts and asking questions about the causes of contradictions. Learners should first determine if the conflicting elements really are related to the conflict, or it is caused by some of proposed alignments, or by contradictions in the models of mapped ontologies. In some cases it can be difficult to find the problem, but the searching process is very useful during learning.

So, solving ontology or ontology mapping uncertainty problems can be natural tack for inquiry learning on all its levels.

Use case 3: Application of ontology and ontology mapping uncertainty for personalization in higher education

Direct usage of ontologies by learners (including ontology evolution, ontology evaluation and ontology mapping) requires specific knowledge and skills. Only some learners mainly in higher education can successfully participated in ontology management tacks. So, these tacks can be seen a personalized tacks for specific groups of advanced learners. Only these learners can understand uncertainty problems, related to ontological models and ontology mapping, and its relation to modeling domain knowledge uncertainty.

For describing initial ontological model of main terminology, used in our Magister degree course "Object oriented programming", we used Protégé and methodology, described in [41]. Our initial model was not complete and was not full and strict description of tutoring content. We then make needed extensions and corrections and store the old version, new version and complete description of corrections. Then we propose the initial version to the students for evaluation. There were 29 students in our course. All the students did the examination test immediately after lection and its results were not satisfactory (average 34 points from 100 maximal, see table 1). The students were highly motivated to make preparation for example and then did the test again. I proposed as an additional exercise to evaluate the initial version of the ontology. Eight students in the group have attended Semantic web course in the past and performed this additional tack. During preparation time students, participated in ontology evaluation asked 12 questions about more strict explanation of some tutoring concepts. All the other students asked only two questions. Results of the two groups are shown in table 1. We have also used ontology evaluation tacks as tools for enhancing learning in other similar situations and can conclude, that evaluation of ontological models is interesting for some of students, leads to discussions on the t content, and increase both satisfaction and results from learning.

	First average scores	Second average scores	Number of asked questions
Group 1, 21 students	34	61	2
Group 2, 8 students	35	75	12

Table 1. Average test results

Ontology evolution strategy can include tacks for adding new classes, properties and axioms by learners after every lecture. Such strategy also can be used in intelligent tutoring systems for extraction of information about learner's knowledge, performance or attitude to the graphical knowledge modeling approach and collaborative learning by doing. Successful addition of new ontology elements or logical errors removal gives information about student's knowledge and skills. Based on this information, personalized learning content can be recommended or proposed in intelligent tutoring systems.

When there are no suitable resources in course content for some learners, ontology mapping can be used in the process of searching and selection of the needed resources from other ontologically-described courses, including from the Web. Well evaluated level of uncertainty in this mapping is important for finding and recommendation of good external learning content. We asked our students, familiar with ontology mapping to evaluate or enrich mappings between ontologies, described its current course and previously attended closely related ones, as well as ontologies, described related courses, found in the internet. Questions of type: "How close are the two similar concepts or relations in two ontologies?", or "How close are semantic descriptions of concepts and its textual description in learning content?" lead to interesting learning activities and are very useful for understanding of the learning content.

Use case 4: Usage of ontology uncertainty in tutoring Medicine

Uncertain knowledge is usual in medicine. Uncertainty is related to inaccurate knowledge, incorrect information, lost or missing information or conflicting information. The physician for example in some cases is not certain about the patient's diseases (the diagnosis has some degree of probability) during treatment. He searches for possible diseases based on the patient's symptoms and laboratory results and can evaluate several variants every with some possibility measure. And his belief can changed over the course of treatment as a result of new observations. The vague nature of medical information makes suitable usage of fuzzy set theory and fuzzy inference for knowledge representation and reasoning. So, fuzzy logic is widely used in medical field because of its ability to handle uncertainty and ambiguity of medical knowledge.

Fuzzy expert systems are widely used semantic models of medical domain knowledge. Fuzzy ontologies also can be used, but currently there are only a few researches in this field. These knowledge models can be very useful for deep understanding of uncertainty in medical domain by explicit representation of the medical domain uncertain knowledge.

Fuzzy expert systems use fuzzy inference engines based on fuzzy logic to deal with ambiguities and uncertainties associated with medical problems. Medical applications of fuzzy expert systems include medical diagnosis systems, medical consultation systems, and disease prediction systems. Expert systems in medical science [42] have not only practical value, but can be very useful for students to help in understanding specifics of medical knowledge. One of the strengths of expert systems, which make them good for learning, is its possibility to give explanation of the reasoning process. The visualization of reasoning procedures is one of the best strategies for understanding of the subject. Probabilistic and fuzzy knowledge models are very useful in modeling uncertain medical knowledge [43].

Leading students to determination of fuzziness of relations or attributes, the type of vagueness (combinatory or degree-vagueness), or its degree are good strategies for tutoring in medical domain by usage of knowledge models, working on uncertainty. For example, learners, participating in fuzzy ontology development should firstly be aware with vague properties of the domain knowledge, and development of fuzzy knowledge models in collaboration with teachers can be the next important step for deep understanding uncertain domains.

During evaluation of fuzzy medical ontologies interesting questions can be asked, related to:

- Correctness (are fuzzy elements convey a meaning which is indeed vague in medical domain or for application specifics);
- Accuracy (if the degrees of fuzzy elements approximate the vagueness in an inaccurate way);
- Completeness (are all the important vagueness of the domain has been represented within the ontology?);
- Consistency (it should not contain controversial information about the domain's vagueness or other contradictions);

Such questions can stimulate deep understanding of medical domain and promote learning.

In learning and scientific research, there are two main types of knowledge according to its sources: knowledge, written in documents and expert knowledge (knowledge of physicians, tutors or researchers, not explicitly written in learning objects). While document-written knowledge is widely accessible, expert knowledge can be implicit and can be gained only by connecting people (for example, by problem discussions and practices). In medicine expert knowledge is valuable part of all the knowledge. To increase the availability of expert knowledge and reduce semantic noise during knowledge transfer, creation of knowledge repositories is proposed in [44]. Knowledge repositories use semantics-based models to represent expert knowledge and make it accessible for learners by expressive visualization tools. Expert knowledge is highly context dependent. In many cases, there is some uncertainty in its interpretation and students should be aware of this type uncertainty.

7. CONCLUSION

Ontologies are more and more frequently used in modeling real world domains, because they provide reasoning capabilities and standardized vocabularies that humans and machines can use efficiently and effectively for knowledge management. Real domains contain uncertain knowledge, but classical ontological theories are based on the crisp logics and can't represent and handle the uncertainty. In this work we analyzed sources and types of uncertainty in real application domains and also uncertainty, related to ontological models and ontology mapping. We also discussed extensions of crisp logics for semantic modeling of uncertainty and possibilities of its usage to improve learning. Extended logics as fuzzy logic or probabilistic logic and ontological modeling, based on these logical formalisms are rarely used in practical ontological modeling, but its usage is rapidly growing. Types of the ontological models, dealing with uncertainty should correspond to the types of uncertainty in real domains and the same models should be used during learning. For example, models, based on fuzzy logic are most useful in medical domain modeling. It is also very important for medical students to understand and manage uncertain knowledge and fuzzy models can be very useful tools.

We propose a model of interactive ontology and ontology alignment evaluation environment, oriented to the usage of uncertainty for e-learning purposes. It integrates easy-to use ontology evaluation, evolution and mapping tools and proposes adaptive interfaces for learners and teachers to make ontology uncertainty management easy and useful for increasing learning quality. During searching mistakes and omissions in ontologies learners perform very useful and interesting activities. During evaluation learners can be involved in concept comparison, relation analysis, information integration and other complex learning activities, that are very useful for higher understanding of the learning content.

Ontology mapping, evaluation and evolution are very useful teaching-learning activities for some learners and some tutoring approaches (as inquiry learning and some branches of higher education) that can make learning more meaningful, interesting and conducive to higher-order thinking and active knowledge construction. Solving uncertainty problems, arising during these activities is natural way for increasing learning satisfaction, comprehension and achieving higher results, and also for collection information about learners in intelligent tutoring systems. We discuss and propose strategies for stimulating learners to reason on proposed mappings, as well as on arisen problems during ontology mapping, evolution and evaluation with mappings. Such rethinking of ontological models or alignments can significantly increase learning outcomes. Ontology uncertainty-related tacks are recommendable for advanced learners in higher education, which have some level of understanding of the ontological modeling. These tacks should be highly personalized according to knowledge and skills for every learner.

Ontology mapping and related uncertainty problems can be useful in solving knowledge and learning content heterogeneity and e-learning systems interoperability problems. It can be very useful for proposing additional resources during personalized learning, and also in supporting learning content reuse.

The proposed model is only theoretical ground, outlining ways and needed tools for involving students in ontology mapping and ontology evaluation process. Literature review showed that there are good ontology visualization, mapping, and debugging tools, but these tools are not integrated in easy-to use for learners intelligent environment, proposing useful support and guidance. Special visualization techniques which help learners in ontology perception and understanding are also needed. So, many efforts should be done to develop good environment, supporting effective use of uncertainty in ontological models directly in learning activities. Another limitation of the proposed model is its applicability only for learners, familiar with ontology development technologies. This is very restricted learner's auditory.

The paper's argument raises but does not try to answer of some interesting questions, as "What is the quality of the ontology and ontology mapping evaluation, performed by students?", "Can learner's participation in ontology development, evaluation, evolution or mapping tasks be useful for ontology development and maintenance?" and "How to find ways of easy and efficient checking of the correctness of learner-made evaluations?". Development of intelligent personalized ontology maintenance and visualization tools is another important research direction, not discussed in this work. The choice of approaches and tools for ontology visualization and navigation depends on the user knowledge and preferences and developing methods and tools for the convenient and informative visualization of ontologies is very important for its usefulness in learning.

Our future research directions are related to implementation of all the elements of our prototype system in Moodle. We will use all these tools during various tutoring courses in higher education and evaluate usefulness of usage of semantic models and uncertainty in different learning and tutoring contexts, having in mind main research questions, defined in our work.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

8. ACKNOWLEDGEMENTS

The author/s would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

[1] S. Rudolph, "Foundations of Description Logics". In *Reasoning Web: Semantic Technologies for the Web of Data, 7th International Summer School,* volume 6848 of Lecture Notes in Computer Science, 2011, pp. 76–136. Springer

[2] R. Peñaloza, "Introduction to probabilistic ontologies", *Reasoning Web. Declarative Artificial Intelligence: 16th International Summer School 2020, Oslo, Norway, June 24–26, 2020, Tutorial Lectures 16*, pp. 1-35.

[3] I. Ceylan, R. Penaloza, "The bayesian ontology language BEL", Journal of Automated Reasoning, vol. 58, No 1, 2017, pp. 67–95. https://doi.org/10.1007/s10817-016-9386-0.

[4] P. Alexopoulos, M. Wallace, K. Kafentzis, and D. Askounis, "IKARUS-Onto: a methodology to develop fuzzy ontologies from crisp ones", *Knowledge and information systems*, vol. *32*, 2012, pp. 667-695.

[5] J. Raad, and C. Cruz, "A survey on ontology evaluation methods". In Proceedings of the International Conference on Knowledge Engineering and Ontology Development, part of the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, 2015.

[6] B. Senthilnayaki, K.Venkatalakshmi, and A. Kannan, "A fuzzy similarity based approach for intelligent web based e-learning". arXiv preprint arXiv:1302.1971, 2013.

[7] F. Riguzzi, E. Bellodi, E. Lamma, and R. Zese, "Reasoning with Probabilistic Ontologies". In *IJCAI*, 2015, pp. 4310-4316.

[8] E. Bellodi, E. Lamma, F. Riguzzi, R. Zese, and G. Cota, "A web system for reasoning with probabilistic OWL". *Software: Practice and Experience*, vol. *47*, No 1, 2017, pp. 125-142.

[9] A. Bellenger, and S. Gatepaille, "Uncertainty in ontologies: Dempster-Shafer theory for data fusion applications". arXiv preprint arXiv:1106.3876, 2011.

[10] I. Ceylan and T. Lukasiewicz, "A tutorial on query answering and reasoning over probabilistic knowledge bases". In: d'Amato, C., Theobald, M. (eds.) Reasoning Web. Learning, Uncertainty, Streaming, and Scalability - 14th International Summer School Tutorial Lectures. LNCS, vol. 11078, 2018, pp. 35–77. https://doi.org/10.1007/978-3-030-00338-83.

[11] K. B. Laskey, P. C. Costa, and T. Janssen, "Probabilistic ontologies for knowledge fusion". In 11th international conference on information fusion, 2008, June, pp. 1-8, IEEE.

[12] M. Niepert, J. Noessner, H. Stuckenschmidt, „ Log-linear description logics". In IJCAI, 2011, pp. 2153-2158.

[13] F. Bobillo and U. Straccia, "fuzzyDL: An Expressive Fuzzy Description Logic Reasoner, Fuzzy Systems", in: Proceedings of the 17th IEEE International Conf. on Fuzzy Systems (FUZZ-IEEE 2008), 2008, pp. 923-930.

[14] J. Euzenat, "Revision in networks of ontologies". Artificial intelligence, vol. 228, 2015, pp. 195-216.

[15] D. Vrandečić, "Ontology evaluation". In Handbook on ontologies, 2009, pp. 293-313. Berlin, Heidelberg: Springer Berlin Heidelberg.

[16] M. McDaniel and V. C. Storey, „Evaluating domain ontologies: clarification, classification, and challenges". ACM Computing Surveys (CSUR), vol. 52, No 4, 2019, pp. 1-44.

[17] F. L. da Silva, B. K. Slodkowski, K. K. A.da Silva, and S. C. Cazella, "A systematic literature review on educational recommender systems for teaching and learning: research trends, limitations and opportunities". *Education and Information Technologies*, Vo1. 28, No 3, 2022, pp. 3289-3328.

[18] A. Almasri, A. Ahmed, N. Almasri, Y. S. Abu Sultan, A. Y.Mahmoud, I. S. Zaqout, and S. S. Abu-Naser, "Intelligent tutoring systems survey for the period 2000-2018", IJARW, 2019.

[19] T. I. Ivanova, "Managing uncertainty in ontology mapping in e-learning context". In 2019 International Conference on Information Technologies (InfoTech), 2019, September, pp. 1- 4, IEEE.

[20] H. Sebbaq, N. E. El Faddouli, and S. Bennani, "Recommender system to support MOOCs teachers: Framework based on ontology and linked data". In *Proceedings of the 13th International Conference on Intelligent Systems: Theories and Applications*, 2020, pp. 1-7.

[21] M. Amirhosseini, J. Salim, "A synthesis survey of ontology evaluation tools,

applications and methods to propose a novel branch in evaluating the structure of ontologies: graph-independent approach". International Journal of Computer (IJC), 2019, vol 33, No 1, pp. 46-68.

[22]C.V.S. Avila, G. Maia, W. Franco, T.V. Rolim, A.O.R. Franco, and V.M.P. Vidal, "OntoVal: A tool for ontology evaluation by domain specialists". In: Proceedings of the 38th International Conference on Conceptual Modeling, Salvador, Brazil, 2019, pp. 4–7.

[23]M. Amith, F. Manion, C. Liang, M. Harris, D. Wang, Y. He, and C. Tao, "Architecture and usability of OntoKeeper, an ontology evaluation tool". BMC medical informatics and decision making, vol. 19, No. 4, 2019, pp. 1-18.

[24]K. Schekotihin, P. Rodler, and W. Schmid, „OntoDebug: Interactive ontology debugging plug-in for Protégé". In Foundations of Information and Knowledge Systems: 10th International Symposium, FoIKS 2018, Budapest, Hungary, May 14–18, 2018, Proceedings vol. 10, pp. 340-359.

[25]M. Poveda-Villalón, A. Gómez-Pérez, and M. C. Suárez-Figueroa, "Oops! (ontology pitfall scanner!): An on-line tool for ontology evaluation". International Journal on Semantic Web and Information Systems (IJSWIS), 2014, vol. 10, No. 2, pp. 7-34.

[26]Z. Dragisic, Y. Li, and P. Lambrix, "RepOSE-CTab-A Protégé Plugin for Completing Ontologies". In Proceedings of the Sixth International Workshop on the Visualization and Interaction for Ontologies and Linked Data co-located with the 20th International Semantic Web Conference (ISWC 2021), Virtual Conference, 2021 (CEUR Workshop Proceedings, Vol. 3023, pp. 56-62.

[27]M. Florrence, "MLGrafViz: Multilingual ontology visualization plug-in for protégé". Computer Science and Information Technologies, Vol. 2, No 1, 2021, pp. 43-48.

[28]T. Özacar, "Extending ontology pitfalls for better ontology evaluation". Journal of Information Science, 2022, pp. 01655515221110990.

[29]K. Shchekotykhin, G. Friedrich, P. Fleiss, P. Rodler, "Interactive ontology debugging: Two query strategies for efficient fault localization". Journal of Web Semantics, 12, 2012, pp. 88-103.

[30]S. K. Anand, S. Kumar, "Uncertainty analysis in ontology-based knowledge representation". *New Generation Computing*, 2022, vol. *40*, No 1, pp. 339-376.

[31]Reul, Q., Pan, J. Z. (2015) KOSIMap: Use of description logic reasoning to align heterogeneous ontologies. In: Description Logics Workshop

[32]A. Solimando, E. Jiménez-Ruiz, G. Guerrini dan, "On the Feasibility of Using OWL 2 DL Reasoners for Ontology Matching Problems". In: Informal Proceedings of the 4th International Workshop on OWL Reasoner Evaluation (ORE-2015) co-located with the 28th International Workshop on Description Logics (DL 2015), Athens, Greece, 2015, pp. 1–15.

[33]O. Couchariere, M. J. Lesot, Bouchon-Meunier, B., „Consistency checking for extended description logics". In The 21st International Work-shop on Description Logics (DL 2008), 2008, Vol. 353.

[34]W. Li, S. Zhang, and G. Qi, "A graph-based approach for resolving incoherent ontology mappings". In Web Intelligence, Vol. 16, No. 1, 2018, January pp.15-35, IOS Press.

[35]S. Malik, "Ontology Based Construction of Bayesian Network". International Journal of Research in Advent Technology, 2019, vol. 7, No12, pp. 1-7.

[36]M. Pedaste, M. Mäeots, L. A. Siiman, T. De Jong, S. A. Van Riesen, E. T. Kamp, and E. Tsourlidaki, "Phases of inquiry-based learning: Definitions and the inquiry cycle". *Educational research review*, vol. *14,* 2015, pp. 47-61.

[37]N. O. P. Vago, M. Sacaj, M. Sadeghi, S. Kalwar, and M. G. Rossi, "On the visualization of semantic-based mappings". In *Third International Workshop On Semantics And The Web For Transport,* 2021.

[38]G. Nemirovski, and A. Nolle, „Map-On: A web-based editor for visual ontology mapping". *Semantic Web*, vol. *8*, No. 6, 2017, pp. 969-980.

[39]E. Marin, "Interactive visualization for ontology mapping: A Preliminary Evaluation of Two Visualization Techniques", 2023.

[40]Z. Berie, D. Damtie, and Y. N. Bogale, "Inquiry-based learning in science education: a content analysis of research papers in Ethiopia", Education Research International, 2022.

[41]L. N. Nongkhai, J. Wang, and T. Mendori, "Developing an Ontology of Multiple Programming Languages from the Perspective of Computational Thinking Education".

International Association for Development of the Information Society, 2022, pp. 66-73.

[42]A. Saibene, M. Assale, and M. Giltri, "Expert systems: Definitions, advantages and issues in medical field applications". Expert systems with applications, 2021.

[43]M. Tavana, and V. Hajipour, "A practical review and taxonomy of fuzzy expert systems: methods and applications". Benchmarking: An International Journal, vol. 27, No.1, 2020. pp. 81-136.

[44] A. Anikin, D. Litovkin, M. Kultsova, E. Sarkisova, and T. Petrova, "Ontology visualization: Approaches and software tools for visual representation of large ontologies in learning". In Creativity in Intelligent Technologies and Data Science: Second Conference, CIT&DS 2017, Volgograd, Russia, September 12-14, 2017, Proceedings 2, pp. 133-149, Springer International Publishing.