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A Semantic MediaWiki-based Approach for the Collaborative Development of Pedagogically Meaningful Learning Content Annotations

Stefan Zander[1], Christian Swertz[2], Elena Verdú[3], María Jesús Verdú Pérez[3], and Peter Henning[4]

[1] FZI Research Center for Information Technology, 76131 Karlsruhe, Germany
zander@fzi.de
[2] Department of Education, University Vienna, Sensengasse 3a, A 1090 Vienna
christian.swertz@univie.ac.at
[3] University of Valladolid, ETSI Telecomunicación, Campus Miguel Delibes, E-47011 Valladolid, Spain
elever@tel.uva.es, marver@tel.uva.es
[4] Karlsruhe University of Applied Sciences, Germany
peter.henning@hs-karlsruhe.de

Abstract. In this work, we present an approach that allows educational resources to be collaboratively authored and annotated with well-defined pedagogical semantics using Semantic MediaWiki as collaborative knowledge engineering tool. The approach allows for the exposition of pedagogically annotated learning content as Linked Open Data to enable its reuse across e-learning platforms and its adaptability in different educational contexts. We employ Web Didactics as knowledge organization concept and detail its manifestation in a Semantic MediaWiki system using import and mapping declarations. We also show how the inherent pedagogical semantics of Web Didactics can be retained when learning material is exported as RDF data. The advantage of the presented approach lies in addressing the constructivist view on educational models: The different roles involved in the content development process are not forced to adapt to new vocabularies but can continue using the terms and classification systems they are familiar with. Results of the usability test with computer scientists and education researchers are positive with significantly more positive results for computer scientists.

1 Introduction

In order to establish good learning content and to introduce adaptive learning systems to the classroom, the constructivist view on educational models claims for the integration of many different roles (e.g., instructors, instructional designers, pedagogues, media designers, and students) in the learning content development process [1–3]. As a consequence, it should be simplified for both authors and instructors [4] and support the aspect of collaboration [2].

The latest generation of e-learning solutions aim to address this by emphasizing the aspects of decentralization and inter-institutional collaboration, which leads to an increasing necessity of accessing and utilizing learning content outside specific e-learning platforms [4, 5]. The realization of such decoupled and unobstructed access requires—among other things—expressive representation frameworks for both the organization and representation of learning content annotations and is of particular relevance in the educational sector [6]. Collaboratively created semantic vocabularies help in improving access for learners and instructors and facilitate the exchange of learning material across different platforms as well as its reuse in different contexts and for different purposes through pedagogically meaningful semantics [4]. Although the benefits that even simple annotation systems offer to the development process of learning content are broadly acknowledged in the e-learning domain (cf. [2, 5, 6]), the process of integrating lightweight annotation systems such as Semantic MediaWikis into educational systems and learning content generation processes has only recently begun [5, 7]. Exacerbating factors are the difficulties in designing and using ontologies as formalisms for representing annotation semantics together with the high engineering experience required by ontology engineering tools that domain experts such as instructors, instructional designers, and content developers usually do not have. Related studies (e.g. [6, 8]) also indicate the lack of available domain ontologies for several subjects together with the lack of standards, tools, and design methodologies.

While Semantic MediaWikis do not seem to be the most obvious candidates for the management of e-learning content, they have been suggested as appropriate tools for this task since they address some problems that exist with common learning management systems (cf. [5, 7]):

- (i) They adopt the Wiki-based authoring style for the creation of lightweight ontologies.
- (ii) Semantic MediaWikis are conducive to reaching a shared agreement about the relevant entities in a universe of discourse—an aspect that is of central importance for the acceptance and broad usage of a domain ontology.
- (iii) They help in making learning content available for the Web of Data[5] and hence contribute to the recently emerging trend of *educational Linked Open Data* (see [5]).
- (iv) Semantic MediaWikis offer a version control system.
- (v) They do not only support the management of content within courses, but the creation of large common content repositories.
- (vi) Semantic MediaWiki offers RDF support.

As a consequence, Semantic MediaWikis seem to be promising candidates to manage collaboratively maintained content repositories. To support and facilitate this trend, we present an approach that allows learning content to be collaboratively authored and annotated with well-defined pedagogical semantics using Semantic MediaWiki as collaborative knowledge engineering tool.

[5] cf. http://www.w3.org/2013/data/

1.1 Research Questions and Contributions

With our approach, we show that we can overcome the limited expressivity of Semantic MediaWikis knowledge representation framework by importing the *Pedagogical Ontology (PO)* and the *Semantic Learning Object Model (SLOM)* created in the INTUITEL project[6] in order to create rich pedagogically meaningful annotations that can be processed by INTUITEL-enabled Learning Management Systems (LMS) and are conducive to their utilization in the educational Web of Data [5] with an acceptable usability. More specifically, this work addresses the following research questions:

(i) *How can the rich pedagogical semantics defined in the Pedagogical Ontology and the Semantic Learning Object Model be made available in a Semantic MediaWiki system for collaborative content authoring while maintaining their formal, model-theoretic semantics?*
(ii) *Can pedagogically enhanced Semantic Media Wikis support the arrangement of content for heterogeneous learning sequences in online learning processes?*
(iii) *Do teachers accept the usability of Semantic Media Wikis as a tool for creating multi-sequenced content online?*

In answering that questions, we show how the concept of Web Didactics and its manifestation in the Pedagogical Ontology and the Semantic Learning Object Model can be integrated into a Semantic MediaWiki system using import and mapping declarations. We demonstrate how the rich pedagogical semantics can be retained, although the underlying knowledge representation frameworks are defined on description logics with differing expressivity (see Section 4.2). The impact of the presented approach is as follows:

(i) We facilitate the reuse of learning material through its annotation with pedagogically meaningful semantic data defined in the Pedagogical Ontology while minimizing the necessity to use external tools or full-fledged ontology editors such as Protégé [9] to create such annotations.
(ii) The presented approach builds on standardized semantic Web technologies and allows learning content annotations to be exported as Linked Data. This enables learning content to be linked to related content and reused outside specific LMSs and in different contexts.
(iii) It does not reduce or negatively impact the efficiency of existing Semantic MediaWiki-based authoring processes (cf. [4, 10]).
(iv) We ensure collaborative authoring since the production of distance learning material requires the collaboration of people with different skills (pedagogues, computer scientists, graphic designer etc).

As a consequence, course instructors are not forced to learn or adapt to new annotation vocabularies in order to create pedagogically meaningful annotations. They can rather continue using the vocabulary terms and classification

[6] http://www.intuitel.de/

systems they are familiar with. The presented approach does also not require an interruption or reconfiguration of content creation processes as appropriate semantics are added during authoring time. Our work builds on the standard Semantic MediaWiki system and can be combined with related approaches, e.g., to add offline editing support or multi-synchronous work mode [11] (see also Section 3).

This document is structured as follows: Section 2 introduces the Web Didactics as a knowledge organization concept that is focused on the collaborative production and representation of learning content. The manifestation of the Web Didactics in the Pedagogical Ontology and the Semantic Learning Object Model (SLOM) is described, followed by a brief introduction to Semantic MediaWiki as collaborative ontology engineering tool. The unique features of the present approach as well as its differentiation to related works are discussed in Section 3. Based on a description of the main characteristics and features of the PO and SLOM, we elaborate in Section 4 how the particular semantics of the Pedagogical Ontology and SLOM can be reflected in the model-theoretic semantics of a Semantic MediaWiki system. In doing so, we discuss different aspects related to the exposition of learning content and its pedagogical semantics as Linked Open Data using a Semantic MediaWiki system. In Section 5, we validate the presented approach and discuss the extent to which the formal semantics of the PO and SLOM can be preserved in the knowledge representation formalism upon which SMW is built. We also present its general applicability in a real-world use case in which a university lecture about network design is exposed as Linked Data together with its collaboratively created pedagogical semantics. In Section 6 results from an usability test where content was created and annotated with the INTUITEL PO and SLOM by teachers from departments of computer technology and departments of education are reported. Section 7 summarizes limitations of the presented approach and outlines open issues to direct future work on the given topic. A final verdict is given in Section 8.

2 Background

This section provides background knowledge about the concepts, tools, and models that are fundamental for the presented approach. We first introduce the concept of *Web Didactics* and explain its main characteristics followed by an overview of the *Pedagogical Ontology (PO)*—a machine-processable representation of selected aspects of Web Didactics. The Pedagogical Ontology together with *the Semantic Learning Object Model (SLOM)*, which is described subsequently, serves as representation basis for the collaborative eLearning content modeling approach presented in this work. We use a *Semantic MediaWiki (SMW)* as technical basis of our approach and provide an overview of its knowledge representation formalism in the last part of this section, as it serves as collaboration platform for the authoring and annotation of learning content.

2.1 Web Didactics

Individualization of learning processes is an old and well established cultural practice. Skimming through books is one simple example for this cultural practices. In the book culture, this is supported by tools like tables of contents, indexes, page numbers, etc. With computer technology, it is possible to support individual learning not only by static, but also by dynamic tools. Due to the qualities of digital electronic universal Turing machines, dynamic tools to support individualized learning require the expression of the pedagogical meaning of content in a machine readable format [12]. Thus the first purpose of the Web Didactics is to support the expression of the pedagogical meaning of content by offering a metadata vocabulary.

While individualization of learning processes is a well known practice, this is not the case for collaborative authorship of content. To support collaborative content production for individualized online learning requires a classification system which has to be suitable for multiple curricula and pedagogies. Thus the second purpose of the Web Didactics is to offer a classification system that supports collaborative knowledge production for multiple curricula and pedagogies [13]. With this approach, the static classification system can be dynamically transferred into the learning time by taking learner behaviour into account. The classification system is thus a collaborative space for the creation of semantically enriched learning material that can be turned into dynamically calculated recommendations and feedback in the learning process.

The model behind the classification system is based on the distinction of knowledge representation in space and knowledge communication in time [14]. Knowledge representations in space are classified by a metadata system and a metadata vocabulary. Knowledge representation in time is represented by learning pathways. The purpose of the ontology developed by Meder was to create a metadata system and a vocabulary that are suitable to express every teaching and learning concept that was developed in the history of teaching and learning. During runtime, this ontology is combined with a learner ontology that describes the behaviour of an individual learner [15].

Formal knowledge representation in space depends on granularity. While the structure of output devices has to be considered for granularity in the context of teaching and learning, granularity of content still can only be estimated. It is thus a heuristic value. We have suggested, to take the properties of the computer screen as an obviously rough orientation to estimate granularity. In the context of computer technology, we consider the amount of content that can be perceived in 5 to 10 minutes as the smallest sensible section of knowledge. This we define as a knowledge object (KO). KOs are the first line of the classification of learning objects we suggest. Every knowledge object is described by a set of metadata. The set of metadata includes the knowledge domain of the content, the topic that is covered, author, license, production time and date, level, if it's suitable for blind, deaf or dumb people, minimum screen resolution and file size, age of the targeted audience, language, and media type and knowledge type. The selection criterion for these metadata is applicability. We tested this by describing algorithms about how to apply those criteria in the learning process. If, for example, the learner tells the system that he his blind, the system will try to avoid the recommendation of content that is not suitable for blind people. Obviously, this depends on the availability of appropriate content.

While most of these meta data are self explanatory and the vocabulary is fairly simple, this is not the case for the knowledge types. As knowledge types the Web Didactic offers a vocabulary that distinguishes receptive, interactive and cooperative knowledge types. Receptive knowledge can be something like an example or an explanation, interactive knowledge can be something like a simulation or a multiple choice question, and cooperative knowledge types include discussions, disputations, group work and so on [16]. The knowledge types are compiled from the pedagogical literature since Comenius and thus allow to express most teaching and learning concepts that are used in western culture, like upfront teaching, programmed instruction, digital problem based learning or inquiry learning.

All knowledge objects with the same topic shape one concept container. Concept containers are the second line of the Web Didactic classification. The concept containers are described by the topic and their relations to other concept containers. These relations are typed relations. Mainly hierarchical and associative relations are distinguished. The topics of the concept containers and the typed links build a thesaurus.

Concept containers are combined into knowledge domains, which are the third line of the Web Didactics. For simplicity, a knowledge domain can be associated with a course. The course is described by a topic again. These topics can be related by typed links. Courses with the same topic can be understood as modules. Modules are on the forth line linked into curricula. Thus a network of domain specific thesauri is related within the classification. This way, the approach can be used for the individualization of modules and curricula, but this idea is behind the scope of this paper.

The classification of knowledge objects, concept containers and knowledge domains is combined with a classification of learning pathways. In other terms: we are using a poly-hierarchical classification system with domain specific thesauri. To do so, the concept containers and the knowledge objects can be arranged into multiple recommended learning pathways by the teacher. This is done by typed relations. These learning pathways are restricted to directed acyclic graphs. The learner can follow one of the recommended learning pathway or create his own learning style. If a learner explicitly of implicitly creates his own learning style, this can be applied to upcoming content based on the metadata vocabulary.

Recommendations for concept containers and knowledge objects are dynamically calculated while the learning process takes place. To do so, data from a learner model and learners log data are combined with the metadata the teacher created. The advantage of this ontology can be illustrated by the fact that all metadata are optional. Even if no metadata are given, recommendations and feedback can be calculated by using the learner log data. Still, with more metadata, the recommendation and feedback are more precise and cover more different situations. With teacher generated learning pathways, for example, learners can use these pathways. If the "blind"-field is filled, the recommendations can consider if the learner is blind or not, and so on.

In comparison with other approaches, the metadata set is small and simple. It thus can easily be applied in practice and used as required in the given context. Still, the metadata support individualized learning. Thus the freedom of the learner in the learning process is increased. This can be illustrated by the lost in hypertext phenomenon. If the learner uses a risky navigation style and looses orientation, the calculated recommendations and feedback can help him to continue his learning process.

At the same time, collaborative knowledge production is supported. It is, for example, possible to split the production of content by using the media types. One team might produce videos, while another team prepares readings and a third team creates forms for tasks. The same can be done on the level of concept containers. If, for example, a list of concept containers is covered by different people or teams, a common list of media and knowledge types that have to be covered in every concept container can be defined. In this case, the classification is used to coordinate the collaborative knowledge production.

2.2 A Pedagogical Ontology for Web Didactics

The pedagogical ontology[7] we developed is based on the Web Didactics vocabulary and classification. The development of the ontology is based on the following observations and experiences:

- Teaching and learning depends on heuristics that are based on authors and learners experiences and cultural backgrounds [17]
- The production of e-Learning material is costly.
- Managing large numbers of learning pathways is difficult for authors and learners.
- The production of learning environments is a professional activity that cannot be conceptualized into a rigid system [18].
- A reasonable granularity of learning material is required to be able to generate a comprehensible classification that is used for adaptations, recommendations and individual learning [19].

For the transformation of the Web Didactic concept into the pedagogical ontology, the context of the project is relevant. The INTUITEL system is intended as a plug in for existing learning management systems. All systems that are considered in the project (Moodle, Illias, Clix, Crayons) use a course as the highest aggregation level. Thus we used level 1 to 3 (knowledge objects, concept containers, knowledge domain) in the ontology only. While the learning management systems used in the project offer a suitable granularity, they are hardly

[7] The pedagogical ontology developed within the INTUITEL project is available at http://www.intuitel.de/public/intui_PO.owl

flexible in terms of offered tools like forums, exercises and so on. Thus the ontology needs a flexible design that supports the adaptation of the vocabulary to the learning management used in a given situation. For practical usage it was also important that the ontology can easily be applied to existing courses.

When turning the metadata set and the vocabulary of the Web Didactic concept into an ontology, the heuristic characteristic needs to be considered. Due to the mentioned theoretical and practical reasons the ontology can not be created as a completed ontology, but needs to be created as an open ontology. To do so, we created the ontology and the INTUITEL system with the vocabulary from the Web Didactic [20, 21], but designed the ontology and the software architecture in a way that keeps the possibility to change the vocabulary. Entries for media types, knowledge types or relation types can be added as needed and taken into account in the learning process. Our 15 years experience showed, that this is not happening very often. The media types vocabulary for example did not change in the last 15 years, since no new media types have been developed.

For the pedagogical ontology, we defined knowledge objects, typed links that form micro level learning pathways between the knowledge objects in the form of directed acyclic graphs, where nodes represent knowledge objects and edges represent specific types of micro learning pathways. We furter defined concept containers and typed links between them in the form of directed acyclic graphs that form macro level learning pathways where edges represent specific types macro learning pathways, and knowledge domains as the basic entities. The ontology is the starting point for the Semantic Learning Object Model developed in INTUITEL.

2.3 The Semantic Learning Object Model (SLOM)

The Semantic Learning Object Model (SLOM) is a new metadata model developed in the INTUITEL project[8] to combine pedagogical and domain-specific knowledge with concrete learning material. SLOM complements existing and well-known eLearning formats such as Sharable Content Object Reference Model (SCORM)[9] and IMS-Learning Design[10] with semantic information that allows for a more intelligent and personalized (i.e., adaptive) processing of learning material in INTUITEL-enabled Learning Management Systems (LMSs). It serves as facilitating data infrastructure for the utilization and integration of externally hosted data in INTUITEL-compliant learning material.

The Semantic Learning Object Model (SLOM) is the format in which the INTUITEL system stores general information about courses, which is necessary to provide learning recommendations and feedback to learners. The SLOM format is implemented as a direct extension of the Pedagogical Ontology and defines how course information needs to be described in order to be compatible with the INTUITEL system. SLOM as a metadata format contains two ontologies for a

[8] http://www.intuitel.de/
[9] http://scorm.com/
[10] http://www.imsglobal.org/learningdesign/

given course, the *Cognitive Map (CM)* and *Cognitive Content Map (CCM)*. The former is the description of topics in a domain of knowledge, while the latter describes the actual learning material of that course. A CM should be universally valid, meaning that CMs can be reused across different courses pertaining to a given topic. CCMs are, in contrast, specific to a given course since they enhance the actual learning content. SLOM as a storage format additionally contains the learning material on which the CCM is based in its original format. The SLOM specification prescribes the structure in which the given material has to be stored in order to be compliant. This entails three main pillars of information that should be compiled into the CM/CCM from the original content format:

1. *Topology*: Information about which elements are in the learning material as well as their topical coherences. In terms of INTUITEL, this means that the SLOM contains definitions for *Concept Containers (CCs)* and *Knowledge Objects (KOs)* of a given domain of knowledge.
   A Knowledge Object in INTUITEL is the smallest addressable part in an eLearning course, which is intended to provide insights into one distinct piece of knowledge. It is the anchor point for extending the content with metadata (e.g. knowledge type, expected learning time, etc.). Generally, this should represent about one screen page and correspond to roughly 5–10 minutes of learning time[11]. A KO always has a URI in context of the CCM it is embedded, which makes it possible to directly index the metadata it contains. Furthermore, if used in a running course, a LMS-ID uniquely identifies the element in the eLearning platform and, in context of a SLOM package, a SLOM-reference that links to the page in the package structure.
   Concept Containers on the other hand are structural components that allow for combining Knowledge Objects in different topics. It is possible to attach one KO to different CCs and thus create complex knowledge coherences across a course.
2. *Sequences*: Learning Pathways (LPs) on different levels that allow interlinking Knowledge Objects and Concept Containers. This is one of the main elements in the INTUITEL system as a whole and gives teachers the opportunity to compile their courses in different ways. On the topical level, *macro Learning Pathways (MLPs)* describe the sequence in which a learner should work through Concept Containers. On the content level, *micro Learning Pathways (μLPs)* describe how learners should work through Knowledge Objects. The latter has only to be done in a smaller context, meaning only inside a given complex of meaning. The total set of Learning Pathways results implicitly by combining MLPs and μLPs. So, although teachers only describe a relatively small number of pathways, the actual number of possibilities of working through a course is the product of them. Generally, learning pathways can be seen as a (set of) directed acyclic graphs.

[11] Naturally, this varies from element to element, but can be taken as a guide value for the creation of courses. Especially in context of different content types (e.g. tests, assignments, definitions, etc.) and media types (e.g. video, text, etc.), this is actually expected to vary.

3. *Background*: In addition to interconnecting elements, the PO and consequently also the SLOM format allows to describe these elements. This concerns the Knowledge Objects (KOs), which, in contrast to Concept Containers (CCs), have a real representation as a course. The respective content elements have properties as seen from a technological and didactical perspective. The former, for instance, concerns their size (e.g. 1MB) or recommended screen resolutions (e.g. 1024x768 pixels), while the latter regards the educational purpose and background of the elements. This could, for example, be the difficulty level (e.g. beginner) or the type of knowledge it contains (e.g. different types of assignments).

A combination of these three pieces of information with learner data allows the INTUITEL system to create recommendations for appropriate learning objects and to produce feedback messages in that process. The more information that can be provided on the course, the more information can be integrated in this process.

2.4 Overview of Semantic MediaWiki

In this section, we provide a concise but non-exhaustive overview of the main language elements of Semantic MediaWiki systems[12]. This overview serves as basis for the subsequently following elaborations on the import and mapping declarations that need to be defined between the knowledge representation formalisms underlying Semantic MediaWiki and external ontologies such as the PO and SLOM as OWL ontologies (see also Section 4.2).

Semantic MediaWiki[13] is a free and open-source extension to the MediaWiki software[14] that allows for adding machine-readable semantic information in the form of semantic annotations to wiki articles. Semantic annotations are materialized in the form of *Categories*, *semantic Properties*, *Subobjects*, and *Concepts* and allow for complementing existing wiki pages with facts and explicitly defined relationships to related articles in a structured and meaningful way. Information represented as semantic annotations can be queried and aggregated in more sophisticated ways compared to articles that use the default elements defined by the MediaWiki language model.

Semantic MediaWiki was developed as a full-fledged framework to complement MediaWiki with functions found in knowledge management systems [23]. One of the main distinguishing features of Semantic MediaWiki compared to MediaWiki is the interoperability of the data created with it, as its underlying description framework is based on concepts, languages, and technologies defined by W3C semantic Web standards[15], the vision of which are to evolve the Web

[12] For a detailed introduction to Semantic MediaWiki and the unique benefits it adds to MediaWiki, we refer the reader to the official Semantic MediaWiki manual [22] or the related literature (e.g. [23, 24].

[13] https://semantic-mediawiki.org/

[14] https://www.mediawiki.org/wiki/MediaWiki

[15] http://www.w3.org/2013/data/

into a global data space of linked data sources, where RDF and common ontologies serve as interoperability infrastructure (cf. [25]). This interoperability infrastructure allows external applications to use and integrate data created with a Semantic MediaWiki in a controlled and meaningful way. It also enables the integration of semantic search capabilities in Semantic MediaWiki systems.

Semantic MediaWiki (SMW) in general does not define a new canonical data or description format since the logical model that builds the basis of its knowledge representation formalism is to a large extend based on the Web Ontology Language (OWL). This reliance enables a direct mapping (cf. [24]) of baseline Semantic MediaWiki elements to OWL language elements (see also Table 2):

- *Categories* in a Semantic MediaWiki system are represented as named classes in OWL ontologies; ontology classes, on the other hand, can be directly mapped to categories in Semantic MediaWiki.
- *Articles* created within Semantic MediaWiki are treated as individuals of an ontology and hence as members of the classes that represent the Semantic MediaWiki categories a page is related to.
- *Properties* are the Semantic MediaWiki pendant to roles in Description Logics and properties in OWL.

Table 1. Direct mapping of OWL language elements to Semantic MediaWiki

OWL Language Element	**Semantic MediaWiki**
OWL Individual	Normal article in the default namespace
`owl:class`	Article in the `Category` namespace
`owl:ObjectProperty`	Article in the `Attribute` namespace
`owl:DatatypeProperty`	Article in the `Attribute` namespace with `[[has Type::...]]` declaration
OWL class expression	Article in the `Concept` namespace[16]

In contrast to OWL properties, i.e., roles in description logic, SMW does not distinguish between *object* and *datatype properties* respectively concrete and abstract roles. Both elements are mapped to articles in the `Attribute`-namespace where Semantic MediaWiki's RDF Exporter (see Sections 4.4 and 5.2) determines a property's type in terms of OWL DL depending on the occurrence of a `[[has type::...]]` declaration. If such a declaration is found on a property's article page, then the property is treated as an `owl:DatatypeProperty` in the export and its value is mapped to the value space of the respective datatype. An external reasoner can then check whether the given value corresponds to the range definition of its associated OWL datatype property.

Unlike OWL, which is built on the *non-unique name assumption* (cf. [26, 27]) and allows identical entities to be referred to via different IRIs, SMW interprets articles with different IRIs as different individuals per default. However, in order to state that two articles with different IRIs are identical, SMW adopts the concept of *redirects* from MediaWiki to express equivalence between differently named categories, properties, and articles. In terms of OWL, the concept of redirects resemble equivalence assertions between individuals using `owl:sameAs` as well as among classes and properties expressed through `owl:equivalentClass` and `owl:equivalentProperty`. Table 2 summarizes the different types of equivalence expressions in OWL and Semantic MediaWiki:

Table 2. Expressing equivalence in OWL and Semantic MediaWiki

OWL Language Element	**Semantic MediaWiki**
`owl:sameAs`	`#REDIRECT [[{pagetitle}]]` —on normal article pages
`owl:equivalentClass`	`#REDIRECT [[{pagetitle}]]` —articles in the `Category`-namespace
`owl:equivalentProperty`	`#REDIRECT [[{pagetitle}]]` —articles in the `Attribute`-namespace

SMW also allows for the declaration of value spaces to restrict a property's value range to a list of allowed values the property may hold. This restriction might be complemented by additional normative and non-normative information. However, normative information can only be specified in an informal way and hence prevents consistency checking by a formal reasoner (which is possible, for instance, in OWL ontologies and common OWL/DL reasoners).

3 Related Work

The fields of ontology engineering, semantic Web technologies and Linked Data are being strongly connected in order to provide intelligent applications that can support learners in organizing their studies and connecting adequate learning resources in pedagogically meaningful learning paths. Many authors have therefore stressed the importance of Linked Data and semantic technologies on e-learning as well as the tools for transforming existing, legacy data into Linked Data [5, 7, 28, 29]. This resulted in developments of so-called *Semantic Learning Management Systems (SLMS)* and *Web Science Semantic Wikis (WSSW)* to exceed the self-contained perspective of current semantic MediaWiki systems in terms of openness for external semantic queries [5]. Such a feature allows content to be collaboratively authored and exposed as Linked Data in an ad-hoc manner and become incorporated into other semantic data structures on-the-fly. This not only requires semantic Web languages such as RDF/S and OWL as interoperability infrastructure but also the authoring of pedagogically meaningful content annotations. Li et al. [7], for instance, demonstrated how learners and content authors can benefit from a collaborative elearning environment backed by Semantic MediaWiki in terms of authoring, access, sharing, and reuse.

The importance of content authoring for the acceptance of educational systems is analyzed by several works (e.g. [3, 6, 10, 30]). Sosnovsky et al. [3] present a topic-based knowledge modeling approach, which was inspired by instructional design practice and claims that *"domain model does not have to be very detailed to ensure the effective adaptive behavior and usability of the system"*. While reusability is ensured, the aspect of collaborative authoring is not considered. The same can be found in [30]. The authors introduce an ontology-aware authoring system for learning designs. It is designed in compliance with some international standards (SCORM and LOM) in order to enhance shareability and reusability of learning designs among users, but nothing is stated about collaborative authoring. Besides, the system collects and searches learning resources suitable to the authors. However the tool does not have the functions to edit metadata. Holohan et al. [10] present a set of software tools aimed at supporting authoring, management, and delivery of learning content that build on semantic Web technologies for knowledge representation and content processing. A key feature of the system is the semi-automatic generation of standard e-learning and other courseware elements through graph transformations on underlying ontologies. Their system also offers features such as adaptivity in terms of students' learning track guidance, ontology engineering, as well as dynamic content delivery based on configurable navigation pathways. Information regarding an ontology-based representation of learning pathway semantics or the pedagogical concepts to which their approach pertains is not provided. The aspect of collaboration is also not addressed in their work. The potential of semantic Web based knowledge representation frameworks for the development of learning content along seven different application domains for ontologies is surveyed in [6]. Their research also corroborates the importance of ontologies for content adaptation, content assembly, and content reuse.

Other works (e.g. [2, 4]) specifically emphasize the multidisciplinary character of the content creation process and underline the relevance of supporting collaboration in involved systems due to the different roles and tasks involved. The integrated framework developed by Dodero et al. [2] supports the collaborative authoring and annotation of learning objects and has been realized in form of an Eclipse RCP application. However, the collaboration module offers functionalities for negotiating and evaluating annotation proposals although in a style different from that found in today's Wiki systems. Extending current semantic MediaWiki systems with additional collaborative editing features such as offline work support and multi-synchronous edits is proposed by Rahhal [11]. Although adaptivity is not addressed, their work extends the presented approach in useful ways. Brut et al. [4] motivate the usage of semantic Web technologies for addressing the challenges of accessing learning content not only across e-learning platforms but also across Web applications, which resulted from the intentional shift of current e-learning solutions towards decentralization and inter-institutional collaboration. The proposed method combines semantic technologies with TF-IDF-indexing, Latent Semantic Indexing, and WordNet-based processing for extending the IEEE LOM standard [31] with ontology-based semantic annotations. While their approach remains ontology-independent, the aspects of collaborative authoring of annotations is not particularly addressed.

Development methodologies to encourage and support domain experts in developing ontologies for the annotation of learning content were proposed by [8, 32]. Unlike the simple is-a relationships provided my many ontologies in the educational context [8], ontologies that provide a richer and more expressive set of relationship types are required. The authors also revealed that a separation of encoded knowledge into concept space and educational content space supports utilization flexibility. These aspects are satisfied by SMW's knowledge representation formalism (and those of all DL ontologies) as encoded knowledge is separated into assertional and terminological knowledge and exported content can be mapped to more expressive ontologies to utilize the full feature set of enhanced LMSs—as demonstrated by the present work.

4 Approach

After having described the expressive means of Semantic MediaWiki's knowledge representation formalism in Section 2.4, we now specify their semantics in terms of the OWL DL part of the Web Ontology Language. We show how pedagogically relevant terms can be mapped to Semantic MediaWiki's language elements and vice versa so that course content can be exported in a format that is compliant to the Pedagogical Ontology and Semantic Learning Object Model. We first discuss the limitations of Semantic MediaWiki's knowledge representation formalism compared to the rather expressive OWL DL language upon which the PO is defined (see also [24]). We then describe the process of importing PO and SLOM elements into Semantic MediaWiki using import and mapping declarations and demonstrate how course designers can collaboratively create semantically annotated learning material. In the last part, we expound how such content can be exported in a format that is compliant to the Pedagogical Ontology and SLOM in order to make them available as Linked Data.

4.1 Overview

The main objective of the presented approach is to enable different roles in the content creation process to use pedagogically expressive annotations in a Semantic MediaWiki system. Terms from external ontologies are extracted and imported into a Semantic MediaWiki system using *import declarations*. Imported terms are declared on special import pages (see Section 4.3). Imported terms can then be mapped to Semantic MediaWiki-specific terms (the individual terms of content authors) using import declarations (see Section 4.4) and serve as *associated terms*. Once import and mapping declarations are defined, these terms can then be used for creating and annotating learning material (see Section 4.6). Once annotated learning material is exported through the RDF Export facility,

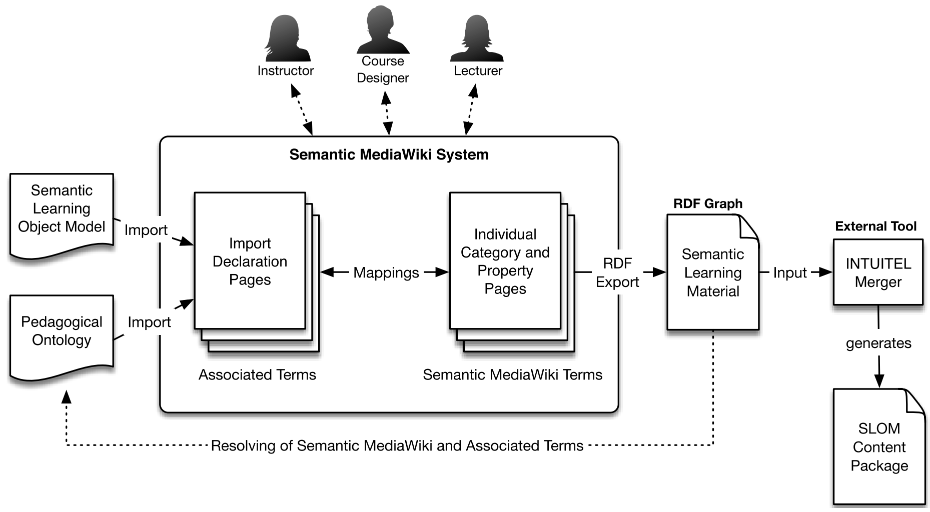

Fig. 1. Overview of the presented approach including subsequent steps

SMW-specific terms are automatically resolved and remapped to their associated ontology terms. (so that the original ontology terms are contained in the exported data). Learning content and its annotations are exported as Resource Description Framework (RDF) data. However, in order to deploy exported learning content in a Learning-Management-System (LMS), the URIs of contained media files need to be dereferenced in order to retrieve the concrete media content and incorporate it in a Content Package (see Sections 2.3 and 7) that can be processed by an INTUITEL-enabled LMS.

4.2 Limitations of Semantic MediaWiki's Knowledge Representation Formalism

This section answers two questions: First, it elucidates why the PO and SLOM can not be directly converted into Semantic MediaWiki although both knowledge representation formalisms are defined on the basis of Description Logics. Second, it discusses reasons why a universal mapping between learning material created and annotated with Semantic MediaWiki and learning material annotated on the basis of the Web ontologies such as the PO and SLOM can not exist.

The axioms that constitute an OWL ontology—irrespectively of the profile—can be separated into axioms representing *terminological*, i.e., schema knowledge and axioms that encodes information about individuals, i.e., *assertional knowledge* (see [33–35]). Although this distinction has no model-theoretic meaning, it is useful for modeling purposes [35]. On TBox and RBox level, ontologies axiomatically define a definite set of terms and constraints, the interpretation of which is determined by the formal semantics of the underlying ontology language in which an ontology is represented (see [36, 37]). The accurateness by which such constraints can be expressed depends on the logical theory and hence on the Description Logic upon which an ontology language is defined. The logical theory also determines the conclusions (logical entailments) that can be deduced from a formal interpretation of the elements semantics.

The PO and SLOM are encoded using the ontology language OWL DL, which is based on the $\mathcal{SHOIN}(\mathcal{D})$ Description Logic that exhibits NExpTime-reasoning complexity while still being decidable [26, 38, 39]. OWL 2 EL [39], which is defined on the family of $\mathcal{EL}$-Description Logics and comparable to Semantic MediaWikis knowledge representation formalism, employs PTime-complete complexity and allows for polynomial time reasoning[17]. More expressive languages such as OWL Full contain a richer set of language elements for defining logical axioms, however, at the cost of being undecidable.

Semantic MediaWiki adopts the set-based semantics of OWL for classes and roles (see [40]) and exhibits features such as equality reasoning and reasoning on the transitivity closures on category and property hierarchies. However, most of the expressiveness incorporated in OWL DL is not available in SMWs knowledge representation formalism. For scalability and consistency reasons, the language model of SMW is built on a less expressive fragment of OWL DL that allows for polynomial time reasoning on large corpuses of instance data at the cost of excluding some of the formal semantics well-known in OWL DL (cf. [24]).

Therefore, not all elements and ontological (TBox) constraints defined in the PO can be directly expressed in form of SMW elements. For instance, the SMW language model does not define elements for explicitly expressing *inverse properties* or *disjointness*. In the latter case, this means that in SMW, it is not possible to define a disjointness restriction on category level that expresses that two categories do not hold any page in common, i.e., an article cannot belong to both categories at the same time. For instance, the formal semantics defined in the PO TBox that the classes `ConceptContainer`, `KnowledgeDomain`, and `KnowledgeObject` are mutually disjoint cannot be expressed using Semantic MediaWikis knowledge representation formalism.

However, SMW provides some basic OWL DL language features that enable the formulation of *complex class expressions*, i.e., defining class membership constraints by means of logical axioms such that different requirements must hold for an individual to become member of a class. The language feature *Concept* enables the declaration of *dynamic categories* which contains only those articles that hold specific properties to pages belonging to another category or properties with specific values. Unlike OWL DL, concepts can not be used in combination with quantifiers or cardinality constraints. SMW does also not define means for expressing restrictions on the formal semantics of the data being annotated as it would be possible with OWL DL.

In consequence, SMW's knowledge representation formalism does not allow for formally evaluating the *logical consistency* of course material being annotated with terms imported from the PO and SLOM, as it would be the case with full-

[17] cf. http://www.w3.org/TR/owl2-profiles/#Computational_Properties

fledged ontology editors such as Protégé[18] and standard DL reasoners. That means that any inconsistency that might be introduced by a course designer cannot be automatically detected by a Semantic MediaWiki at design time of a course, but have to be dealt with at later stages, e.g., by external components since the limited expressiveness of Semantic MediaWikis knowledge representation formalism restraints users from the peril to unintentionally introduce formal inconsistencies on ABox, RBox, and TBox level to their ontologies [24].

In addition to the differing expressivity aspect of the underlying knowledge representation formalisms, a second aspect that need to be taken into consideration for exposing collaboratively created learning material as Linked Data is *schema compliance*. In contrast to ontological domain specifications, SMW does not make any assumptions regarding pre-existing classification schemes or vocabularies used for the description of domain knowledge. This means that elearning content creators have the freedom to individually define the vocabulary terms depending to the universe of discourse to which their learning material pertains. Due to the difference in terms of schema compliance between the PO and SMW[19] a universally valid approach can not be realized. Instead, import and mapping declarations for existing vocabularies or classification schemes need to be defined on an individual basis. However, such terms can be reused and refined by different content authors. This approach fits well into the given scenario as Semantic MediaWiki in general is an appropriate tool for authoring the instance data of complex ontologies since these are subject to more frequent changes compared to the rather stable terminological knowledge of ontologies.

4.3 Creating Vocabulary Import and Mapping Declarations

In a first step, the set of external vocabulary terms that should be available for content authors in a Semantic MediaWiki system must be declared using the special page `MediaWiki:SMW_import_{namespace}`. The special page `smw_import_{namespace}` contains a list of those vocabulary terms that should be imported and for which mapping declarations could be made; the elements can be individually chosen. The page belongs to the Mediawiki namespace and has the prefix `smw_import_`. It can only be created by users with administrator status and involves the declaration of an individual namespace in form of a `qname` (indicated in the {`namespace`}-part) to uniquely identify and reference imported terms in the mapping declarations of the associated Semantic MediaWiki terms.

Once the special import page is created, it can then be populated with import declarations. For making the PO and SLOM elements available in a SMW sys-

[18] http://protege.stanford.edu/

[19] The PO allows for the description of domain knowledge in a way so that an INTUTEL-enabled system is able to process such data and provide sophisticated services in the form of individual recommendations; Semantic MediaWiki, in contrast, does not exhibit any predefined or default schema nor impose any restrictions on the definition of individual schema information—apart from those imposed by the underlying data model.

tem, the import declarations of the import page must follow a specific notation and structure, which is illustrated in Figure 2[20].

```
http://www.intuitel.eu/public/intui_PO.owl#|
[http://www.intuitel.de/public/intui_PO.owl
Pedagogical Ontology of the INTUITEL Project]
 AbstractOrientation|Category
 ActionReceptive|Category
 AddressSource|Category
 AnimationPresentation|Category
 [...]
 containsConceptContainer|Page
 containsKnowledgeObject|Page
 containsLearningObject|Page
 hasBottomUpLikeRelation|Page
 hasCharacterizingObjectProperty|Page
 hasChronologicalLikeRelation|Page
 hasFromNewToOldLikeRelation|Page
 hasFromOldToNewLikeRelation|Page
 hasRecommendedAge|Type:Number
 isLinkedWithSlomPackageElement|Type:Text
 isLinkedWith|Type:Text
 isSuitableForBlind|Type:Boolean
```

Fig. 2. Excerpt of import declarations for Pedagogical Ontology's Elements

For each vocabulary that is to be imported into a Semantic MediaWiki instance, a base URI must be specified. In most Semantic Web vocabularies, it is common practice to specify terms as fragments of the vocabularys URI. For instance, the URI of the class `KnowledgeDomain` defined in the PO is

`http://www.intuitel.eu/public/intui_PO.owl#KnowledgeDomain` .

Before an agent can retrieve a machine-processable representation of the given concept, it first needs to strip-off the fragment part from the vocabularys URI and then de-reference the base URI (see [41]).

The following lines in the special import page declare each vocabulary element that will be imported and might be reused. This is the main part of the special import page and mandatory for declaring the mappings between the associated ontology terms and the individually defined SMW terms. Each line in the main part of the special import page starts with a whitespace followed by the

[20] For readability reasons, we sorted the elements alphabetically and separated category and page import declarations; we also included both element types (PO and SLOM) is this excerpt although we advocate to separate PO and SLOM elements for maintenance reasons.

specific name of the element (for most vocabularies, this is the fragment of the elements URI). The text after the pipe symbol ('|') declares the context in which an element can be used in the wiki. This part is important, as Semantic MediaWiki distinguishes between classes and properties to be imported: classes can only be used as categories; OWL object-, data-, and annotation properties can only be mapped to Semantic MediaWiki properties (see Table 1). The default type assignment for object properties is `Page`. For OWL datatype properties, a datatype must be explicitly stated using the `Type:{some datatype}` declaration, otherwise the default datatype `Page` is set. Vocabulary terms that should be imported as categories must be declared as `Category` using the category namespace identifier.

In order to separate the default PO elements from the SLOM elements contained in the PO, it is useful to create a separate import declaration page (e.g. `smw_import_slom`) to hold only those import declarations pertaining to the SLOM-specific datatype properties. Since all SLOM elements are defined as OWL datatype properties in the PO, each import declaration contains a type declaration that refers to a specific SMW datatype (see *List of Semantic MediaWiki Datatypes*[21]).

4.4 Creating Mapping Declarations for Associated Terms

The import vocabulary function of Semantic MediaWiki allows for the declaration of mappings between individually defined Semantic MediaWiki-specific terms and terms for external vocabularies, the so-called *associated terms*. In a second step, those mapping declarations need to be added to the Semantic MediaWiki property and category pages that are to be mapped to the imported vocabulary elements. This is done using the following statement on the individual property or category page:

```
[[imported from::{namespace}:{element_name}]]
```

The special property `imported_from` signals SMW that the element onto which page this declaration was added actually refers to the element specified by its namespace and name (e.g. `foaf:knows`) after the double colons '`::`'. Basically, all elements from external vocabularies in general and the PO specifically can be imported as described above. For instance, a mapping declaration on a category page that refers to the `intuit:KnowledgeDomain` class of the PO can be added to the category page in the following way:

```
[[imported from::intui:KnowledgeDomain]]
```

By interpreting this statement, the system can relate the category page to the associated term since it has been made available previously on the import declaration page. More information about the import of external vocabularies into

[21] http://semantic-mediawiki.org/wiki/Help:Properties_and_types#Datatypes_for_properties

a Semantic MediaWiki system can be found on the help page of the import vocabulary function in the Semantic MediaWiki Manual[22].

The import and mapping declarations also play a crucial role in the export of Semantic MediaWiki-authored course material as they built the basis for mapping the individual vocabulary terms defined by the course creator back to the respective elements of the PO and SLOM. This means, that the URIs of those categories and properties for which mappings have been declared are replaced by the URIs of the elements the mapping declarations refer to. This is an important aspect as terms being defined in a SMW system are local to it, i.e., when the URI of an element that is defined inside a Semantic MediaWiki system is exported to RDF via SMW's RDF export functionality, the element's namespace per default resembles the namespace of the MediaWiki system from which the element was exported. Technically, the associated terms from external vocabularies work like any other term in the Semantic MediaWiki, but the RDF data that are created when selected pages from the wiki are exported directly contain resolved PO and SLOM terms. In consequence, the Semantic MediaWiki terms are replaced during the export by its *associated terms* for which mappings have been declared.

4.5 Integrating Elements from External Ontologies

Although we have described the import and mapping declarations for the PO and SLOM elements exclusively, these elaborations can also be used for integrating arbitrary OWL ontologies in Semantic MediaWiki and making their elements available. For instance, the Pedagogical Ontology uses terms from the *Dublin Core Ontology*[23] for annotating its elements with title and description information using `dc:title` and `dc:description`. In order to maintain compliance with the annotation vocabulary of the PO, we recommend to also import these terms into a Semantic MediaWiki and use the corresponding wiki pages for the annotation of individually created learning material (CM and CCM). When the learning material is exported via the RDF Exporter (see Section 5.2), external tools can interpret and process these annotations along with the standard Dublin Core annotations contained in the PO, since their Semantic MediaWiki-specific namespaces will be replaced by the URIs of the associated terms (see previous section), even in case the terms are named differently.

4.6 Defining Individual Annotations

All elements from the imported external ontologies or vocabularies (PO, SLOM, Dublin Core, etc.) can be used for annotate content in the same way that any SMW property. Annotations in SMW are defined by specifying the value for the element after the colon ':', that is, `[[{element_name} : ... ]]`, where

[22] https://semantic-mediawiki.org/wiki/Help:Import_vocabulary
[23] http://dublincore.org/schemas/rdfs/

{element_name} is the SMW property that has been mapped to the imported vocabulary element.

First of all, each page in a Semantic MediaWiki system should be associated to a Semantic MediaWiki category, for example:

```
[[Category:ConceptContainer]]
```

where ConceptContainer should be mapped to the corresponding term of the PO (whose vocabulary must be imported beforehand into a Semantic MediaWiki system as detailed in Section 4.4).

Next, the page could be annotated making use of external vocabulary elements. For example, the following declaration in the page KD_A:

```
[[containsConceptContainer::CC_1|Name of the CC_1]]
```

relates CC_1 with KD_A by the property Property:containsConceptContainer (imported from the PO). Besides, a link to the page is included in the actual wiki page (the text following the pipe symbol '|' is shown rather than the real name of the linked page).

The #set statement can also be used for specifying properties' values in order to not show them on an article page: #set:{element_name}={element_value}. The following excerpt illustrate its usage in adding SLOM-specific metadata to an article page

```
{{#set:isSuitableForBlind=false}}
```

where the property isSuitableForBlind was defined as a new Boolean-type SMW property and mapped to the corresponding SLOM element.

5 Use Case: Adding Pedagogical Semantics to an E-Learning Course at the University of Valladolid

This section provides a description of the steps needed to model eLearning Course Content using a collaborative tool like Semantic MediaWiki. The specific objective is annotating existing learning content in order to make it into INTUITEL-compliant learning material. A real course about "Network Design" held at the Telecommunications School of the University of Valladolid has been used as use case[24].

This course focuses on different design aspects of four types of networks. There are two main alternative approaches to learn this course: (1) studying the different types of networks with their design considerations separately; (2) organizing the content hierarchically, in which the design aspects are considered as main topics, analyzing each aspect per type of network. Therefore, the cognitive map defined by the teachers of this course includes two macro learning pathways, using two of the MLP types pre-defined in the pedagogical ontology. Figure 3 shows part of the cognitive map, which has in total 24 CCs.

[24] Access to the Semantic MediaWiki system in which the course is modeled can be granted on request; please contact zander@fzi.de.

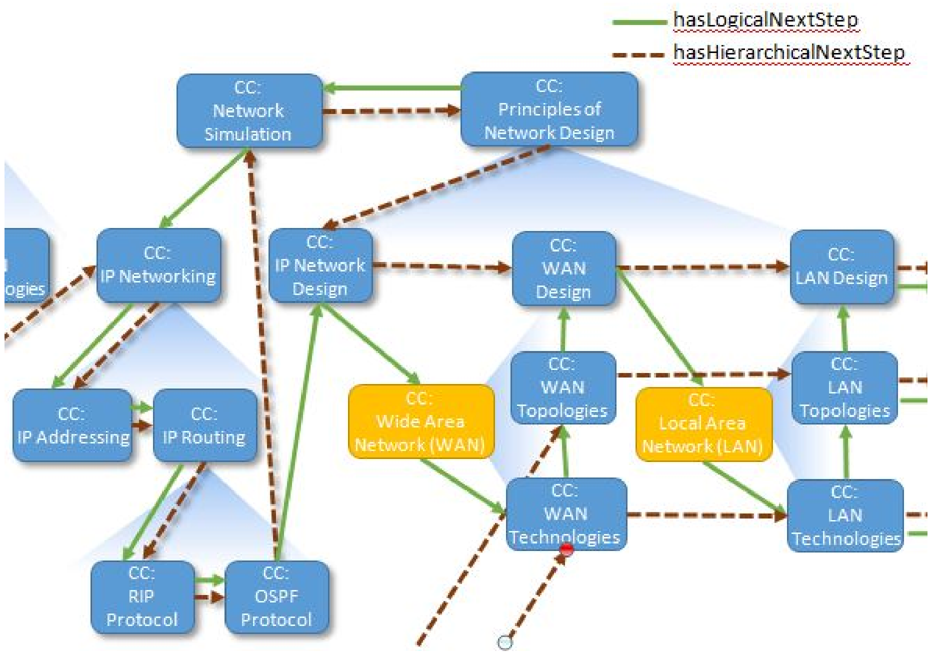

Fig. 3. Excerpt of the cognitive map of the course "Network Design"

The above mentioned first approach corresponds to the pathway labelled as `hasLogicalNextStep` while the second one is labelled as `hasHierarchicalNextStep`. For example, arrows of type `hasLogicalNexStep` guide from CC `Wan Technologies` to CC `Wan topologies` and, then, to CC `Wan design`, studying consecutively all the different aspects for the type of network WAN. However, in the `hasHierarchicalNextStep` pathway, CC `LAN technologies` is located after CC `WAN technologies`, following the approach of consecutively studying the different aspects, technologies in this case, for each type of network (WAN, LAN, etc).

The main page of the course represents the Knowledge Domain. This page contains an index or table of contents with 24 topics or lessons of the given course (the concept containers). With this approach, the CCs contained in a KD (e.g. `NetworkDesign`) can be specified in a straightforward way as illustrated in the SMW markup code excerpt displayed in Figure 4:

Each Learning Object (KD, CC, KO) has its own page in a Semantic MediaWiki system. Pages can be created and annotated by different authors. When creating the page, or later, it must be associated with the correct Semantic MediaWiki category. Therefore, three categories have been created together with their correspondent mappings to LO elements for the three different learning objects: `Category:KnowledgeDomain`, `Category:ConceptContainer` and `Category:KnowledgeObject`.

Once the learning material is semantically annotated, it can be exported to OWL/RDF format by means of Semantic MediaWiki's RDF Export facilities.

```
[[Category:KnowledgeDomain]]

[[containsConceptContainer::ccPrinciplesOfNetworkDesign
  |Principles of Network Design]]
[[containsConceptContainer::ccNetworkSimulation|Network Simulation]]
[[containsConceptContainer::ccIPNetworking|IP Networking]]
```

Fig. 4. Excerpt of the Semantic MediaWiki page `kdNetworkDesign`

5.1 Annotating E-Learning Course Content

This section shows some examples of how imported elements can be used for annotating real course content

The first example corresponds to a wiki page for a CC, which is equivalent to a unit of the course. The CC page contains the metadata annotations as well as a list of all the course KOs. Figure 5 depicts how the imported elements can be used for annotating a wiki page that corresponds to a CC:

```
[[Category:ConceptContainer]]
=[[title::Concept Container -- Network Simulation]]=

<!-- Description of the CC's content -->
[[description:: This Concept Container ...]]

Contents of this topic:
*[[containsKnowledgeObject::KO_PresentationSimulationOPNETModeler |
  Presentation about Simulation with OPNET Modeler]]
*[[containsKnowledgeObject::KO_LaboratoryExerciseOPNETModeler |
  Laboratory exercise with OPNET Modeler]]
```

Fig. 5. Excerpt of the Semantic MediaWiki page `ccNetworkSimulation`

First of all, the page is associated with the category `ConceptContainer`. Next, the LO is annotated making use of the DC elements `title` and `description`. All these elements used for annotation should have been previously imported, as described in previous sections. Finally, the content, i.e., the knowledge objects the CC consists of are specified in form of a list of KOs. Each KO is linked and associated by the property `containsKnowledgeObject`, which previously should be mapped to its associated PO term (see Section 4.4).

A CC page should contain also the CCs it links to, but using the adequate properties in order to form the INTUITEL *macro learning pathways*. In the current CM—as mentioned above—two Macro Learning Pathways have been defined:

– `hasLogicalNextstep` as a sub property of `hasFromOldToNewLikeRelation`
– `hasHierarchicalNextstep` as a sub property of `hasTopDownLikeRelation`

where `hasFromOldToNewLikeRelation` and `hasTopDownLikeRelation` are defined in the INTUITEL PO. Since SMW supports the definition of semantic sub properties, these two custom macroLP properties can be directly mapped to SMW-compliant properties (that might share identical labels). The range of those SMW-compliant macroLP properties are SMW pages that belong to the category CC.

Therefore, two new SMW properties (and the correspondent SMW articles) have been created:

`Property:HasLogicalNextstep` and `Property:hasHierarchicalNextstep`

Then, they must be defined as sub properties of two new SMW properties, which map to the imported PO properties.

For example, the page of `Property:HasLogicalNextstep` contains the following statements (corresponding to two special properties of the wiki):

```
[[Has type::Page]]
[[subproperty of::HasFromOldToNewLikeRelation]]
```

where `HasFromOldToNewLikeRelation` is another specific SMW property mapped to the imported PO term.

The same should be done for each custom macroLP property. Then, they can be used in pages of CCs.

For example, the page of declarations `ccNetworkSimulation` includes:

```
[[hasLogicalNextstep::ccIPNetworking]]
[[hasHierarchicalNextstep::ccPrinciplesOfNetworkDesign]]
```

The second example corresponds to a wiki page for a KO. A KO page will contain the CMM metadata annotations as well as the content of the KO or references to resources as PDF files. For example, the excerpt shown in Figure 6 is part of the declarations page of `KO_LaboratoryExerciseOPNETModeler`.

All the properties must be created the first time by defining SMW properties and then mapping them to the elements of the imported vocabulary.

A KO page should also contain links to other KOs, but using the adequate properties in order to form the INTUITEL *micro learning pathways*. There are no custom micro-level relations in the CMM, but properties defined in the INTUITEL PO. Then, once the SMW properties have been created and mapped to the correspondent imported PO properties, they can be used in pages of KOs in order to relate KOs to form a micro learning path.

5.2 Exporting the Semantically Annotated E-Learning Content

The INTUITEL-compliant learning material can be exported into OWL/RDF format by means of SMW facilities. The Semantic MediaWiki's RDF Export function is called by using the special RDF Export page. It generates an OWL/RDF

```
[[Category:KnowledgeObject]]

{{#set:hasKnowledgeType=ktStepByStepGoodPractice}}
{{#set:hasMediaType=mtVideoPresentation}}
{{#set:hasEqfLevel=6
 |hasEstimatedLearningTime=12 minutes
 |hasLanguage=ES
 |isSuitableForBlind=false
 |isSuitableForDeaf=false
 |isSuitableForMute=true
 |hasRecommendedAge=10}}
```

Fig. 6. Excerpt of the article page `KO_LaboratoryExerciseOPNETModeler`

document with the import and mapping declarations for the articles pages of the individual elements. The export function also assigns URIs to all articles that are exported, and replaces the URIs of those Semantic MediaWiki TBox elements for which a mapping declaration to their corresponding, i.e., associated elements from the PO has been defined.

The RDF Export function generates an OWL/RDF document with regard to the import and mapping declarations for the article pages of the individual elements. The export function also assigns URIs to all articles that are exported, and replaces the URIs of those Semantic MediaWiki TBox elements for which a mapping declaration to an associated element from the PO has been defined. The pages corresponding to the examples of the previous section have been exported using the special RDF Export page. Next we are going to show how some annotations are represented in the exported files.

Figure 7 displays an excerpt of the exported RDF file for the wiki page `ccNetworkSimulation` represented as Manchester OWL Syntax[25] (see the origin annotated wiki page in Figure 5). The lines

```
Individual: wiki:CcNetworkSimulation
  Types:
    intui:ConceptContainer,
    swivt:Subject
```

allows to identify this object as an instance of the class `ConceptContainer` defined in the published INTUITEL PO. This is the exporting result of the annotation in line 1 of the code excerpt of Figure 5.

With reference to the wiki article about the concept container `NetworkSimulation`, the exported RDF document does not miss any relevant information.

For example, the 2 KOs annotated in the origin wiki page (lines 8 and 10 of the code excerpt of Figure 5) can be retrieved from this RDF file as

[25] http://www.w3.org/TR/owl2-manchester-syntax/

```
Prefix: dc: <http://purl.org/dc/elements/1.1/>
Prefix: owl: <http://www.w3.org/2002/07/owl#>
Prefix: rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
Prefix: xsd: <http://www.w3.org/2001/XMLSchema#>
Prefix: rdfs: <http://www.w3.org/2000/01/rdf-schema#>
Prefix: wiki: <http://kalmar30.fzi.de/index.php/Spezial:URI-Aufl%C3%B6ser/>
Prefix: intui: <http://www.intuitel.eu/public/intui_PO.owl#>
Prefix: swivt: <http://semantic-mediawiki.org/swivt/1.0#>

Ontology: <http://kalmar30.fzi.de/index.php/Spezial:RDF_exportieren/CcNetworkSimulation>

Import: <http://semantic-mediawiki.org/swivt/1.0>

Annotations: swivt:creationDate "2015-09-08T11:51:24+02:00"^^xsd:dateTime

AnnotationProperty: swivt:creationDate
AnnotationProperty: rdfs:isDefinedBy
AnnotationProperty: rdfs:label

Datatype: rdf:PlainLiteral
Datatype: xsd:string
Datatype: xsd:dateTime
Datatype: xsd:double
Datatype: xsd:integer

ObjectProperty: wiki:HasLogicalNextStep1
ObjectProperty: wiki:HasHierarchicalNextStep1
ObjectProperty: swivt:page
ObjectProperty: intui:ContainsKnowledgeObject

DataProperty: swivt:wikiPageModificationDate
DataProperty: swivt:wikiNamespace
DataProperty: dc:title
DataProperty: dc:description
DataProperty: swivt:wikiPageSortKey
DataProperty: swivt:creationDate
DataProperty: wiki:Modification_date-23aux

Class: intui:ConceptContainer
Class: swivt:Subject

Individual: wiki:CcNetworkSimulation

  Annotations:
    rdfs:label "CcNetworkSimulation",
    rdfs:isDefinedBy
          <http://kalmar30.fzi.de/index.php/Spezial:RDF_exportieren/CcNetworkSimulation>

  Types:
    intui:ConceptContainer,
    swivt:Subject

  Facts:
    wiki:HasLogicalNextStep1  wiki:CcIPNetworking,
    intui:ContainsKnowledgeObject  wiki:KO_ExampleOPNETModeler,
    intui:ContainsKnowledgeObject  wiki:KO_LaboratoryExerciseOPNETModeler,
    swivt:page  <http://kalmar30.fzi.de/index.php/CcNetworkSimulation>,
    intui:ContainsKnowledgeObject  wiki:KO_VideotutorialOPNETModeler,
    intui:ContainsKnowledgeObject  wiki:KO_PresentationSimulationOPNETModeler,
    wiki:HasHierarchicalNextStep1  wiki:CcPrinciplesOfNetworkDesign,
    dc:title  "Concept Container - Network Simulation"^^xsd:string,
    swivt:wikiNamespace  0,
    swivt:wikiPageSortKey  "CcNetworkSimulation"^^xsd:string,
    dc:description  "This Concept Container contains information about Network Simulation
          as a tool for designing all type of networks."^^xsd:string,
    swivt:wikiPageModificationDate  "2014-03-05T09:36:46Z"^^xsd:dateTime

Individual: wiki:KO_VideotutorialOPNETModeler
Individual: wiki:CcPrinciplesOfNetworkDesign
Individual: wiki:KO_PresentationSimulationOPNETModeler
Individual: wiki:KO_ExampleOPNETModeler
Individual: wiki:KO_LaboratoryExerciseOPNETModeler
Individual: wiki:CcIPNetworking
```

Fig. 7. Excerpt of the exported Concept Container `ccNetworkSimulation`

the property `intui:containsKnowledgeObject` links the CC with the 2 wiki pages containing the relevant data of those KOs (lines 56 and 59 in Figure 7). Besides, the specific wiki properties `property:HasHierarchicalNextstep` and `property:HasLogicalNextstep` are used in order to locate this CC in the different Macro Leaning Pathways it belongs to:

```
Individual: wiki:CcNetworkSimulation
  [...]
  Facts:
    wiki:HasLogicalNextStep wiki:CcIPNetworking,
```

Therefore, this shows how the approach could be used for collaborative definition of different learning paths. The same wiki content can be studied in different sequences, defined by the macro learning paths. Students, by themselves or guided by an intelligent tutor systems like INTUITEL, can select different learning paths thanks to the previously wiki annotations.

Figure 8 shows an example of the recommendations provided by the INTUITEL system when using this INTUITEL-compliant annotated material. This example corresponds to a Moodle site connected to the intelligent system. The learner is visiting a KO, which is part of the concept container `Network Simulation` (the one corresponding to the code shown in Figure ...) and the INTUITEL system is showing its content recommendations on the top-left side of the window. The preferred learning pathway of the student is the once labelled as `HasLogicalNextstep` thus two KOs belonging to the next CC in that pathway, CC `IPNetworking`, are recommended.

To conclude, we have shown that the default RDF Export function of Semantic MediaWiki, when the imported elements are used consistently, is able to preserve the pedagogical and formal semantics encoded in the PO. Therefore, those elements can be used by pedagogical teams in order to annotate the wiki pages of the course with pedagogical metadata. Those metadata will be the input for intelligent tutor systems like INTUITEL, which will recommend students learning pathways adapted to their particular needs and context.

6 Usability Test

An user evaluation study was conducted to study the usability and the efficiency of the proposed approach from a teacher or instructional point of view. The goal of the evaluation is to test, if the approach is useful for pedagogical teams while they create content and annotate content with pedagogical metadata while measuring the overall user satisfaction. Improvements in learning performance is not considered and tested since the proposed approach only addresses authoring workflows. Due to the fact that exported learning material can not be inconsistent because of the description logic family upon which Semantic MediaWiki's knowledge representation formalism is defined, we did not test for that in the evaluation.

Fig. 8. Recommendations computed by the INTUITEL system based on the exported learning material for the course Network Design

If users are satisfied with the approach, we can assume that Semantic MediaWikis are a promising tool for the production and annotation of learning content with pedagogically meaningful and expressive ontological semantics. We assume that users are satisfied if the usability and the efficiency as rated by the users shows positive results. Since we additionally assume that sometimes online courses are created by people who are none computer experts, we compared users from departments of Computer Technology and users from departments of Education to research if the usability of SMW is acceptable for both user groups. Thus the research questions of our empirical study are:

RQ1: Does the usability test indicate an user satisfaction (usability and efficiency) in the positive half of the usability test, i.e., a value above 3.5?

RQ2: Does the measured usability show no differences in user satisfaction among faculties from Computer Technology departments and from departments of Education?

For testing the usability, an we used a freely available standard usability test. Since we conducted a post-test, we decided to use the Post-Study System Usability Questionnaire (PSSUQ) as suggested by Lewis [42]. In this test, system usefulness, information quality and interface quality are measured. Since our research questions asks for the overall user satisfaction only, we used the test as a general indicator for usability. This is in line with the psychometric evaluation of the test [43].

The Hypotheses to be evaluated in this study are

H1: The usability test indicates an user satisfaction (usability and efficiency) in the positive half of the usability test result, i.e., a value above 3.5.

H2: The usability test indicates that there are no relevant differences in terms of user satisfaction among users from departments of Computer Technology and users from departments of Education.

For the first hypothesis, we used the middle of the scales as decision criterion. If the results are in the positive half of the scale, we consider an acceptable user satisfaction as indicated. For the second hypothesis, we used two decision criteria: If the results for both groups are in the positive half of the scale and do not show significant differences, we assume that the usability of SMW is acceptable for people from departments of Education as well as for people from departments of Computer Technology.

For the usability test, a Semantic MediaWiki was set up. Example content was created. The INTUITEL PO and SLOM were imported. Staff members from departments of Computer Technology and from departments of Education, who were involved in the INTUITEL project, were invited to participate as experimental subjects. Since the survey was taken anonymously, the exact position of the single experimental subject who actually participated in the study is not known. We invited junior and senior researchers and all of them participated. Thus we know that junior and senior researchers participated in the study. The experimental subjects were selected since they were familiar with the INTUITEL PO and SLOM and the Webdidactic concept. Thus we can assume that the process of learning the metadata system and the vocabulary did not influence the results of the usability test.

Six junior and senior researchers from departments of Computer Technology and nine junior and senior researchers from departments of Education participated in the usability test. Access data to the prepared Semantic MediaWiki and a usability questionnaire were sent to the participants. On the starting page of the Semantic MediaWiki, background information and instructions for the test were provided. The background information included (i) links to the imported ontologies, (ii) links to sample courses to illustrate structural coherences, and (iii) links to Semantic MediaWiki support pages. Thus participants could easily look up classes and properties, copy annotations from existing pages and retrieve information from available help pages. The instructions for the test as shown in Figure 9 were provided on the starting page after the background information.

The usability test was provided as a spreadsheet file. The participating experimental subjects filled in the questionnaire in the spreadsheet and sent the

```
2.2 Conduct the test

Task 1: Create individual terms, ie., annotations in form of properties and/or categories
that you will use for annotating the course you create in Task 2.

Task 2: Create a 9-page-course with 3 Concept Containers (CCs) and 3 Knowledge Objects (KOs)
per CC, where two learning pathways are used in each CC and among the CCs.
 1. Create the first page of your test course as a knowledge domain, i.e., add it to the
    category 'KnowledgeDomain' (edit this page to do this):
    Example 1
    Example 2
    YOUR FIRST PAGE HERE (copy the line above and edit it to create your first page)
 2. Create 3 exemplary concept containers (CCs).
 3. Create two macro learning pathways (MLP) between the CCs
 4. Create 3 exemplary knowledge objects (KOs) in each CC and create/copy example content.
 5. Annotate each KO. Use at least one annotation property for knowledge type,
   media type and level.
 6. Create two micro learning pathways in one of the CCs
```

Fig. 9. Excerpt of the task descriptions for the usability testing

file to the research team. The items were based on the usability test as suggested by Lewis [42]. The labels (SYS and INFO) were taken from Lewis and indicate two subscales of the usability test. Since our Hypotheses refer to the overall user satisfaction, the subscales are not relevant for our study. The items were adopted in order to reflect the actual test situtation where a Semantic Media Wiki was used to annotate content with INTUITEL metadata.

In the usability test, a seven point Lickert scale was used with 7 as "strongly agree" and 1 as "strongly disagree". As statistical methods to analyze the observed results, we mainly used descriptive statistics. We calculated the mean for each item, the overall mean, and the means for faculties from departments of Computer Technology and from departments of Education.

For our first hypothesis (*"The usability test indicates an user satisfaction (usability and efficiency) in the positive half of the usability test result, i.e., a value above 3.5"*) the results show that the overall mean of all answers was $\overline{x} = 4.45$. This is nearly one point above the middle of the scale, while the result is in the lower part of the positive half of the scale. Additionally, the individual averages of all users who participated in the study were in the positive part of the scale, ranging from 3.79 to 5.64. Thus 100% of the users rated the overall usability as positive. The mean of the items that ask for efficiency (SYS 3, SYS 5, SYS 6, SYS 7, SYS 8) is 4.74. The mean of all other items is 4.26. Both values are in the positive half of the scale. Thus, users feel that the usability and the efficiency of the system is good. These results do not falsify our hypothesis H1, which we thus keep up.

For our second hypothesis (*"The usability test indicates that there are no relevant differences in terms of user satisfaction among users from departments of Computer Technology and users from departments of Education."*) the results show that the average of faculties from departments of Computer Technology

Table 3. Items of usability test

Label	Item
SYS 1	Overall, I am satisfied with how easy it is to use Semantic Media Wiki as an authoring tool
SYS 2	It was simple to use this system to create pedagogically meaningful annotations
SYS 3	I can effectively complete the given tasks
SYS 4	I am able to create individual terms and map them to the imported vocabulary terms
SYS 5	I am able to efficiently create new courses (Knowledge Domains)
SYS 6	I am able to efficiently create Concept Containers (CCs)
SYS 7	I am able to efficiently create Knowledge Objects (KOs)
SYS 8	I am able to efficiently create Learning Pathways
SYS 9	It was easy to learn how to use collaboratively created annotations using this system
SYS 10	I feel comfortable using this system
INFO 1	Whenever I make a mistake using this system, I recover easily and quickly
INFO 2	The information (such as online help, on-screen messages, and other documentation) provided with Semantic Media Wiki is clear
INFO 3	It is easy to find the information I needed
INFO 4	The information provided for using the imported pedagogical terms is easy to understand
INFO 5	The information provided is effective in helping me complete the tasks and scenarios
INFO 6	The organization of information using the provided vocabulary terms is clear
INFO 7	I feel comfortable using the Semantic Media Wiki syntax
INFO 8	This system has all the expressive features and capabilities I expect it to have
INFO 9	Overall, I am satisfied with this system

was $\overline{x} = 4.85$, while the average of faculties from departments of Education was $\overline{x} = 4.16$. Both results are clearly in the positive half of the scale. The difference appears small. To test the relevance of the difference, we applied the procedure as suggested by [44]. At first, a descriptive investigation for normal distribution has been conducted (according to Rasch et al., a Kolgomorov-Smirnow-Test is not appropriate for our sample size). The distribution has a slight skewness to the right, is relatively flat, and does not show relevant deviations from a normal distribution. Next, a Levene-Test for $H_0\colon \sigma_1^2 = \sigma_2^2$ has been calculated. The result is highly significant (Levene-test, $p < 0.001$). Thus, we have to assume that the variances are heteroscedastic. This has been considered in the degrees of freedom that have been used in the calculation of the t-test. Since we assume differences among researchers from departments of Computer Technology and researchers from department of Education, a t-test for $H_0\colon \overline{x}_1 = \overline{x}_2$ has been calculated. As we have no prior data that could justify a single sided test, we calculated a double sided test. The result shows that the difference is significant (t-test, $p<0.01$). There is a significant difference among faculties from departments of Computer Technology and faculties from departments of Education. This result does falsify our hypothesis H2, which we thus reject.

With respect to H2, the difference between faculties from departments of Computer Technology and faculties from departments of Education could have been expected, since it is necessary to enter Semantic MediaWiki markup syntax into the content pages. An interface that supports the data entry process, for instance by drop down menus, or a syntax checking method was not provided. Since writing markup code is uncommon for faculties from departments of Education, it is not astonishing that the results are lower. In turn, it might be considered as astonishing, that the people from departments of Education still judged the system with an overall positive result. Additionally, the difference is significant, but not very high. Thus the results show the potential of using Semantic MediaWikis as a tool to create semantically enriched content for teaching and learning and indicate a need for usability improvements.

The overall results as expressed in the overall means reported before are also clearly visible in the means per item as shown in figure 10. In the figure, the means per item for all users are shown as Sum. The x-axis refers to the items of the usability test that are listed in Table 3. All means for all items are above 3.5, with one exception. The item "It is easy to find the information I need (INFO 3)" was judged negatively by people from departments of Education. At the same time, the difference between the people from departments of Computer Technology and people from departments of Education was relatively high for this item. This can be explained by the fact the the information about the metadata system was provided as import result pages in the Semantic MediaWiki. These pages show the information like code with hypertext markup. Thus these pages were most probably difficult to read for people from departments of Education.

The assumption that working with syntax is unfamiliar for people from departments of Education and thus reduces the usability in terms of retrieving necessary information and entering metadata is supported by the answers on

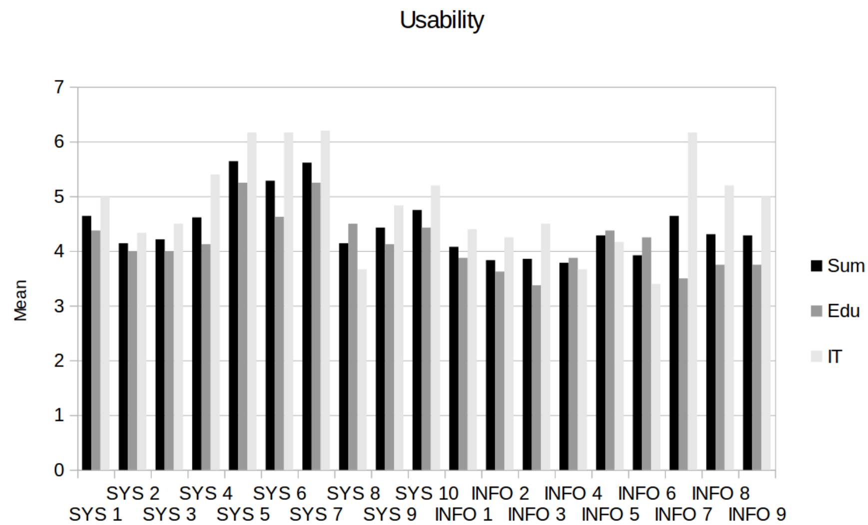

Fig. 10. Results of the usability test

item INFO 7 "I feel comfortable using the Semantic Media Wiki Syntax". While the average of people from departments of Computer Technology was 6.17, the average of people from departments of Education was 3.5. This suggests that Semantic MediaWikis as used in our study, are appropriate for computer specialists, but should be enhanced with tools to enter metadata for non computer specialists. Still, the overall satisfaction which was asked for in item SYS 1 was quite high for all participants. And even the creation of individual terms, which is not an easy concept from people from departments of Education, was judged clearly positive. This again shows the high potential of Semantic MediaWikis as a tool to create semantically enriched content for teaching and learning.

7 Limitations

In this section, we critically review the presented approach and highlight its limitations that serve as indicators for directing future work and research:

1. *No guarantee for schema compliance during the authoring process*
   SMW has been created with the idea in mind to extend wikis with machine-processability of their content to suport knowledge organization and sharing while maintaining its inherent wiki authoring style [7, 23]. The presented approach, therefore, can not support checking for schema compliance during authoring processes per default—in particular due to the following reasons:
   (i) SMW does not make any assumptions regarding existing or prescribing schemas; therefore, it is not possible to define a schema against which created learning content can be checked for compliance.

(ii) The knowledge representation formalism underlying SMW is built upon a description logic fragment that does not allow for the creation of unsatisfiable assertions, i.e., the data created with SMW can per design never be inconsistent (cf. limitation #2).

These facts also limit the model checking capabilities of SMW and the automated transformation of learning content into other formats such as IMS Learning Design and SCORM (see Section 2.3). Such transformations still require a priori specification of mapping declarations plus external tools or activities for building content packages. Checks whether the imported elements are used correctly and annotations are consistent with PO and SLOM semantics can only be conducted posterior to an authoring process when learning material is exported and requires the deployment of an external OWL-DL-compliant reasoner[26]. An integration of consistency and compliance checks in the authoring process, e.g., in form of an Extension, would have a positive impact on INFO 1 and INFO 2 (see Figure 10).

2. *Limited expressivity of Semantic MediaWiki's knowledge representation formalism*
   Semantic MediaWiki's knowledge representation formalism is a less expressive subset of the description logic upon which OWL and hence the PO and SLOM are defined (cf. Section 4.1). Due to this unilateral incompatibility, only a limited set of the TBox and RBox axioms, in particular constituting axioms, can be imported but not axioms that use OWL DL language elements for defining the semantics of those terms (e.g., disjointness, quantifiers, inverse relationships, equivalence, or class membership restrictions etc). This prevents SMW content authors to utilize the entire feature set of pedagogical semantics encoded in the PO and SLOM during the authoring process. While it is possible to use imported terms as intended, i.e., according to the semantics defined in the PO, SMW's default reasoning capabilities do not allow for consistency or compliance checking during the authoring process, as indicated by the comparatively low scores of INFO 1 and INFO 2.
3. *Creation of self-contained learning units requires external tools such as the INTUITEL Merger*[27]
   The presented approach, in its current version, exports the articles' content plus contained annotations in form of RDF graphs and requires additional tools for building self-contained learning content packages that can be used in an INTUITEL-enabled Learning Management System (LMS)[28] If concrete media files such as PDF documents, presentations, video or audio files are linked in exported article pages, only their dereferencable URIs are exported but not their actual content. In order to retrieve such media and amalgamate

[26] One possibility to overcome this limitation is integrating DL reasoning capabilities via a Semantic MediaWiki Extension.

[27] The INTUITEL Merger is specified in Deliverable 6.1: http://www.intuitel.de/wp-content/uploads/2015/06/INTUITEL_318496_D6_1_MergerDoc.pdf

[28] While this aspect has no direct influence on the authoring process and its usability, which was studied in the evaluation, it might impede market penetration of the presented approach specifically and SWMs in generally.

it with wiki content and corresponding annotations, their URLs need to be dereferenced and its media content stored locally to build a self-contained content package. This involves a remapping of multimedia content file URIs in the exported RDF graphs since they still point to the URI of the Semantic MediaWiki that hosts those files. The INTUITEL Merger has been implemented as a self-contained tool that performs URI dereferencing and remaps the URIs of contained content files to their location in a SLOM content package, i.e., the learning unit loaded into a LMS. Future work aims at integrating the INTUITEL Merger with SMW in order to create self-contained content packages directly within SWM.

4. *Import of ABox data (instances) by default requires manual intervention* ABox data can not be imported directly by default and need to be added manually to a Semantic MediaWiki system. This has some implications for ontologies that also contain instance data. The PO, for instance, defines one specific instance for each knowledge and media type to enable the formulation of assertions such that a KO participates in a `hasMediaType`-relation to the singleton instance that corresponds to the specific media type class[29]. Although the model-theoretic semantic of such an assertion is different, it allows for the usage of instances both on ABox and TBox level and corresponds to the notion of *DL nominals* (see [33–35]). This concept is useful in situations where classes should also be used as single individuals and where it seems unnatural to have multiple instances of one class (cf. [45]). To overcome this limitation, we have created an ontology import tool for Semantic MediaWiki[30] that analyzes all ABox axioms of an ontology, creates article pages of constituting elements, and assigns them to the corresponding categories, i.e., the classes of which the instances are members of in the ontology. It also analyzes relationships between instances and tries to resemble them in the target SWM system.
5. *Annotating content requires knowledge of the vocabulary and the wiki markup language* In the current version, the system requires sound knowledge of the metadata vocabulary in the PO that is used to annotate content. Our usability study showed that this might keep users from using Semantic MediaWiki as an editing tool. This seems similar to editing content itself, which required learning the wiki markup language and their formal semantics until recently. The necessity to learn the wiki markup language was perceived as a restriction by non-computer specialists that kept many people away from contributing to Wikipedias. To overcome this restriction, the VisualEditor for MediaWiki has been developed and deployed in most Wikipedias. This makes the production of content for non-computer specialists much easier

[29] The same applies for knowledge types.

[30] The Ontology Import Tool will be released as open source and can be downloaded from the official INTUITEL project Web site as well as from the Open Source section of the FZI Research Center for Information Technology Web site https://www.fzi.de/forschung/open-source/.

and suggests to develop an enhancement for Semantic MediaWiki that supports the annotation of content with a tool that might for instance be based on drop down lists.

The last point in particular illustrates that the presented approach requires an additional technical annotation facility that not only helps non-technical experts in understanding the intended semantics of imported terms but also shows additional information about them, i.e., how they are linked together. One possibility to do that is by defining semantic templates[31] specifically designed for imported ontology elements. Such templates can then be used in combination with Semantic Forms[32] to guide non-technical users in particular in the annotation process and hence contribute towards an improved usability of the system.

Other limitations, that are not related to the primary focus of this work but might be required by learning content authors are, e.g., true synchronous collaborative editing of wiki articles and real-time change tracking (see e.g.[11]).

8 Conclusion

In this work, we present an approach for the collaborative annotation of learning material using pedagogically well-defined semantics in a Semantic MediaWiki system. We introduce Web Didactics as knowledge organization system together with the Pedagogical Ontology and the Semantic Learning Object Model as manifestations of the Web Didactics concepts. We also discuss limitations of Semantic MediaWiki's knowledge representation formalism and demonstrate how pedagogically meaningful terms from the PO and SLOM can be made available in a Semantic MediaWiki system through import and mapping declarations. These declarations constitute the foundation to map imported ontology terms to the individual vocabulary used in a Semantic MediaWiki for the annotation of learning content so that content developers are not forced to adapt to new vocabularies but can use the terms and classification systems they are familiar with. Through a network design course taught at the University of Valladolid, we show how imported terms can be used for the annotation of real course material and how the inherently defined pedagogical semantics can be preserved when the course content is exported as Linked Data. This use case also demonstrates that when PO and SLOM terms are used in a consistent manner, a direct mapping between those terms and Semantic MediaWiki language elements can be realized without compromising the formal semantics of the PO and SLOM. We study the impact of the presented Semantic MediaWiki-based annotation approach in terms of its usability for researchers and lectures from Computer Technology and Education departments. Results were promising and proved a good overall usability. This reveals the potential of Semantic MediaWikis to create semantically enriched content for teaching and learning.

[31] http://semantic-mediawiki.org/wiki/Help:Semantic_templates
[32] https://www.mediawiki.org/wiki/Extension:Semantic_Forms

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