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Context-Adaptive Learning Designs by Using Semantic Web Services

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Abstract: IMS Learning Design (IMS-LD) is a promising technology aimed at supporting learning processes. IMS-LD packages contain the learning process metadata as well as the learning resources. However, the allocation of resources – whether data or services - within the learning design is done manually at design-time on the basis of the subjective appraisals of a learning designer. Since the actual learning context is known at runtime only, IMS-LD applications cannot adapt to a specific context or learner. Therefore, the reusability is limited and high development costs have to be taken into account to support a variety of contexts. To overcome these issues, we propose a highly dynamic approach based on Semantic Web Services (SWS) technology. Our aim is moving from the current data- and metadata-based to a context-adaptive service-oriented paradigm. We introduce semantic descriptions of a learning process in terms of user objectives (learning goals) to abstract from any specific metadata standards and used learning resources. At runtime, learning goals are accomplished by automatically selecting and invoking the services that fit the actual user needs and process contexts. As a result, we obtain a dynamic adaptation to different contexts at runtime. Semantic mappings from our standard-independent process models will enable the automatic development of versatile, reusable IMS-LD applications as well as the reusability across multiple metadata standards. To illustrate our approach, we describe a prototype application based on our principles.

Keywords: IMS Learning Design, Semantic Web Services, Learning Context, Service oriented Architecture, WSMO, E-Learning, IRS III

1 Introduction

IMS Learning Design (IMS-LD) is a promising technology to support learning processes. It enables the integration of learning activities with available learning resources based on an established standard. Following the IMS-LD specification (IMS, 2006), the description of a learning process is included into a composite learning object together with the used learning resources - the physical data assets. Whereas the learning resources are allocated at design-time of a specific learning design, the actual learning context – e. g. the needs of an individual learner - is known at runtime only. Therefore, a learning design based application can not adapt dynamically to specific learning contexts and only few opportunities to reuse a learning design do exist (cf. Amorim, Lama, Sánchez, Riera, & Vila, 2006 and Knight, Gašević, & Richards, 2006).

To overcome these issues and thus enable a dynamic adaptation to the learning context and learner needs, we follow the idea of providing the learner with a dynamic supply of appropriate learning-related functionalities at runtime. The considered functionalities are in principle provided by several organizations and accessible by means of Web service technology. Using Web services, the resulting services [1] are autonomous and platform-independent computational elements, and thus the delivered resources can be shared with anyone through the Internet. However, standard Web service technology does not provide the facilities to completely describe the capability of a service in a way to be understood by software programs - the meaning of inputs, outputs and applicable constraints, as well as the context in which a service can be used. In contrast, Semantic Web Services (SWS) technology provides an infrastructure in which new services can be added, discovered and composed continually, and the organizational processes automatically updated to reflect new forms of cooperation. It combines the flexibility, reusability, and universal access that typically characterize a Web service, with the expressivity of semantic mark-up, and reasoning of Semantic Web (Berners-Lee et al, 2001). Based on semantic descriptions of functional capabilities, a SWS broker automatically selects and invokes Web services appropriate to achieve a given goal in a specific context.

In our vision, learning processes are described in terms of user objectives (learning goals) and abstract from any specific data and metadata standard. Goals are accomplished by automatically selected functionalities fitting the actual user needs and process contexts. Functionalities support the process accomplishment by delivering the adequate resources to the user. To actualize this vision, we adopted a layered approach: Web services provide the base layer of executable functionalities; a SWS broker and ontologies support the gradual abstraction from the functionality selection, composition, and invocation to the process context adaptation; finally, semantic mappings will enable the automatic development of versatile, reusable IMS-LD applications as well as the reusability across multiple metadata standards in order to achieve interoperability of a specific learning design. The result is a highly dynamic service-oriented framework based on semantic Web services (SWS) technology.

In this way, we enable a paradigm-shift from the current manual allocation of resources at design-time to an automatic allocation of functionalities at run-time, which indeed provides the dynamic adaptation to different contexts. Furthermore, the introduction of standard-independent semantic process models addresses the reusability across multiple metadata standards. Finally, both the dynamic adaptation and standard independence lead to a reduction of the development costs.

The rest of the paper is structured as follows: the following section provides brief background information about the the specific approach adopted – i.e. IRS-III (Cabral et al 2006) as SWS broker and WSMO (WSMO Working Group, 2004) as reference ontology for describing services; Section 3 analyses the issues of current e-Learning technologies to detail the motivation of our approach; Section 4 then describes our approach of using a SWS-oriented architecture to support learning contexts, followed by a section introducing our ontological framework; Section 6 explains a prototype application based on IMS-LD and our SWS based approach, followed by the description of the implemented semantic mappings to enable the context-adaptation at runtime in Section 7. To validate the benefits of our approach, Section 8 provides a formalized comparison of our approach with the current state of the art. Finally, Section 9 summarizes the contributions of our work and provides an outlook to future work.

2 Background: IRS-III, a broker-based approach for SWS

IRS-III (Cabral et al 2006), the Internet Reasoning Service, is an implementation of a SWS broker environment. It provides the representational and reasoning mechanisms, which enable the dynamic interoperability and orchestration between services as well as the mediation between their semantic concepts. IRS-III utilizes a SWS library based on the reference ontology Web Service Modelling Ontology (WSMO) (WSMO Working Group, 2004) and the OCML representation language (Domingue et al 1999) to store semantic descriptions of Web services and knowledge domains. Different forms of service implementations can be described, encapsulated and exposed as SWS by using IRS III: standard WSDL-based services, Java functionalities or LISP functions.

WSMO is a formal ontology for describing the various aspects of services in order to enable the automation of Web service discovery, composition, mediation and invocation. The meta-model of WSMO defines four top level elements:

- *Ontologies* (Gruber, 1993) provide the foundation for describing domains semantically. They are used by the three other WSMO elements.

- *Goals* define the tasks that a service requester expects a Web service to fulfil. In this sense they express the requester's intent.

- *Web Service* descriptions represent the functional behaviour of an existing deployed Web service. The description also outlines how Web services communicate (choreography) and how they are composed (orchestration).

- *Mediators* handle data and process interoperability issues that arise when handling heterogeneous systems.

3 Current Issues of the Learning Design Approach

IMS-LD is entirely based on providing a learner with learning resources appropriate to a given learning objective. Like other technologies in this area - e. g. ADL SCORM (Advanced Distributed Learning, 2006) based on IMS Simple Sequencing –, IMS LD follows an approach of providing a learner with composite content packages containing the learning resources as well as the standard specific process metadata. Learning support usually is based on the following practices:

- Use of specific metadata and learning resources – whether data or services - to support a specific learning objective.

- Resources are manually associated with specific learning objectives based on the subjective appraisals of a individual learning designer.

- Learning resources are allocated at design-time, i.e. when the actual learning context is not known.

Due to these facts, the following limitations have been identified (cf. Amorim, 2006, Collis, Strijker, 2004 and Knight, Gašević, & Richards, 2006):

L1. *Limited appropriateness and dynamic adaptability to actual learning contexts.* It is assumed that every learning objective occurs in a specific context which could be defined by the preferences of the actual learner – e. g. her native language or her technical platform. Learning data is allocated at design-time of a learning process – i.e. when the composite content package is developed. This limits the appropriateness of the data to the actual learning context, since the actual learning context can only be considered at runtime of a learning process. Moreover, the use of data excludes the dynamic adaptability a priori. In parallel to data-centric approaches, analogous issues can also be observed with service-oriented approaches. However, in that case, the issues are related to the allocation of services only.

L2. *Limited reusability across different learning contexts and metadata standards.* Due to L1, for every different learning context or specific learner requirement a new learning design (content package) has to be developed. For example, a learning package suiting the needs of a learner with specific preferences – e. g. her native language – cannot be used for other contexts or learners having distinct requirements. Since metadata is described based on standard-specific specifications, an individual content package cannot be reused across different standards.

L3. *High development costs*. Due to L1 and L2, high development costs have to be taken into account when developing IMS LD-compliant e-Learning packages.

4 Context-Adaptive Learning Designs based on Automatic Service Selection and Invocation

This section describes our vision as well as the approach to support context-adaptive learning designs. Moreover, we use the formalization introduced in the previous section to highlights the benefits of our approach.

4.1 Vision

To overcome the limitations L1 and L2 described in Section 3, we consider the automatic allocation and invocation of functionalities at runtime. A typical learning related service functionality provides the learner for instance with appropriate learning content or topic-specific discussion facilities. Learning processes are described semantically in terms of a composition of user objectives (learning goals) and abstract from specific data and metadata standards. When a specific learning goal has to be achieved, the most adequate functionality is selected and invoked dynamically regarding the demands and requirements of the actual specific context. This enables a highly dynamic adaptation to different learning contexts and learner needs.

This vision is radically distinctive to the current state of the art in this area, since it shifts from a data- and metadata-centric paradigm to a context-adaptive service-oriented approach. Moreover, using adequate mappings, our standard-independent process models can be translated into existing metadata standards in order to enable a reuse within existing standard-compliant runtime environments.

Addressing the limitations L1 and L2 identified in Section 3, we consequently reduce the efforts of creating learning process models (L3): one unique learning design can adapt dynamically to different learning contexts and can be translated into different process metadata standards.

4.2 Approach: Semantic Abstractions from Learning Data and Metadata

Our approach is fundamentally based on utilizing SWS technologies to realize the following principles:

P1. Abstraction from learning data and learning functionalities

P2. Abstraction from learning process metadata standards

To support these principles, we introduce several layers as well as a mapping between them in order to achieve a gradual abstraction (Fig. 1):

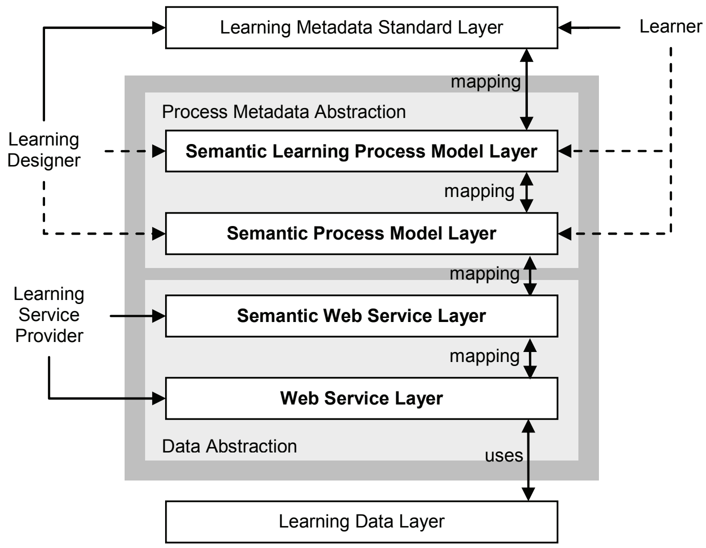

Fig. 1. Semantic layer architecture for supporting context-adaptive learning designs

Abstraction from Learning Data and Functionalities

To abstract from existing learning data and content we consider a Web Service Layer. It operates on top of the data and exposes the functionalities appropriate to fulfill specific learning objectives. This first step enables a dynamic supply of appropriate learning data to suit a specific context and objective. Services exposed at this layer may make use of semantic descriptions of available learning data to accomplish their functionalities.

In order to abstract from these functionalities (Web services), we introduce an additional layer – the Semantic Web Service Layer. This layer enables the dynamic selection, composition and invocation of appropriate Web services for a specific learning context. This is achieved on the basis of formal semantic, declarative descriptions of the capabilities of available services which enable the dynamic matching of service capabilities to specific user goals.

Abstraction from Learning Process Metadata

A first layer concerned with the abstraction from current learning process metadata standards is the Semantic Learning Process Model Layer. It allows the description of processes within the domain of E-Learning in terms of higher level domain concepts - e. g. learning goals, learners or learning contexts. This layer is mapped to semantic representations of current learning metadata standards in order to enable the interoperability between different standards. To achieve a further abstraction from domain specific process models – whether it is e. g. a learning process, a business process or a communication process – we consider an upper level process model layer – Semantic Process Model Layer. This layer introduces for instance the mapping between learning objectives and business objectives to support all kind of organizational processes.

Mappings

Based on mappings between the described layers, upper level layers can utilize information at lower level layers. In particular, we consider mappings between a learning objective and a WSMO goal to enable the automatic discovery and invocation of a Web service (Web Service Layer) from, for instance, a standard-compliant learning application (Learning Application Standard Layer). As a result, a dynamic adaptation to individual demands of a learner within a specific learning context is achieved by using existing standard-compliant learning applications. It is important to note, that we explicitly consider mappings not only between multiple semantic layers but also within a specific semantic layer.

5 Ontological Framework

This section describes the ontological framework aimed at implementing the semantic layers introduced in Section 4.2.

5.1 Ontology Stack

To implement the described semantic layers (Section 4.2), we follow an approach of a staged ontological mapping between semantic models of a process at different levels of abstraction. Our approach considers different ontologies aimed at providing abstract semantic descriptions of data as well as processes. Figure 2 gives an overview of the main ontological representations considered in our approach as well as their relationships.

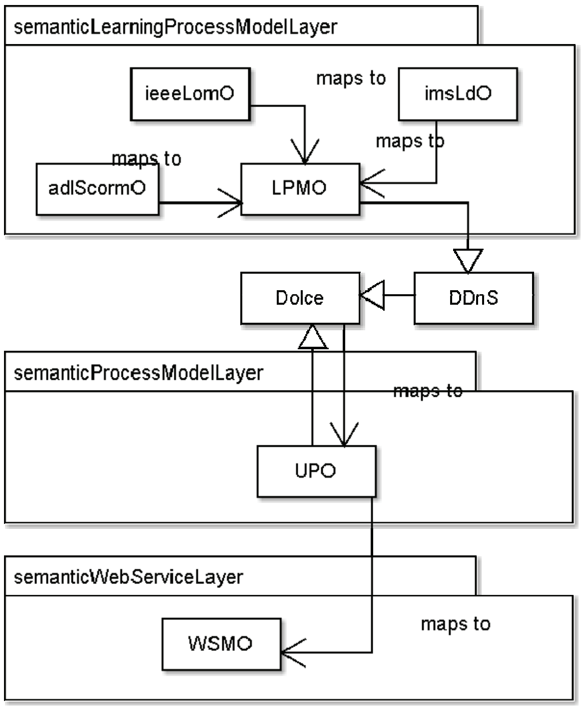

Fig. 2. Conceptual overview of proposed ontological framework

The Learning Process Modelling Ontology (LPMO) implements the Semantic Learning Process Model Layer and is aimed at modelling a learning process from a general point of view - independent from any supported platform or learning technology standard. It is mapped to ontological representations of E-Learning metadata standards. Currently, representations of the following metadata standards are introduced: IMS Learning Design (IMS, 2006) (imsLdO), ADL SCORM 2004 (Advanced Distributed Learning (ADL), 2006) (adlScormO), and IEEE LOM (Duval, 2002) (ieeeLomO).

The general Upper Process Ontology (UPO) abstracts from the process domain and implements the Semantic Process Model Layer. The UPO is currently being developed as part of the SUPER project [5] and will enable the description of a process independent from its specific purpose and can be mapped to domain specific process ontologies such as the LPMO. In order to enable a high level of interoperability of our ontologies, we intend to align the LPMO as well as the UPO to the DOLCE foundational ontology (Gangemi et al, 2002). In particular, context descriptions are based on the Descriptions and Situations module (DDnS) (Gangemi et al, 2003) of Dolce. Furthermore, the UPO is mapped to the WSMO standard. Therefore, these ontologies realise a gradual mapping between a standard learning application and WSMO entities. It has to be highlighted, that our ontological architecture explicitly considers mappings not only between several semantic layers but also within a specific semantic layer. This enables for example the mapping of our LPMO concepts to other existing semantic descriptions of learning related concepts.

5.2 Semantic Learning Process Model Layer

From an e-Learning perspective, the LPMO has to be perceived as the central ontology within our architecture, since it describes the semantics of a learning process from a general point of view and independent from any supported platform or learning technology standard. The following figure depicts an extract of the proposed LPMO containing some of its main concepts as well as some mappings to key concepts within different semantic layers:

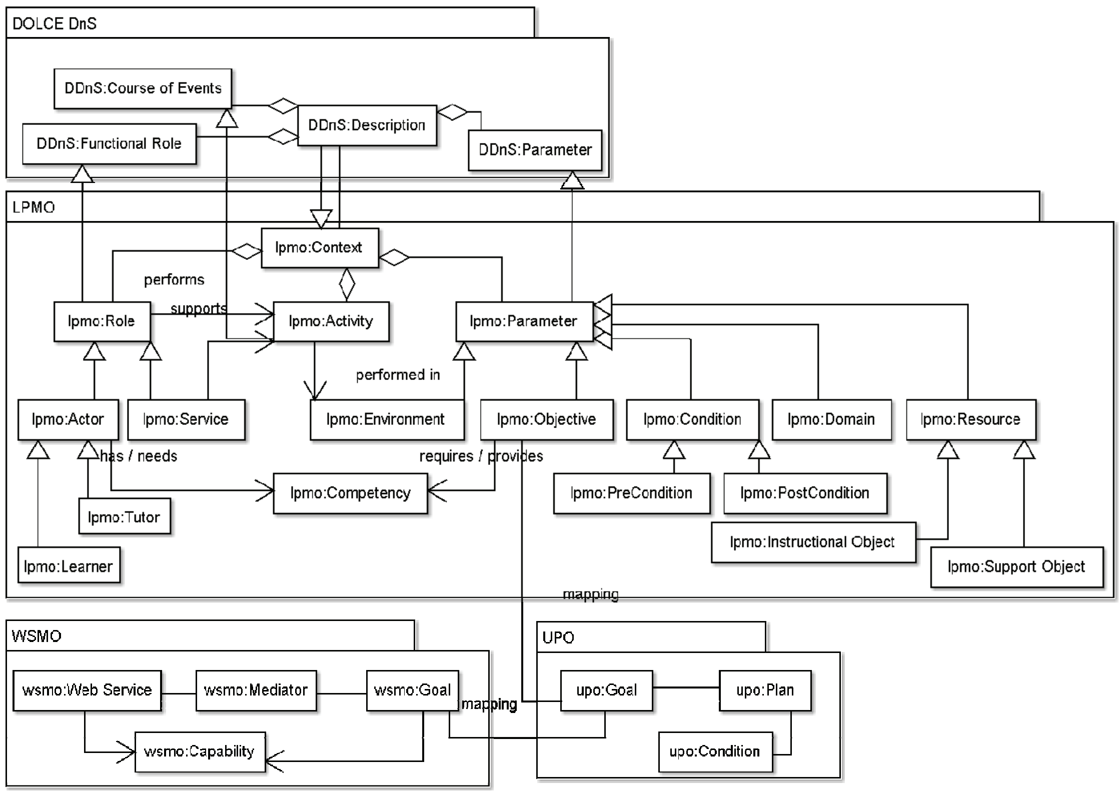

Fig. 3. Conceptual model of parts of the LPMO and key mappings to the UPO and the WSMO framework

As shown in Figure 3, a learning objective as defined in the LPMO is mapped to a *upo:Goal* – which represents a central concept within the Semantic Process Model Layer. This concept is furthermore mapped to the *wsmo:Goal* to enable a mapping and matching of appropriate Web services. Besides the proposed mappings between several semantic layers, mappings are also considered within a specific layer to enable a wide applicability of our approach. E. g. semantic concepts of our LPMO can be mapped to other existing semantic concepts representing learning-related entities within different approaches – e. g. learning process modules as defined in (Naeve et al, 2006) and (Koper, 2004).

6 Deploying a Context-Adaptive Learning Design

To illustrate the feasibility of our approach, we describe a prototype application based on our conceptual framework (Section 4.2). The following sections report the generic application architecture and the steps to specialize it. The current prototype realizes a simple use case scenario described in Section 6.1. Although both IMS LD and ADL SCORM are supported in the scenario, the following sections focus on the IMS LD-compliant application only. In general, the approach for deploying ADL SCORM based application followed analogous implementation steps.

6.1 Example Scenario: Supporting Language Learning in different Learning Contexts

In this example scenario, several learners request to learn three different languages: English, German, Italian. It is assumed that each learner has different preferences – e.g. him/her spoken native language – which have to be considered. For example, a German native speaker learning the language “English” should be provided with German learning resources to teach the English language. In addition, two different metadata standards should be supported: IMS LD and ADL SCORM. Following the current approach of creating an IMS LD-compliant content package which contains all physical learning resources, for every individual learner a specific package would have to be created in order to achieve a high level of appropriateness to the individual learner needs. In addition, for every metadata standard which has to be supported, a new standard-compliant process model has to be created. Applying the vision and approach introduced in Section 4, one unique process model – the learning design – can adapt dynamically at runtime to different contexts and needs.

6.2 SWS-oriented Architecture

Our current implementation makes use of standard runtime environments: IRS III (Section 2) is used as development environment for WSMO descriptions and as SWS broker; the Reload software suite [4] is used for editing and runtime processing of IMS LD. Several distributed Web service and data repositories provide the functionalities to achieve learning goals. Figure 4 outlines the Semantic Web Service Oriented Architecture (SWSOA) used in the current prototype. The defined architecture realizes both P1 and P2 principles described in Section 4.

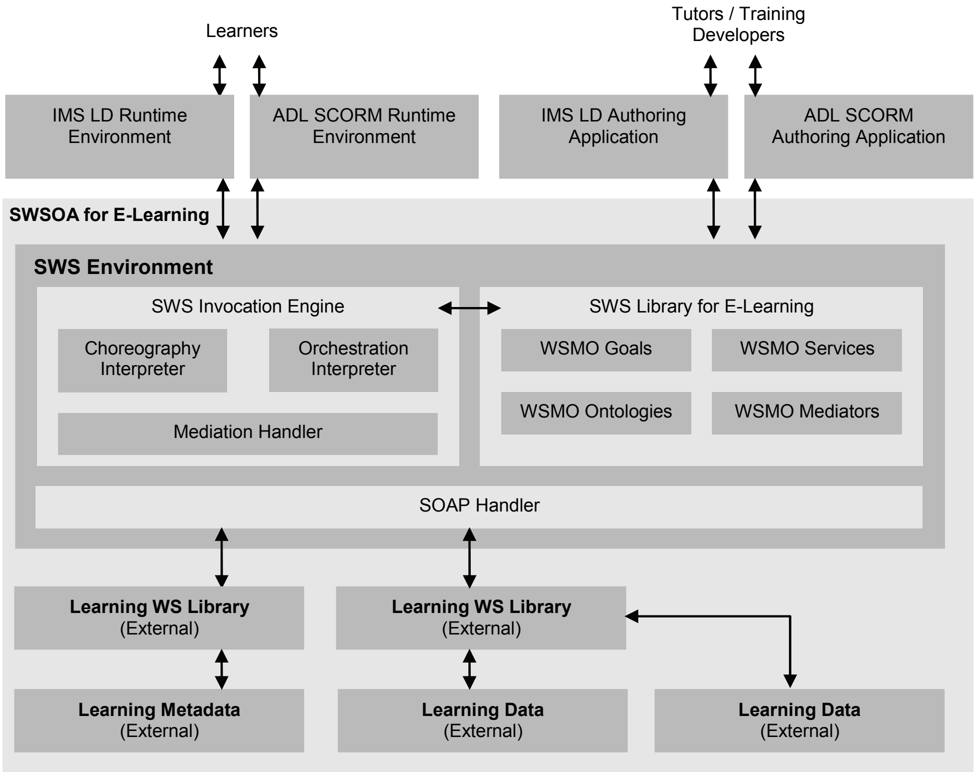

Fig. 4. SWS-based software architecture as utilized in the prototype application to support context-adaptive learning designs

6.3 Implementation Steps

To support the scenario described in Sections 6.1, the following elements had to be provided within the generic architecture presented above:

1. *Learning Web services libraries*. Web services were provided to support the authentication of the learner, the retrieval of semantic learner profiles, learning metadata and learning contents. Web services utilized in this demonstrator were partly developed within the LUISA project [1].

2. *WSMO Ontologies*. To implement the Semantic Learning Process Model Layer, initial semantic representations of ADL SCORM, IMS LD, the LPMO and content objects provided by the Open Learn Project [3] have been created. To support individual learner preferences, we particularly consider semantic learner profiles, describing the native language of every learner. All ontologies have been developed by using OCML (Domingue et al., 1999) as ontology language.

3. *Mappings between semantic layers as well as metadata standards*. We created mappings between the initial implementations of semantic representations of metadata standards (IMS LD, ADL SCORM) and the LPMO as well as WSMO. For instance, we defined a mapping between the *lpmo:Objective* and the objective description used within the IMS LD metadata (*imsld:Objective*). Moreover, semantic learning object descriptions based on the LPMO were mapped to OpenLearn content units (*ol:Content Unit*), whereas the language of a content unit (*ol:Language*) was mapped to the native language of a learner (*lpmo:Language*). Since the UPO is not currently supported by any run- time environment, the LPMO objective is directly

mapped to a WSMO goal. Figure 5 depicts the main ontological mappings as defined in our prototype. The defined mappings are performed at runtime as specific functionalities. These functionalities are exposed as Web services, which are part of an external learning Web services Library. The following Section 7 details the implemented mappings.

4. *WSMO Goal, Web Service, and Mediator descriptions* of the available Web services, based on the concepts defined in the WSMO ontologies.

5. *Standard-compliant content packages describing the learning activities.*
An IMS LD compliant was provided and included into IMS content packages. Instead of grounding the learning activities to static learning data, no static resources were associated with these learning processes. In contrast, only references to the described WSMO goals were associated with every learning activity. This mapping is achieved by associating a learning activity within the learning metadata with HTTP references to a web applet enabling to request the achievement of a specific WSMO goal from the SWS broker.

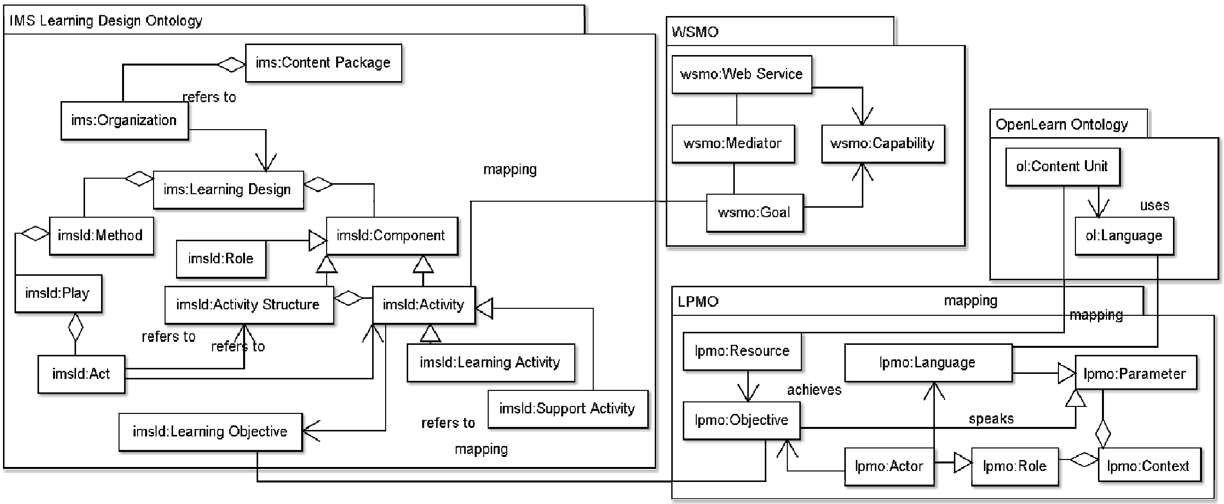

Fig. 5. Ontological mappings between IMS LD, WSMO, LPMO and Open Learn concepts as utilized in the prototype

7 Context-Adaptive Learning Design: Runtime Mappings

In this section, we illustrate the mappings needed to support an automatic allocation of learning resources. All mappings described below are performed at runtime within the involved runtime environments (Reload and IRS-III) to accomplish the automatic adaptation to the actual learning context. The last sub-section sequences the mappings and reports the obtained results.

7.1 Mapping between IMS LD and WSMO

If we consider the scenario described in Section 6.1, four learners with different native languages – English, French, and Spanish and German – require to learn or improve their skills in three different languages – German, Italian, and English. By using our IMS LD compliant e-Learning application, all learners will be provided with one unique context-adaptive IMS LD content package. The package includes the learning process metadata, but it does not contain any physical resource. Instead, each learning activity refers to a WSMO goal. This enables the SWS broker (IRS-III) to select and invoke appropriate services able to achieve the goal.

The mapping between the IMS LD metadata and appropriate WSMO goals is achieved by associating IMS LD learning activities with HTTP references to a web applet enabling to request the achievement of a specific WSMO goal from the SWS broker. The following listing shows an extract of the used IMS LD metadata:

IMS LD-Activity

```
<learning-design identifier="ld-47655dbc-0970-60fa-bc2e-
b90f8a5db328" level="A" sequence-used="false"
uri="http://irs.open.ac.uk/DynamicLanguagesIMSLDRemote">

   <title>DynamicLanguagesIMSLDRemote</title>

   <activities>

        <learning-activity identifier="la-a7a97066-9de3-e013-
        4650-3fcb0b6e1d67" isvisible="true">
           <title>LernGermanDynamicAdoptionActivity</title>
           <activity-description>
               <item identifier="item-26a864b7-7d76-fa0c-6193-
               efabb4a11fca"
               identifierref="http://luisa.open.ac.uk/imsld_Sup
               portLearningActivity.htm" isvisible="true" />
           </activity-description>
         </learning-activity>

   </activities>

</learning-design>
```

Listing 1. Partial source code IMS LD activity referring to web applet to request achievement of a SWS goal

The Web applet, which is invoked by using the reference shown above, sends an HTTP request to the IRS III SWS broker to achieve the learning goal by providing the necessary parameters which define the learning context (*userLanguage, objective*). The following code listing shows an extract of the source code of this applet:

Request for Goal-Achievement

```
xmlhttp=new XMLHttpRequest();

xmlhttp.onreadystatechange=postFileReadyDynamic;

pURL = "http://luisa.open.ac.uk:3000/achieve-
goal?ontology=luisa-services&goal=achieve-objective-meta-
goal&has-method=%22getURL%22&has-imsld-objective=%22" +
objective + "%22&has-context=%22" + userLanguage + "%22";

xmlhttp.open("GET", pURL, true);

xmlhttp.send(null);
```

Listing 2. Portion of source code of web applet requesting the achievement of a learning goal from the SWS broker

7.2 Mapping between WSMO Goal and WSMO Web Service

In our example scenario, several Web services are invoked to retrieve semantic learning metadata, learner profile descriptions and E-Learning content as well as to map between different semantic concepts. Therefore, a mapping between a WSMO goal and WSMO Web services was implemented based on the WSMO framework.

Usually, different services are able to achieve a given goal. This means, several Web services are linked to a specific WSMO goal by using a dedicated WSMO mediator (WSMO WG Mediator).

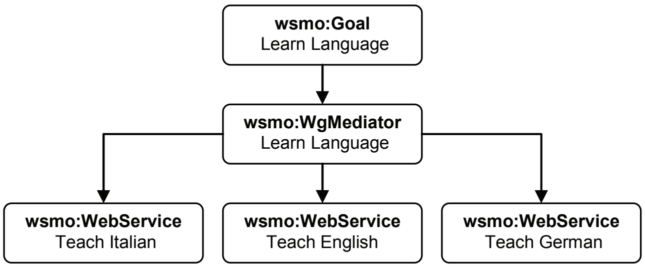

Fig. 6. Linking of WSMO goals, mediators and Web services

Based on semantic capability descriptions of available services, the most appropriate service can be selected to suit a given goal. The following OCML code listing shows a portion of a WSMO description of Web service able to provide learning content to teach the language German:

wsmo:WebService

```
(DEF-CLASS ACHIEVE-OBJECTIVE-GERMAN-WEB-SERVICE
           (GOAL)
           ?GOAL
           ((HAS-INPUT-ROLE
             :VALUE
             HAS-METHOD
             :VALUE
             HAS-IMSLD-OBJECTIVE
             :VALUE
             HAS-CONTEXT)
            (HAS-INPUT-SOAP-BINDING
             :VALUE
             (HAS-METHOD "string")
             :VALUE
             (HAS-IMSLD-OBJECTIVE "string")
             :VALUE
             (HAS-CONTEXT "string"))
            (HAS-OUTPUT-ROLE :VALUE HAS-PROVIDER-URL)
            (HAS-OUTPUT-SOAP-BINDING
             :VALUE
             (HAS-LEARNING-OBJECT "string"))
            (HAS-METHOD :TYPE STRING)
            (HAS-IMSLD-OBJECTIVE :TYPE IMSLD-OBJECTIVE)
            (HAS-CONTEXT :TYPE LPMO-CONTEXT)
            (HAS-PROVIDER-URL :TYPE STRING)))

(DEF-CLASS ACHIEVE-OBJECTIVE-GERMAN-WEB-SERVICE-CAPABILITY
   (CAPABILITY)
   ?CAPABILITY
     ((USED-MEDIATOR :VALUE ACHIEVE OBJECTIVE-GERMAN-MED)
        (HAS-ASSUMPTION
             :VALUE
             (KAPPA
               (?WEB-SERVICE) (= (WSMO-ROLE-VALUE ?WEB-SERVICE 'HAS-
               IMSLD-OBJECTIVE)"Learn German")))))
```

Listing 3. Partial source code of a WSMO Web service and its capability description

In Listing 3, a WSMO description defines the assumption of a Web service that the objective provided by the IMS LD content package is valued by “Learn German”. The WSMO service used in our prototype application to achieve this objective requires an orchestration of several services to support this learning objective. Therefore, the goal achievement triggers a sequence of services needed to get information about the actual learner, to retrieve content appropriate to her specific objective as well as to select content appropriate for her specific requirements.

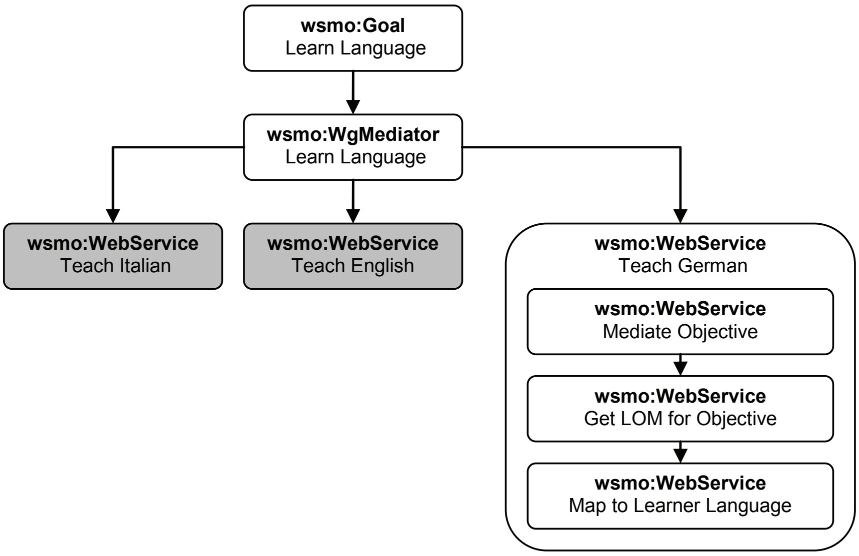

Fig. 7. Orchestration of Web services to achieve a specific goal aimed at language learning

For instance, if a learner is authenticated as an English-speaking person (*lpmo:Language=English*) and uses an IMS LD-based package to learn the language German, an *imsld:Activity* with the *imsld:Objective=Learn German* is mapped to a specific WSMO-Goal. The accomplishment of such a goal involves the selection, orchestration and invocation of different Web services, which perform the described mappings and retrieve appropriate learning content: (i) the *imsld:Objective* is mapped to the *lpmo:Objective* concept; (ii) the *lpmo:Objective* is used to retrieve the semantic learning object metadata (LOM) of an appropriate learning object; (iii) the retrieved LOM is used to obtain an Open Learn learning unit appropriate to the individual language of the learner and its current objective. Each of these goals is accomplished by a distinct Web service dynamically selected at runtime.

7.3 Mappings between Semantic Concepts of IMS LD, LPMO and Learning Resources

Furthermore, we introduced mappings between semantic concepts of the IMS LD metadata, the LPMO as well as the used learning content objects. As shown in Section 6.3, we provide a mediation between different objective descriptions (*lpmo:Objective*, *imsld:Objective*) as well as a mapping between the native language of the learner and the language of the utilized learning content (*lpmo:Language*, *ol:Language*). These mappings were implemented using semantic descriptions of the relevant concepts as well as Web services which are able to mediate and map between these concepts. The mapping services were implemented as LISP functions which were exposed as Web services by using the IRS III Publisher (Cabral et al, 2006). At runtime, these services are invoked as part of a more complex service orchestrations to achieve a specific learning objective. The semantic concepts were implemented in OCML. The following figure presents the mapping of the language of a content object with the native language of the learner.

wsmo:Ontology-Concept

```
(def-class lpmo-context ()
((has-language-title :type
string))
)
```

wsmo:Ontology-Concept

```
(def-class lpmo-id-object ()
((has-lpmo-id :type string))
)
```

WebService

```
(defun map-lpmo-object-user-language (input1 input2)
(ocml::select-ontology 'ocml::luisa-mapping-services)
(let* (
(string1 (ocml::findany '?x `(ocml::has-slot-value ,input1
'ocml::has-lpmo-id ?x)))
(string2 (ocml::findany '?x `(ocml::has-slot-value ,input2
'ocml::has-language-title ?x)))

(inst (first (ocml::setofall '?x `(and (and (ocml::instance-of ?x
'ocml::teach-german-object)
(ocml::has-lpmo-id ?x ,string1))
(ocml::has-language ?x ,string2))))))

(ocml::the-slot-value inst 'ocml::has-provider-url)))
```

wsmo:Ontology-Concept

```
(def-class teach-german-object ()
((has-language :type string)
 (has-provider-url :type string)
 (has-cost :type string)
 (has-lpmo-id :type string))
))
```

Listing 4. LISP based service and semantic concepts to map learning objects to the native language of a learner

7.4 Performing Mappings at Runtime

At runtime, an end-user (learner) accesses a standard-compliant player and loads the standards-compliant content packages as defined in bullet 5 of Section 6.3. The learning application then sequentially presents all of the learning activities that would have to be performed. An initial activity first authenticates the learner and retrieves the semantic learner profile description. The WSMO goal associated with such an activity is invoked, and the SWS broker dynamically selects and invokes the WSMO Web service showing the appropriate capabilities to achieve the specified goal. At this point, the learner preferences are set within the player environment. In the same way, when the learner selects an individual objective within the standard content package, our infrastructure dynamically selects and invokes semantic Web services according to him/her preferences and stated objectives. For instance, if a learner is authenticated as an English-speaking person (*lpmo:Language=English*) and uses an IMS LD-based package to learn the language German, appropriate Web services are selected and invoked as described in Section 7.2.

Figure 8 depicts a screenshot of the Reload IMS LD Player while presenting a standard-compliant IMS LD content package and dynamically invoking SWS appropriate to fulfill the given learning objective "Learn German" of an English-speaking learner:

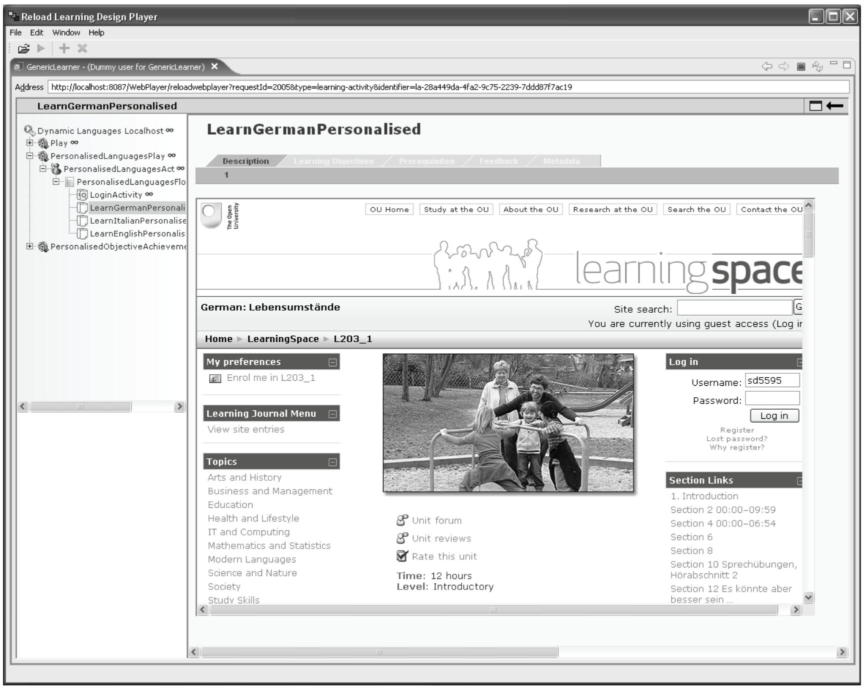

Fig. 8. Reload IMS LD Player while dynamically adapting to the learning needs of an English-speaking learner

Figure 9 depicts a screenshot of the same learning activity within the provided IMS LD after another Learner was authenticated as a French-speaking learner. It has to be highlighted that with our approach the IMS LD adapted to the specific learning context by selecting an appropriate service to provide learning content in the French language only. Moreover, the contents provided by the application have been retrieved from two distinct sources.

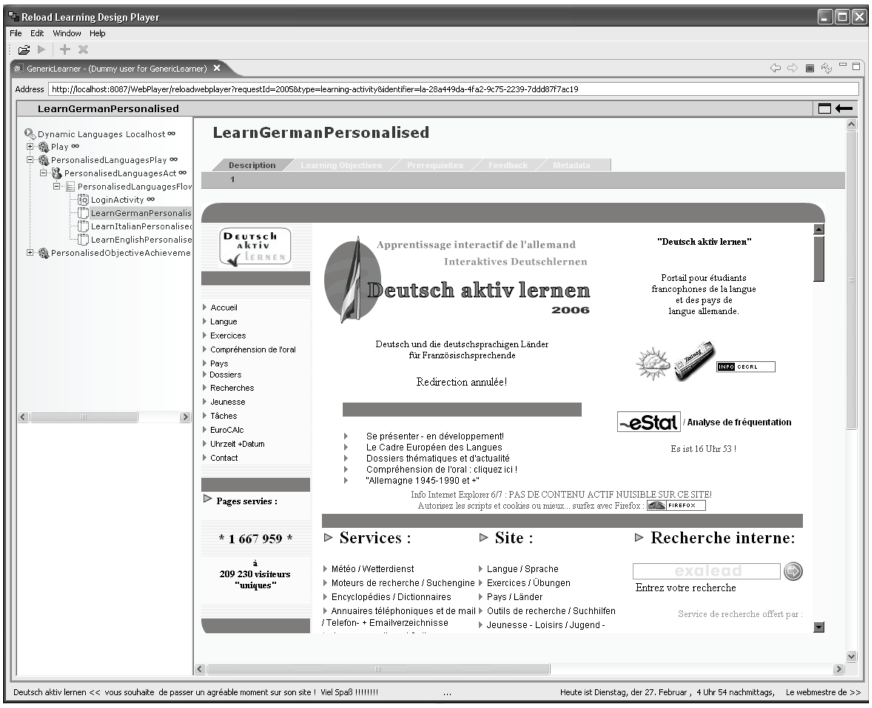

Fig. 9. Reload IMS LD Player while dynamically adapting to the learning needs of an French-speaking learner

Although the considered scenario is very simple, our approach already introduces a dynamic context-adaptation at runtime. Since the application fully realizes the general principle and approach stated in Section 4, the scenario could be easily extended in the future to achieve a dynamic adaptation to more complex learning contexts.

8 Comparing Context-Adaptive Learning Designs with the Current State of the Art

This section provides an attempt to formalize and compare the efforts required to develop learning designs by following the current state of the art in contrast to the effort to be spent by applying the approach proposed in this paper.

8.1 Required Learning Design Effort based on the current State of the Art

Let us think of a number of real world learning processes *p*, which have to be supported based on a number of process models *m* whereas each model has to be developed by spending an effort e_m. The actual learning context for every process can be defined by *n* context parameters $\{c_1..c_n\}$ – e. g. the technical platform or native language of the actual actor – which have possible parameter values:

$$\forall c_i \in \{c_1..c_n\}, v(c_i) = |c_i| + 1$$

where $|c_i|$ represents the number of possible values of each parameter, and the unit allows us to introduce the "no-specification" case.

Furthermore, we consider different process metadata standards *s*. We assume that different process data is available to fit all different context parameter values and that process models for all different kind of process contexts have to be provided. Then, the necessary cumulative development effort e_{cum} by following the traditional approach can be formalized as follows:

$$e_{cum} = f(m) = m * e_m$$

with

$$m = f(p) = (\prod_{i=1}^{n} v(c_i) - 1) * p * s \cdot$$

Consequently, the necessary effort can be described with:

$$e_{cum} = f(p) = (\prod_{i=1}^{n} v(c_i) - 1) * p * s * e_m$$

Based on this formula, we can expect an enormous linear increase in the development costs with an increase in the number of processes which have to be supported.

8.2 Required Effort by applying Context-adaptive Learning Designs

Let us refer to the formalization introduced in Section 8.1. According to our vision, the number of process models *m* necessary to support different processes *p* is equal to *p*. However, we have to consider a first effort $e_{initial}$ to fully provide the facilities to support our semantic framework: i. e.

semantic representations of the process contexts, mappings to metadata standards as well as SWS descriptions. Thus, the effort to be spent can be described as follows:

$$e_{cum'} = f(p) = e_{initial} + p * e_m$$

Figure 10 depicts a generic comparison of this effort with the efforts of traditional approaches as described in Section 3.

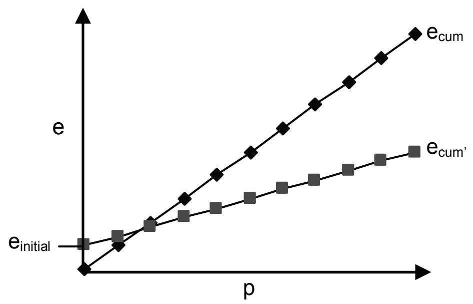

Fig. 10. Comparison of development efforts between SWS based and traditional learning design approach

As shown in Figure 10, we foresee that the advantages of our SWS based vision can be observed with an increasing number of learning processes, since it benefits from lower process model development efforts but requires an initial amount of work to provide necessary facilities.

8.3 Validation based on Example Scenario

To support the use case described in Section 6.1, we have to support three different learning processes according to the formalization introduced in the previous section. Each of the learning processes is dedicated to teach a specific language: Italian, German and English. Therefore $p=3$. In addition, we have to support one learning context parameter c – the native language of the learner. This context parameter can be valued by five different values v – English, German, French, Spanish, and an unknown native language. Furthermore, two different metadata standards s have to be supported – IMS LD and ADL SCORM. Therefore, the cumulative effort to describe the necessary process models respectively the necessary content packages can be expressed as follows:

$$e_{cum} = f(p) = 4*3*2*e_m = 24*e_m$$

The prototype application (Sections 6, and 7) implemented by applying the vision and approach described in Section 4 to support the example scenario (Section 6.1), took into account the same 3 different learning processes p aimed at teaching 3 different languages:

$$m = f(p) = p = 3$$

with

$$e_{cum'} = f(p) = e_{initial} + 3*e_m$$

If we assume an effort e_m of 1 man-month (mm) and assume furthermore the availability of all facilities enabling our development approach, we do not have to consider the initial development effort $e_{initial.}$ for comparing the efforts for supporting the described scenario by following our approach and the traditional approach as described in Section 6.1:

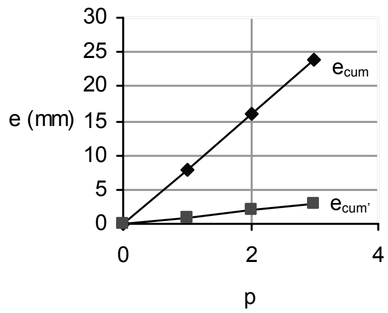

Fig. 11. Comparison of development efforts between SWS based and traditional approach based on introduced use case scenario

Figure 11 shows that supporting the example scenario by following the traditional approach does require an amount of 24 mm. Every new learning process has to be taken into account with a necessary amount of 8 mm to satisfy just the simple requirements of the example use case. In contrast, by following our SWS-based approach, every new learning process can be supported with just one additional mm. Due to the dynamic adaptation at runtime, a standard-compliant learning design could basically suit all different kind of individual learner requirements and context parameters in the future.

We want to highlight that generalizing the effort of creating different learning process models is highly simplistic and is just utilized, to enable a quantification and comparison of expected efforts. Moreover, it is important to note that the initial effort $e_{initial}$ could also be high (e.g. 10 mm), but also in this case, considering 2 processes to represent only, using the approach proposed here already provides an advantage.

9 Conclusion

Our approach - the support of learning objectives based on a dynamic invocation of SWS at runtime of a learning design - follows an innovative approach and is distinctive to the current state of the art in this area. By using SWS technology, our approach overcomes the limitations described in Section 3 and supports a high level of standard-compliancy and reusability within existing runtime environments, since it is fundamentally based on compliancy with current E-Learning metadata standards. In particular, the following contributions should be taken into account:

- Dynamic adaptation to specific learning contexts at runtime
- Automatic allocation of learning resources based on comprehensive semantics
- High reusability across learning contexts and metadata standards
- Platform- and standard-independence
- Reuse and integration of multiple available learning resources and sources
- Decrease of development costs

Since our framework is an ongoing work, next steps have to be concerned with the implementation of complete ontological representations of the introduced semantic layers as well as of current e-Learning metadata standards and their mappings. For example, currently the Semantic Process Model Layer is not used and semantic mappings between the Learning Process Model Ontology and the IMS LD standard are only developed in extracts. Nevertheless, the availability of appropriate Web services aimed at supporting specific process objectives has to be perceived as an important prerequisite for developing SWS based applications. To provide more valid quantifications of the expected benefits, further case studies are needed to illustrate the formalized measurements introduced in the sections above. Besides that, future work could also be concerned with the mapping of semantic process models across different process dimensions – e. g. business processes or learning processes to enable a complete integration of a SWSOA in an organizational process environment.

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11 Footnotes

[1] It is important to note that the meaning of *service* as used in this paper detaches from the one used within the IMS-LD specification. In our view, a service is a generic computational element that implements a specific functionality and is accessible over the web.

[2] LUISA Project - Learning Content Management System Using Innovative Semantic Web Services Architecture (http://www.luisa-project.eu/www/).

[3] Open Learn Project: Online Educational Resources (http://openlearn.open.ac.uk/).

[4] Reload Project (http://www.reload.ac.uk/).

[5] SUPER – Semantics Utilized for Process Management within and between Enterprises (http://www.ip-super.org/).