Supporting Interoperability and Context-Awareness in E-Learning through Situation-driven Learning Processes

Stefan Dietze*, Alessio Gugliotta, John Domingue
Knowledge Media Institute,
Open University,
MK7 6AA, Milton Keynes, UK
{s.dietze, a.gugliotta, j.b.domingue}@open.ac.uk

Abstract. Current E-Learning technologies primarily follow a data and metadata-centric paradigm by providing the learner with composite content containing the learning resources and the learning process description, usually based on specific metadata standards such as ADL SCORM or IMS Learning Design. Due to the design-time binding of learning resources, the actual learning context cannot be considered appropriately at runtime, what limits the reusability and interoperability of learning resources. This paper proposes Situation-driven Learning Processes (SDLP) which describe learning processes semantically from two perspectives: the user perspective considers a learning process as a course of learning goals which lead from an initial situation to a desired situation, whereas the system perspective utilizes Semantic Web Services (SWS) technology to semantically describe necessary resources for each learning goal within a specific learning situation. Consequently, a learning process is composed dynamically and accomplished in terms of SWS goal achievements by automatically allocating learning resources at runtime. Moreover, metadata standard-independent SDLP are mapped to established standards such as ADL SCORM and IMS LD. As a result, dynamic adaptation to specific learning contexts as well as interoperability across different metadata standards and application environments is achieved. To prove the feasibility, a prototypical application is described finally.

Keywords: Semantic Web Services, E-Learning, Interoperability, Context-Awareness, WSMO.

1 Introduction

The increasing availability of learning resources raises the need to discover and deliver the most appropriate learning resources to the learner to satisfy his/her learning needs within the actual learning situation. A learning *situation* constitutes the actual *context* which has to be addressed and is defined by e.g. the used technical environment or specific learner characteristics such as his/her native language.

The current state of the art in E-Learning is mainly represented by approaches based on software systems, such as *learning content management systems (LCMS)* which provide a learner with composite learning contents – the so called *learning objects (LO)*. Usually, a LO contains a description of a learning process - the learning path which has to be followed by the learner to fulfil his current learning objective –

which is referred to a set of learning resources, whether these are data or services. Interoperability between LCMS is currently supported through metadata standards such as IEEE LOM (Duval, 2003), ADL SCORM (ADL SCORM, 2004) – based on IMS Simple Sequencing - or IMS Learning Design (IMS LD) (IMS Global, 2003) supporting the description of learning processes as well as learning objects. To satisfy a given learning need, a learning designer manually describes the learning process and allocates learning resources. Even though current E-Learning metadata standards try to address dynamic context-adaptability by introducing facilities such as the IMS LD Level B properties, their capabilities are limited and still rely on the manual pre-allocation of resources and a pre-defined selection strategy. Due to the design-time binding of learning process and learning resources, the actual runtime context of the learning process cannot be considered appropriately and therefore, a learning object cannot adapt dynamically to the specific context or learner needs. Consequently, reusability of a LO across distinct learning contexts or E-Learning applications is limited.

The use of *Web services* instead of data addresses these issues partially. However, since Web services are deployed using purely syntactic technologies such as SOAP (W3C, 2003a), WSDL (W3C, 2001), and UDDI (W3C, 2003b), which do not provide information about the semantic meaning of the service functionalities, utilized data or usage constraints, services cannot be discovered, composed and invoked automatically. *Semantic Web Services (SWS)* technology (Fensel et al., 2006) aims at the automatic discovery of distributed Web services as well as underlying data on the basis of comprehensive semantic descriptions utilizing ontologies (Gruber, 1995) as formal specification of a service conceptualization. First results of SWS research are available, in terms of reference ontologies – e.g. OWL-S (Joint US/EU ad hoc Agent Markup Language Committee, 2004) and WSMO (WSMO Working Group, 2004) – as well as comprehensive frameworks - e.g. DIP project results (http://dip.semanticweb.org) - and applications. Whereas existing SWS frameworks enable the semantic description of Web services and data exposed by a Web service, they do not entirely encourage the representation of learning situations and processes, in which resources are used. In other words, SWS descriptions represent a process from a system perspective as an orchestration process which involves the invocation of services and the manipulation of data. In contrast, process metadata descriptions such as IMS LD or ADL SCORM provide non-semantic descriptions about a learning process from a user perspective.

The approach described in this paper bridges the gap between learning situations and resources based on semantic *Situation-driven Learning Processes (SDLP)* that consider the user as well as the system perspective of a process. Learning processes are described as sequences of learning goals which lead from an initial to a final situation, where each goal is supported through dynamic SWS goal invocations. SDLP are composed dynamically and accomplished by automatically allocating learning resources (data, services) at runtime to adapt to different learning contexts. To achieve this vision, our approach is based on the following principles: abstraction from learning resources and semantic contextualization of learning process models.

The abstraction from the actual resources – data as well as services – supports the semantic representation of the system-perspective of a process through established SWS technology and is aimed at the automatic discovery of resources which provide the required capabilities for a given context. Based on semantic descriptions of functional capabilities of available Web services, a SWS broker automatically selects and invokes Web services appropriate to achieve a given user goal. The contextualization of learning process models aims at the semantic representation of learning processes as sequences situation-specific learning goals to support the user-perspective of a process. It makes use of *Semantic Web (SW)* technology to provide the necessary contextualized descriptions and is mapped to different metadata standards to enable their interoperability.

The rest of the paper is organized as follows. The following Section 2 introduces our motivation which led to our vision of context-adaptive learning processes described in Section 3 together with our proposed approach. Section 4 then introduces the utilization of SWS to abstract from learning resources whereas Section 5 explains a metamodel for Situation-driven Processes (SDP). SDP are derived for the E-Learning domain in Section 6 and their deployment within a context-adaptive E-Learning application is described in Section 7. We compare our approach with the current state of the art in E-Learning in Section 8, and report some related work in Section 9. Our contributions are summarized and discussed in the last Section 10.

2 Motivation

Current technologies aimed at supporting learning processes are mainly based on the following practices:

- *Widespread use of proprietary, non-semantic metadata standards,* such as IMS LD and ADL SCORM, to describe a learning process. A process is described based on a common syntax – the metadata specification – but not enriched with descriptions of a semantic meaning in a machine-processable way.
- *Manual allocation of learning resources at design-time of a process.* Data and services are manually associated with specific learning objectives based on the limited knowledge and subjective decisions of a specific individual. Since process descriptions rely on syntactic descriptions only, the allocation of appropriate resources requires the manual interpretation of the semantics of a process model. Moreover, the allocation of learning resources at design-time of a process - i.e. when the specific learning process metadata is described - contradicts the consideration of the actual learning context, what is possible at runtime only.
- *Workflow-centred notion of a learning process.* Learning processes usually focus on the description of the learning workflow to be followed rather than on the learning context – e. g. the specific requirements of the addressed learning situation.

For instance, to support a learner who intends to learn a particular language, e.g. French, usually a learning designer manually provides a learning object which contains the learning process based on a particular metadata standard and allocates learning assets to each of the learning activities. Imagine a learning process consisting of two learning activities, where the first introduces basic knowledge about the French language and the second one adds advanced vocabulary and grammar information. Each activity will be associated manually with a set of audio-visual learning assets or is referred at design-time to a Web service which retrieves appropriate learning resources. The composed LO is provided to the learner, for instance through open E-Learning platforms such as OpenLearn (http://openlearn.open.ac.uk/), and finally presented within a metadata compliant runtime environment or LCMS.

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

L1. *Limited reusability across different learning contexts and metadata standards*. A learning process model – including references to associated resources - suiting the context and the preferences of a specific learner cannot be used across distinct learning contexts. Moreover, the conformance of a learning process model with a specific metadata standard ensures interoperability across systems following the same standard, but does contradict the usage of the same model in information systems adopting different standards. As a result, distinct learning process models have to be developed to meet multiple contexts and learner needs.

L2. *Limited appropriateness and dynamic adaptability to actual learning contexts.* A learning object usually is composed of both, the workflow of learning activities and the set of required learning resources. Due to the designtime-binding of learning resources and learning process metadata, the actual learning context – known at runtime only – cannot be considered appropriately. Moreover, the use of data excludes the dynamic adaptability to a specific context a priori. The use of services instead of data addresses some of these issues but does not enable context-adaption based on the automatic allocation of services at runtime.

L3. *Limited use of distributed heterogeneous learning resources.* Since learning resources usually are allocated manually at design-time, distributed heterogeneous data and services are neither widely reused nor integrated into learning application environments sufficiently. Nevertheless, standardized methodologies to solve heterogeneities between terminologies used by distinct data or service providers are not available. Therefore, interoperability and scalability of current E-Learning applications is limited.

L4. *High development costs.* Due to L1, L2, and L3 distinct learning objects – including distinct learning process models and learning resources - have to be developed to support different learning contexts appropriately. Therefore, high development costs have to be taken into account to provide appropriate process support.

3 Context-Adaptive Learning Processes: Vision and Approach

This section describes our vision and approach to context-adaptive learning process composition and accomplishment aimed at overcoming the limitations L1 – L4 described in Section 2.

Vision: Situation-driven Learning Processes

We consider the automatic, situation-aware allocation of resources at runtime of a learning process based on dynamic service invocations. Learning processes are described semantically as a composition of user goals within a specific learning situation, the actual context. Learning goals are achieved dynamically through automatic discovery of appropriate services for a given goal within a specific situation. Figure 1 depicts this vision of a situation-driven learning process.

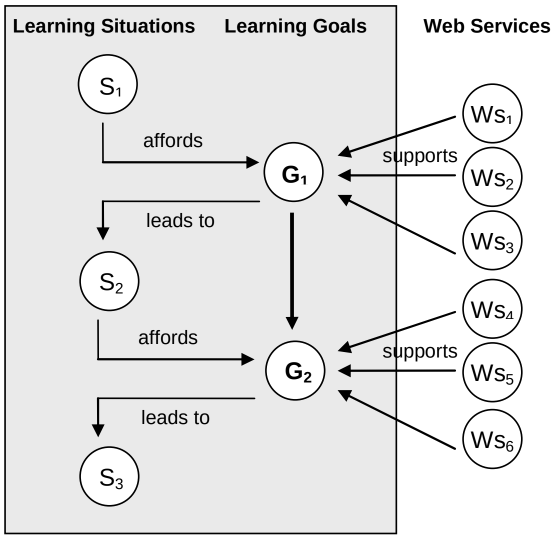

Fig. 1. Situation-driven learning processes.

Semantic learning process models abstract from specific resources – whether data or services - and metadata standards. Given an initial situation and knowledge about the desired final situation, learning processes are composed dynamically and accomplished automatically. Based on semantic descriptions of available resources, the most appropriate resource is selected automatically to achieve a certain learning goal within the actual learning (runtime) context. This vision enables a highly dynamic adaptation to different learning contexts and learner needs. Moreover, using adequate mappings, standard-independent semantic learning process models can be transformed into existing (non-semantic) metadata standards in order to enable their reuse within existing standard-compliant runtime environments.

By addressing limitations L1 – L3, the described vision consequently reduces the efforts of creating learning process models (L4): one unique learning process model can adapt dynamically to different process contexts and can be translated into different process metadata standards.

Approach

Our approach is fundamentally based on realizing the following principles:

- Learning resource abstraction.

- Contextualization of learning processes.

To support these principles, we introduce a layered approach to achieve a gradual abstraction and finally, a gradual mapping between resources – data and services – and process metadata (Figure 2):

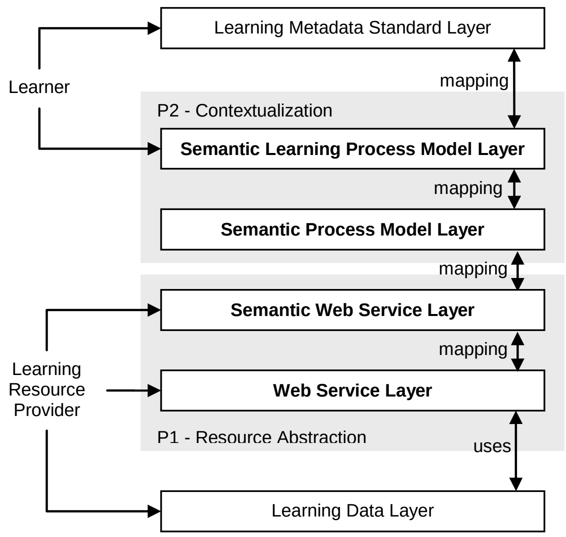

Fig. 2. Conceptual framework to gradually abstract from learning process resources and contextualize learning process models.

P1. Learning Resource Abstraction.

To integrate heterogeneous resources, we foresee the abstraction from existing learning data and content. A *Web Service Layer* is considered which exposes functionalities appropriate to fulfill specific learning objectives. These functionalities range from querying learning data repositories to filtering of data or the computation of competency gaps. This abstraction from learning process data enables a dynamic discovery of appropriate 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 objective within a particular learning context. This is achieved on the basis of formal semantic, declarative descriptions of the capabilities of available services to enable the dynamic matching of service capabilities to specific user goals. Due to the semantic abstraction from learning resources, additional distributed resources can be integrated into the application framework by simply adding semantic resource descriptions following a common SWS standard, such as WSMO (WSMO Working Group, 2004) or OWL-S (Joint US/EU ad hoc Agent Markup Language Committee, 2004). Please note, that the aforementioned layers make use of established standard Web service and SWS technologies.

P2. Contextualization of Learning Processes.

Whereas the aforementioned layers utilize existing technologies, the contextualization of learning processes introduces two novel semantic layers. A first layer concerned with the semantic contextualization of current learning process metadata standards is the *Semantic Learning Process Model Layer*. It allows the comprehensive description of situation-driven processes within the domain of E-Learning as a composition of learning goals which occur in specific learning situations described by parameters such as the current learning environment or the actual user preferences. This layer is mapped to semantic representations of current learning metadata standards in order to enable the interoperability between different standards and furthermore, the automatic transformation between them.

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 enables the description of contextualized domain-independent processes and introduces the high-level concepts – e. g. process goals, roles or process parameters – which are subject across different process domains. Thus, this layer enables a mapping between different domain-specific process model layers - for instance the mapping between learning objectives and business objectives.

Based on semantic mappings, upper level layers can utilize information at lower level layers. It is important to note, that we explicitly consider mappings not only between multiple semantic layers but also within a specific semantic layer. For instance, within the Semantic Learning Process Model Layer different semantic conceptualizations could be utilized and aligned with each other in order to support reusability across different application scenarios each using a distinct terminology and conceptual E-Learning model.

The following Table 1 provides an overview of our approach, mapping the lacks introduced in Section 2 with the elements of our approach that address them at different levels of abstraction: design principles, conceptual layers, implementation aspects. The implementation aspects (ontologies and supporting software) are elaborated further in the following sections.

Table 1: Overview on approach followed to address L1-L4.

<table>
<tr><td rowspan="2">Adressed lacks:</td><td colspan="4">L4</td></tr>
<tr><td colspan="2">L3</td><td colspan="2">L1, L2</td></tr>
<tr><td>Design principles:</td><td colspan="2">P1: Learning Resource Abstraction</td><td colspan="2">P2: Learning Process Contextualization</td></tr>
<tr><td>Conceptual layers:</td><td>Web Service Layer</td><td>Semanti Web Service Layer</td><td>Semantic Process Model Layer</td><td>Semantic Learning Process Model Layer</td></tr>
<tr><td>Ontologies:</td><td></td><td>Web Service Modelling Ontology (WSMO)</td><td>Situation-Driven Process Ontology (SDPO)</td><td>Learning Process Modelling Ontology (LPMO)</td></tr>
<tr><td>Supportive software:</td><td>Supporting Web services</td><td colspan="3">IRS-III</td></tr>
</table>

Design principle P1 addresses the identified lack L3 (Section 2), whereas P2 is aimed at overcoming L1 and L2. Both, P1 and P2 target L4 by aiming at a decrease of development efforts. To follow P1 the Web Service as well as the Semantic Web Service Layers have been introduced, whereas the Semantic Process Model Layer and the Semantic Learning Process Model Layer support the contextualization of learning processes (P2). To implement the Semantic Web Service Layer, established SWS technology has been utilized: the *Web Service Modelling Ontology (WSMO)* and the Semantic Execution Environment *IRS-III* (Cabral et al., 2006) (Section 4). The *Situation-Driven Process Ontology (SDPO)* populates the Semantic Process Model Layer (Section 5), while the *Learning Process Modelling Ontology (LPMO)* derives SDPO for E-Learning and facilitates the Semantic Learning Process Model Layer (Section 6). Nevertheless, several Web services - aimed at learning-related functionalities such as LO retrieval, competency gap calculation or learning process composition - have been implemented and incorporated as SWS into the SWS-oriented application framework (Section 7).

4 Abstracting From Learning Resources through Semantic Web Services (WSMO) and IRS-III

In this Section we introduce the abstraction from learning process resources through a Web Service Layer and a Semantic Web Service Layer, which are based on established Web service and SWS technologies. The introduction of a Web Service Layer enables the integration of distributed heterogeneous learning data sources (Data Layer) into an open E-Learning application environment. Furthermore, services can provide any kind of learning-related functionality, such as data transformations or the computing of a competency gap between a desired learning objective and specific competencies of a learner. Whereas Web services technology facilitates the reuse of distributed software functionalities through the Web, it does not support the automatic integration and discovery of appropriate services and thus, always requires the manual allocation of appropriate Web services. By providing formal descriptions with well defined semantics, SWS technology facilitates the machine interpretation of Web service descriptions.

Introducing the Semantic Web Service Layer enables the automatic discovery, orchestration and invocation of appropriate services based on comprehensive semantic formalizations of distributed services. SWS are based on a Semantic Web Service broker which hosts semantic descriptions of available services to enable the automatic discovery and composition of appropriate services. Since utilized data is a crucial important aspect of a Web service, semantic descriptions of data are an implicit part of a SWS description. Thus, the Semantic Web Service Layer enables abstraction not only from services but also from data, and consequently their integration based on formal semantics.

We adopt the *Web Service Modelling Ontology* as reference ontology model for SWS descriptions. WSMO is a formal ontology for describing the various aspects of heterogeneous services. The conceptual model of WSMO defines four top level elements:

- *Ontologies* 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 fulfill. In this sense they express the requester's intent.
- *Web service* descriptions represent the functional behavior 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.

WSMO includes ontologies as one of its main entities; thus it is not limited to SWS descriptions exclusively. Therefore, all semantic layers – Semantic (Learning) Process Model Layer as well as Semantic Web Service Layer – can be supported by a unique Semantic Execution Environment based on WSMO.

IRS-III (Cabral et al., 2006) the Internet Reasoning Service, is a *Semantic Execution Environment* (SEE) that also provides a development and broker environment for SWS based on WSMO. A client sends a request which captures a desired outcome or goal – specified as WSMO Goal - and, using the set of Semantic Web Service capability descriptions, IRS-III proceeds through the following steps:

1. Discover potentially relevant Web services.
2. Select set of Web services which best fit the incoming request.
3. Invoke the selected Web services whilst adhering to any data, control flow and Web service invocation constraints.
4. Mediate any mismatches at the data or process level.

IRS-III adopts ontological descriptions to achieve the automatic discovery of appropriate services. In particular, IRS-III incorporates and extends WSMO as core epistemological framework of the IRS-III service ontology which provides semantic links between the knowledge level components describing the capabilities of a service and the restrictions applied to its use.

5 Situation-Driven Processes for Semantic Web Services

To achieve the vision described in Section 3, the Semantic Process Model Layer aims at providing the semantic representation to incorporate SWS descriptions into reasonable process settings. Therefore the Semantic Process Model Layer introduces the domain-independent notion of semantic *Situation-driven Processes (SDP)* which describe two perspectives on a process:

1. *The user perspective*: describes the process as composition of user Goals
2. *The system perspective*: which describes the process in terms of services which support each user Goal.

A semantic SDP Model consists of *SDP Situations* (*S*) and *SDP Goals* (*G*) as main entities. Utilizing the notion of concepts as described in (Gangemi, Mika, 2003), a situation is described by a set of concepts *C*. Consequently, an initial situation *Si* is defined by a set of *x* concepts:

$$Si = \{c_1, c_2, .., c_x\}, c_i \in C$$

A desired final situation is defined by the union of *Si* and a set of *y* additional desired concepts *cd*.

$$Sf = Si \cup \{cd_1, cd_2, .., cd_y\}, cd_i \in C$$

A SDP Goal represents a particular objective from a user perspective. Each Goal assumes a specific situation, described in its Goal assumption description *Ga* by a set of *a* concepts and describes the state after its invocation as its effect *Ge* by utilizing a set of *e* concepts:

$$Ga = \{c_1, c_2, .., c_a\},\ Ge = \{c_1, c_2, .., c_e\}$$

A Situation-driven Process *SDP* is a particular ordered set of *n* user Goals:

$$SDP = \{G_1, G_2, .., G_n\},$$

where each goal *G* is described in terms of its assumption G_a and its effects G_e. The initial situation is a subset of the assumption of the first goal of *SDP*

$$Si \subseteq Ga_1,$$

and the final situation *Sf* represents a subset of the union between *Si* and the set of all concepts which are described in the set of effects *Ge* of each of the *n* Goals of the *SDP*:

$$Sf \subseteq Ga_1 \cup Ge_1 \cup Ge_2 \cup ... \cup Ge_n$$

Moreover, each particular Goal G_i is supported by a set of p_i *SDP Brokered Goals BG* which are linked to SWS and describe the outcome of a Web service from the system perspective (Section 4). BG provide the union of all concepts described as the effects of Goal G_i:

$$Ge_i \subseteq BGe_1 \cup BGe_2 \cup .. \cup BGe_{p_i}$$

For instance, to enable the accomplishment of a specific SDP Goal within a learning process, i.e. to acquire a specific competency, one BG could be aimed at providing required E-Learning assets out of specific databases whereas another aims at computing a specific calculation, such as the current competency gap of the learner. In this way, the achievement of Brokered Goals at runtime subsequently progresses the actual situation, for instance by adding additional resources, until a desired user situation is reached. For instance in Figure 4, BG_1 and BG_2 are achieved at runtime while gradually progressing situation S_1 to $S_{1.1}$ and $S_{1.2}$. Finally, achievement of BG_3 ensures that S_2 is satisfied.

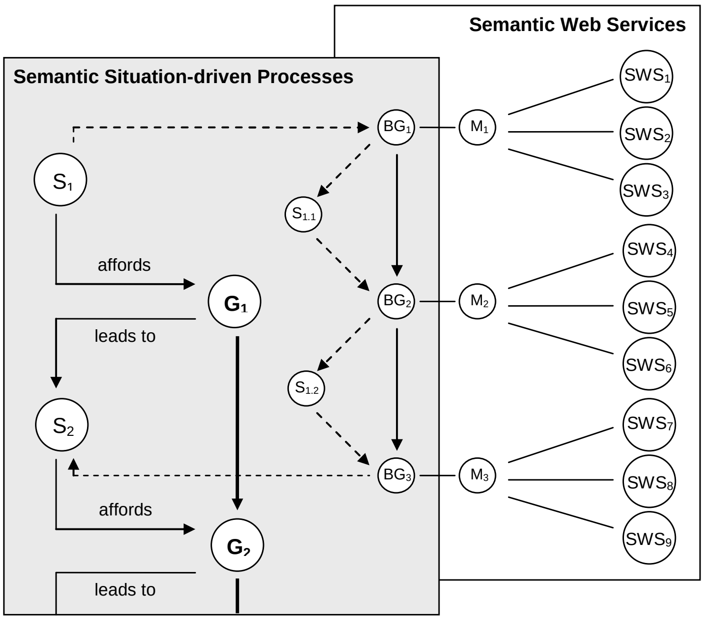

Fig. 4. Utilizing SWS to support situation-driven process Goals.

Brokered Goals are instantiated as domain-specific derivations of WSMO-based SWS Goals and thus, are mapped through *Mediators (M)* to SWS in order to enable the dynamic achievement at runtime through a SWS broker engine in terms of SWS service discovery, orchestration and invocation. Therefore, a SDP model extends the expressiveness of SWS facilities by enabling the incorporation of SWS Goals into meaningful process contexts. We would like to emphasize that process situations are highly dependent on the domain and nature of a process – for instance, whether it is a business or a learning process – since each domain emphasizes different situation parameters. For instance, a learning process situation is strongly dependent on parameters such as the competencies of the learner, whereas a business situation may focus on parameters such as the costs for a specific business task. Therefore, the SDP metamodel is not meant to be instantiated directly, but has to be derived in terms of domain-specific SDP models. Such conceptual models of domain contexts based on the SDP metamodel provide the facilities to represent existing process metadata schemas to enable the transformation of semantic SDP into non-semantic metadata standard manifestations. Our vision foresees a SDP lifecycle consisting of 3 stages which have to be supported by a SDP compliant application to suit a given user situation:

i) Automatic composition of domain-specific SDP.
ii) Transformation of SDP into metadata manifestation.
iii) Accomplishment of SDP-based process in terms of BG achievements.

The abstract metamodel of SDP is defined in terms of a *SDP Ontology* (*SDPO*) expressed by using the OCML representation language (Motta, 1998). SDPO describes a metamodel of processes as composition of situations (contexts) and Goals independent from their specific domain setting. In order to enable a high level of interoperability of the SDPO, it is aligned to an established foundational ontology: the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) (Gangemi, Guarino, Masolo, Oltramari, Schneider, 2002) and, in particular, its module Descriptions and Situations (D&S) (Gangemi, Mika, 2003). Figure 5 depicts the central concepts and relations of SDPO.

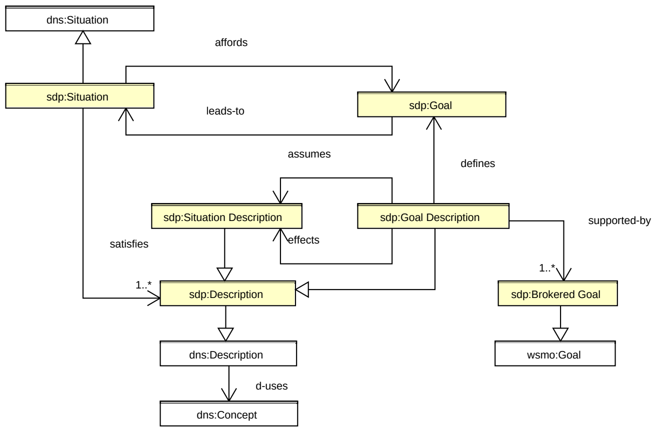

Fig. 5. Core concepts of the SDP Ontology (SDPO).

6 Situation-Driven Learning Processes

The Semantic Learning Process Model Layer (Section 3) is supported through the *Learning Process Modelling Ontology (LPMO)* which supports the semantic description of learning processes and process contexts following the SDP metamodel (Section 5). Besides its alignment to SDPO, LPMO is aligned to E-Learning metadata standards to enable interoperability. Figure 6 depicts an overview of the major semantic representations which have been provided.

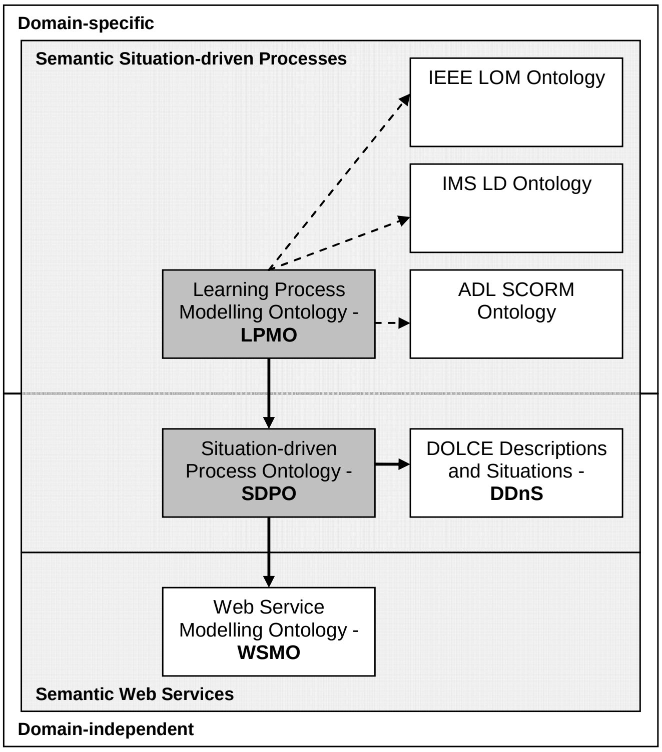

Fig. 6. Stack of ontologies to support Situation-driven Learning Processes.

LPMO extends the SDPO by specifying (a) the concepts that can be used in domain-specific descriptions of E-Learning situation, (b) a set of Brokered Goals supporting learning Goals.

Figure 7 depicts the main elements used to define learning situation descriptions.

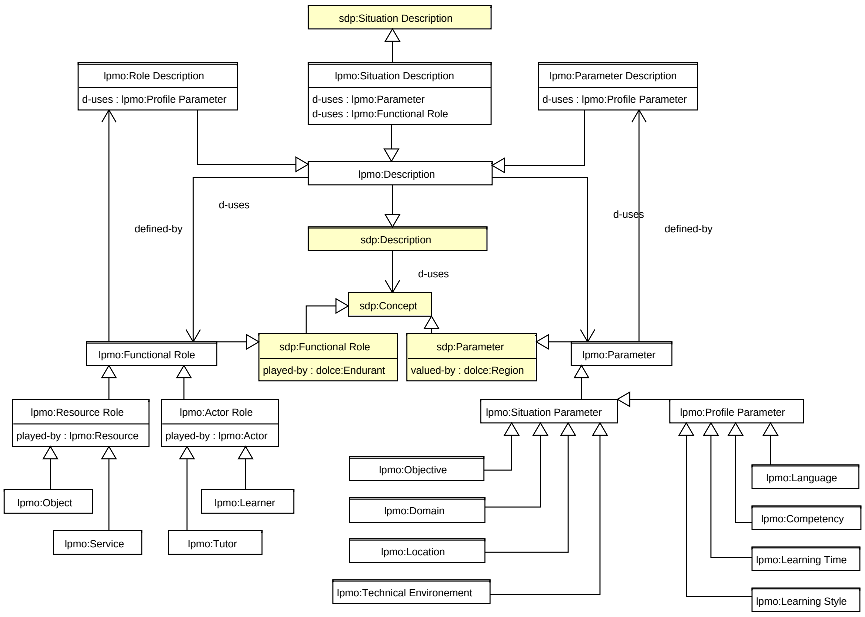

Fig. 7. Learning Process Model Ontology as domain-specific SDP derivation.

A situation description of the semantic SDP model is specialised into a E-Learning situation description *(lpmo:Situation Description)* in terms of specific *functional roles* and *situation parameters* (*d-uses*). Roles and parameters are inherited from the D&S ontology through the SDP Ontology. The former are the roles of *actors* and *resources* in learning situations. The latter are the characteristics that describe the learning situation.

It is important to note that the LPMO allows the description of learning situations in domain-specific terms by using domain-specific parameters *(lpmo:Parameter*) such as competencies *(lpmo:Competency*). The situation description *(lpmo:Situation Description)* is of central character, since it describes the entire context of a specific learning situation, such as the learning domain *(lpmo:Domain)*, the actual learner *(lpmo:Actor)* or his/her actual objective *(lpmo:Objective)*. Specific parameters, for instance the learner (*lpmo:Actor*), are described by a dedicated description (e.g. *lpmo:Actor Profile)* using specific parameters (e.g. *lpmo:Profile Parameters*).

Moreover, we would like to highlight that a specific domain – such as E-Learning - can be populated through the use of the LPMO, but also through several distinct ontologies which are aligned to the SDP metamodel. The alignment between different conceptual models of one specific domain can be achieved by concrete mappings as well as the use of mediation facilities as described in Section 4. Based on semantic representations of E-Learning-specific metadata standards – IMS LD and ADL SCORM - and the manual description of mappings to LPMO, standard compliancy with non-semantic metadata standards as well as interoperability between them is supported. Further elaboration of these mappings can be found in (Dietze et al., 2007a).

7 Situation-Driven Composition and Accomplishment of Learning Processes

This section explains the automatic composition and accomplishment of a learning process for a given learning situation using a SWS-based prototype application.

Scenario

To prove the feasibility of our approach, a proof-of-concept prototype was provided which utilizes the introduced framework to support a specific use case. The proposed application components and ontologies are used within the EU FP6 project LUISA (http://www.luisa-project.eu/www/). The prototype deploys the ontology framework introduced in the previous sections and supports the SDP lifecycle introduced in Section 5. Particularly, the lifecycle involves the automatic composition of SDP based on the LPMO, and the transformation into distinct process metadata manifestations for two standards, namely ADL SCORM and IMS LD, and the automatic process accomplishment, in terms of dynamic achievements of learning goals.

To reach awareness about the current learning situation, the learner is authenticated to retrieve information about his/her actual preferences. Moreover, learners are enabled to define appropriate situation-specific parameters, such as his/her current learning aim, the available learning time or the preferred metadata runtime environment. The situation description is gradually refined throughout a specific session, for instance by adding the actual competency gap. The generation of an appropriate SDP for E-Learning, which targets the actual context is accomplished in two steps which are supported by distinct services: first an appropriate SDP is composed which targets the actual situation followed by the transformation of a metadata-independent SDP into the desired metadata standard. Figure 8 depicts the utilized architecture

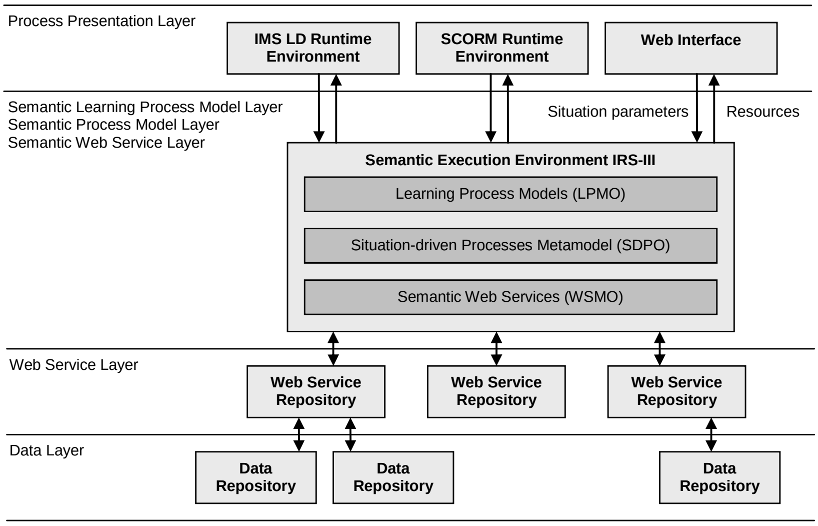

Fig. 8. Architecture to support runtime reasoning on SDLP and SWS.

During runtime presentation of the process model within a dedicated runtime environment, each learning activity itself is accomplished by Brokered Goal achievement requests sent to the SEE, respectively IRS-III. Hence, at runtime, the SEE enables a further adaptation to the specific situation by automatically selecting the most appropriate resources for a given SDP Brokered Goal. IRS-III makes use of WSMO-based SWS descriptions, semantic LPMO models which are based on the SDP metamodel. Please note, that IRS-III therefore provides reasoning on all semantic layers described in Section 3. Multiple runtime environments interact with IRS-III to provide information about the current real-world situation on the one hand and present and accomplish LPMO-based processes on the other hand. Semantic process instances are presented within a dedicated web- based interface whereas standard-compliant runtime environments (IMS LD, ADL SCORM) are utilized to present non-semantic metadata representations of a learning process.

Situation-driven Composition of Learning Goals

Utilizing the gradual mapping between E-Learning-specific Brokered Goals and WSMO Goals, not only processes but also entire application scenarios are accomplished by automatically achieving Brokered Goals at runtime through the Semantic Execution Environment. Therefore, to follow our scenario, a sequence of high level Brokered Goals is achieved at runtime to support S1 – S3. Figure 9 depicts the utilized Goals:

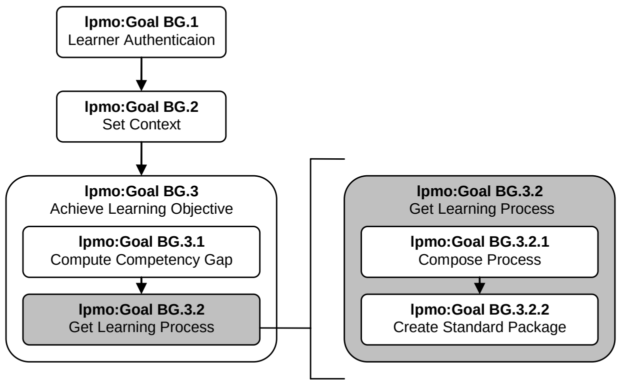

Fig. 9. Goal orchestration to create context-adaptive and metadata-compliant learning processes.

After a gradual refinement of the available information about the actual situation context – learner authentication (*BG.1*), situation refinement (*BG.2*), computation of competency gap (*BG.3.1*) – a Goal is achieved to provide a learning process (*BG.3.2*). The learning process, respectively the SDP for E-Learning, has to suit the given situation and in particular the desired metadata standard. Hence, *BG.3.2* is decomposed into two sub Goals which are aimed at composing a semantic context-aware learning process model (*BG.3.2.1*) based on the LPMO and transforming the process model into a metadata format appropriate for the given context (*BG.3.2.2*).

The first one (*BG.3.2.1*) is accomplished by a Web service which takes into account specific situation parameters of *Si*, for instance the preferred educational method of the learner or his/her available learning time. In order to reason about the desired final situation *Sf* of the learner, a particular situation parameter is taken into account, the *Aim* of the learner. Each particular Aim, for instance "Learning French", is linked to a set of desired competencies, for instance "French Language Advanced Level" and "French Language Expert Level". Therefore, these competencies are part of the final situation *Sf* which is achieved by accomplishing the process. This fact is considered during the process composition by considering specific activities to gradually reach the desired final situation.

The entire composition is performed by a Web service, which follows the formalization described in Section 5 to compose a LPMO-based process as a set of Goals and Brokered Goals to progress from the initial situation *Si* to the final situation *Sf*. Since Goal descriptions as well as Brokered Goal descriptions, particularly their assumptions and effects, are pre-described within the LPMO, Goals (Brokered Goals) are selected, composed and instantiated at runtime. Following this approach, given an initial situation *Si* and a final situation description *Sf*, a *SDP* (based on the LPMO) to progress from *Si* to *Sf* can automatically be composed of specific Goals, and consequently Brokered Goals, which show the appropriate assumptions and effects to provide all desired concepts which are subset of *Sf* but not *Si*. These are then instantiated given the particular input concepts which describe the current situation. Usually, composition functionalities will be provided by different services following distinct composition strategies. In this way, different stakeholders can implement their individual composition strategies, whereas the most appropriate for a given situation context is discovered and invoked at runtime by the Semantic Execution Environment.

The outcome of *BG.3.2.1* is a dynamically created learning process model which is described semantically by utilizing LPMO as domain-specific derivation of SDP and which is composed of learning Goals which each refer to a set of Brokered Goals. We would like to highlight, that each learning activity itself is described as a semantic learning Goal and is dependent on the actual situation. Hence, at runtime, the achievement of contextualized Brokered Goals considers the actual learning situation parameters and enables a more fine-grain adaptation to the actual learning context.

Situation-driven Metadata Transformation based on Semantic Mappings

Whereas the previous section was focused on the entire approach of composing SDP at runtime, this section explains the situation-driven transformation of a LPMO-based process into a non-semantic metadata standard based on mappings (Dietze et al., 2007a). To suit the actual situation – in particular the specifically used metadata runtime environment – the metadata-independent process provided by the achievement of *BG.3.2.1* is transformed into the desired metadata standard. For instance, if the current situation description indicates that the actor utilizes an ADL SCORM compliant runtime environment, the standard independent LPMO-based process model is transformed into an ADL SCORM compliant metadata manifestation which represents the generated LPMO-based process and is contained in an IMS content package.

The transformation into appropriate metadata standards is accomplished by SWS invocations, such as *WS.3.2.2.1* and *WS.3.2.2.2* as depicted in Figure 10.

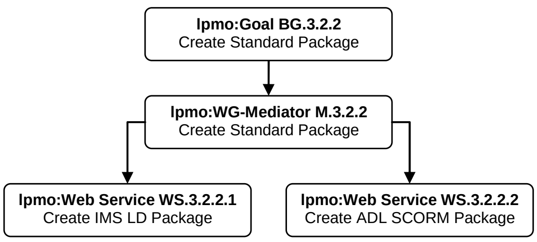

Fig. 10. Semantic Web Services to provide metadata standard compliant learning packages.

As depicted above, these Web services are published as SWS and associated with Goal *BG.3.2.2* via a dedicated Web Service-Goal-Mediator (WG-Mediator). The actual situation parameters are utilized by the Semantic Execution Environment to identify and invoke the most appropriate service – in this case whether *WS.3.2.2.1* or *WS.3.2.2.2* - for the given context on the basis of semantic capability descriptions.

We would like to highlight, that for each metadata standard transformation, different Web services can be provided which each follow a distinct transformation strategy. This may be necessary, since the semantics of a metadata schema are usually not completely unambiguous and thus, their interpretation and finally, their semantic alignment can vary and completeness may not be feasible.

The following listing shows a portion of the OCML code of the SWS description of *WS.3.2.2.1* aimed at providing an IMS LD compliant manifestation based on a given process.

lpmo:WebService

```
(DEF-CLASS CREATE-IMSLD-PACKAGE-WEB-SERVICE
           (LPMO-GOAL)
           ?GOAL
           ((HAS-INPUT-ROLE
             :VALUE
             HAS-PROCESS
             :VALUE
             HAS-CONTEXT)
            (HAS-INPUT-SOAP-BINDING
             :VALUE
             (HAS-PROCESS "string")
             :VALUE
             (HAS-METADATA-STANDARD "string"))
            (HAS-OUTPUT-ROLE :VALUE HAS-PACKAGE-URL)
            (HAS-OUTPUT-SOAP-BINDING
             :VALUE
             (HAS-PACKAGE-URL "string"))
            (HAS-PROCESS :TYPE LPMO-PROCESS)
            (HAS-METADATA-STANDARD :TYPE LPMO-METADATA-STANDARD)
            (HAS-URL :TYPE STRING)))

(DEF-CLASS CREATE-IMSLD-WEB-SERVICE-CAPABILITY
   (CAPABILITY)
   ?CAPABILITY
     ((USED-MEDIATOR :VALUE GET-LEARNING-DATA-MED)
        (HAS-ASSUMPTION
             :VALUE
             (KAPPA
               (?WEB-SERVICE) (= (WSMO-ROLE-VALUE ?WEB-SERVICE 'HAS-
               CONTEXT)"IMS LD")))))
```

Listing 1. SWS capability description of WS.3.2.2.1.

Please note, that the capability description indicates that the grounded Web service provides packages compliant with the metadata standard IMS LD and thus, this service is only invoked in case this metadata standard is desired. The authors would like to emphasize, that each transformed metadata manifestation still follows the SDP approach of describing user and system perspective on a process. This is achieved by referring user goals within a metadata manifest to SDP Brokered Goal achievements through HTTP references to a web applet which requests the achievement of a BG from a SEE. Particularly, the Web service reported here (WS.3.2.2.1.) not only dynamically generates the IMS LD content package but also a set of JavaScript files which are included into the package. These scripts – one for each Brokered Goal of the learning process – are capable of sending achievement requests for the respective BG to the Semantic Execution Environment IRS-III at runtime of the process - further details can be found in (Dietze et al., 2007b) - and hence, they implement our vision of SDP as described in Section 5.

Runtime Accomplishment of SDP through dynamic Goal Achievements

At runtime, a process is presented either in a metadata standard-specific runtime environment or a runtime environment dedicated to interpret semantic LPMO-based process models. As introduced in Section 5, each activity within a SDP-based process is described in terms of a situation-specific Goal from the user perspective and a set of Brokered Goals which define the Goal from the system perspective. This principle applies to dynamically created LPMO-based process models as they are domain-specific derivations of the SDP metamodel, and particularly to metadata standard-compliant manifestations of LPMO-based processes. Figure 11 depicts screenshots of three different process runtime environments, each presenting a distinct representation of a LPMO-based process. Whereas a specifically developed user interface is utilized to interpret and present semantic process instances of the LPMO, two player applications of the RELOAD-project (http://www.reload.ac.uk/) are utilized to present dynamically created XML-manifestations following the IMS LD and ADL SCORM standard.

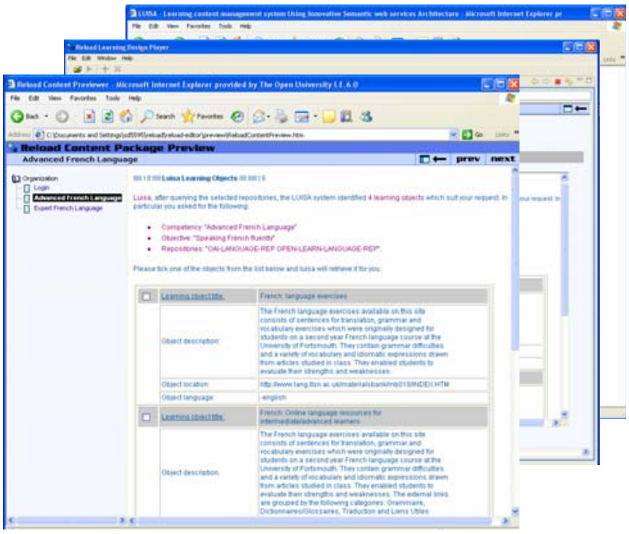

Fig. 11. Screenshots of distinct interfaces presenting LPMO-based processes.

Each of the interfaces depicted above presents a representation of a dynamically composed process aimed at teaching the French language at different levels. In this individual learning situation, a specific situation description described by a learning aim to acquire French language skills for a specific learner competency profile and setting requirements led to the composition of a learning process which is described in terms of two distinct learning activities, respectively learning Goals *G.5* ("Learn French Advanced Level") and *G.6* ("Learn French Expert Level") which are depicted in Figure 12.

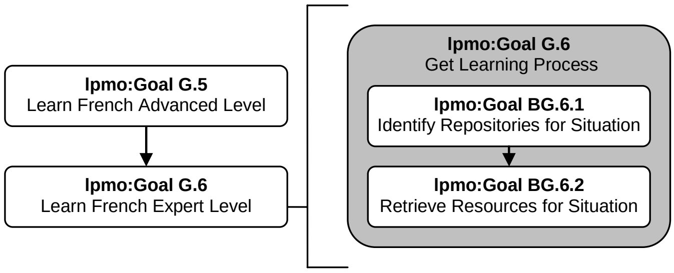

Fig. 12. Learning Goals supported by a sequence of Brokered Goals.

Each learning Goal – such as *G.5* and *G.6* – is supported through the runtime achievement of two Brokered Goals which enable to progress from the initial situation to the desired situation. In case of *G.6*, the initial situation is defined by the learner's profile parameters, such as the native language or technical environment and in particular the learner's competency profile parameters. The actual situation description includes in particular that the previous learning Goal *G.5* is achieved and its prospective competency ("French Language, Advanced Level") is achieved and is part of the current situation description.

The two Brokered Goals *BG.6.1* and *BG.6.2* gradually modify the actual situation by adding specific parameters. *BG*.6.1 provides a list of matching learning resource repositories, whereas *BG.6.2* provides a selection of learning resources which support the entire situation. In that way, the initial situation of *G.6* is gradually modified by achieving Brokered Goals through SWS Goal achievements via a Semantic Execution Environment until the final situation of *G.6*, defined in the semantic effect description of *G.6*, is reached. Similar Goal achievements are orchestrated to achieve each activity of a specific process at runtime.

We would like to highlight, that following the SDP approach enables not only the dynamic composition of a specific process for a specific situation but also the achievement of each activity at runtime, and consequently considers situation-specific parameters at runtime to enable selection of appropriate resources within a specific context setting.

8 Evaluation

In this section, we introduce an evaluation model that provides an attempt to formalize and compare the efforts required to develop learning processes by following the common current practice in contrast to the approach proposed in this paper.

Current State of the Art

Let us consider a number of real world learning processes p, which have to be supported based on a number of process descriptions *m*. Each description has to be developed by spending an effort e_m. The latter represents the amount of work to annotate a learning process by using one of the existing metadata specifications (e.g. IMS LD, SCORM), and it has been considered constant. In particular, we consider s different process metadata standards.

The actual learning context for every process can be defined by *n* context parameters $\{c_1..c_n\}$, such as the technical platform or the native language of the learner. Each context parameter has got a number of possible parameter values:

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

where $|c_i|$ represents the number of all possible values of each parameter, and the unit defines the "no-specification" case. 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.

According to the limitations introduced in Section 2, the necessary cumulative development effort e_{cum} to support all learning processes, learning contexts and metadata specifications by following the traditional approach can be formalized as follows:

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

i.e. creating all the necessary process descriptions m, where:

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

i.e. we have to create a different process description for each possible process, context and metadata specification. Therefore, the necessary effort can be summarized with:

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

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

Applying Learning SDP

Let us refer to the formalization introduced in the previous subsection. According to our approach and differently to the current state of the art, the number of process models *m* necessary to support different processes *p* is equal to *p*: the same SDP description can be used within different contexts and automatically mapped into different metadata specifications. However, we have to consider a first effort $e_{initial}$ to fully provide the facilities to support our semantic framework; i.e. the semantic representations of the process contexts, the mappings to metadata standards, as well as the SWS descriptions. Thus, the cumulative effort in our approach can be summarized as follows:

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

where e_{SDP} is the effort to represent a process according to the semantic descriptions of our approach. Given our experience, we can assume that $e_m \cong e_{SDP}$.

Therefore:

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

Figure 13 depicts a generic comparison of this effort with the efforts of traditional approaches. We foresee that the advantages of our vision can be observed with an increasing number of learning processes, since it benefits from lower process description development efforts, but requires an initial amount of work to provide necessary facilities. In the following subsection, we provide a concrete comparison, based on the scenario introduced in Section 7.1.

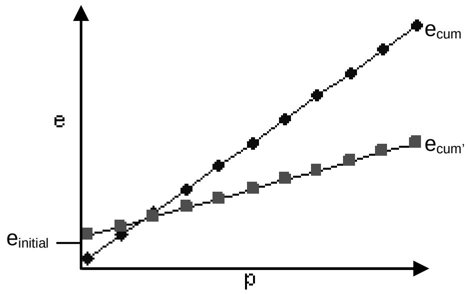

Fig. 13. Comparison between SCP-based and current state of the art-based approaches, according to the proposed model.

Validation based on Example Scenario

To support the use case scenario which is currently being supported through our prototype application, we have to describe two different learning processes: “Modelling with Fourier Series” and “Speaking French Language”. Therefore, *p=2*. In addition, we have to support two learning context parameters *c*: the native language of the learner and the learning domain. The former can be valued by 5 different values *v* (English, German, French, Spanish and an unknown native language); the latter can be valued by 3 different values (Languages, Math and an unknown domain). Furthermore, two different metadata standards *s* have to be supported (IMS LD and ADL SCORM). Therefore, the cumulative effort to describe the necessary process descriptions can be expressed as follows:

$$e_{cum} = f(p) = e_m * 2 * (5 * 3 - 1) * 2 = e_m * 56$$

while the effort to develop the prototype application introduced in Sections 7 can be estimated as follows:

$$m = f(p) = p = 2$$

with

$$e_{cum'} = f(p) = e_{initial} + 2 * e_m$$

If we assume an effort e_m of 1 person-month (pm), as well as the availability of all facilities enabling our development approach – i.e. we do not have to consider the initial development effort $e_{initial}$, we obtain the comparison in Figure 14.

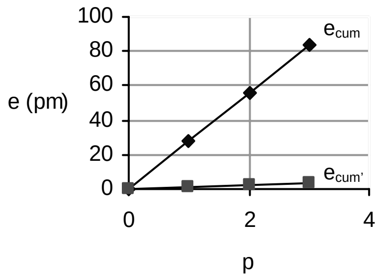

Fig. 14. Comparison of development efforts between SDP-based and traditional-based approaches in the introduced scenario.

Figure 15 illustrates the point, that supporting the example scenario by following the traditional approach does require an amount of 56 pm. Every new learning process has to be taken into account with a necessary amount of 28 pm to satisfy just the simple requirements of the example use case. In contrast, by following our SCP-based approach, every new learning process can be supported with just 1 additional mm.

We want to highlight that generalizing the effort of creating different learning process models is a simplistic approach. Therefore, it was just adopted to enable a quantification and comparison of expected efforts. Moreover, the choice of assuming the initial effort $e_{initial}$ null follows the idea of comparing the running framework (i.e. ready for use for learning designers) with the existing practices in E-Learning. In fact, the initial effort $e_{initial}$ could even be higher. For example, to implement the application described in Section 7.1, we spent 10 pm. However, considering 2 processes to represent, our approach already provides an advantage.

9 Related Work

Given the framework and ontologies described above, L1-L4 (Section 2) are addressed by supporting the dynamic composition of context-adaptive learning processes, their transformation into distinct metadata standards and their automatic accomplishment in terms of SWS Goal achievements.

Several other existing approaches follow the idea of using Semantic Web or Web service technologies to provide dynamic as well as personalized, and context-sensitive support for learning objectives, each addressing a subset of the mentioned lacks L1-L4 (Section 2). To quote a few examples, Knight et al. (2006) as well as Baldoni, Baroglio, Patto and Torasso (2002) are concerned with bridging learning contexts and resources by introducing semantic learning context descriptions. This allows the adaptation to different contexts based on reasoning over provided context ontologies, but does not provide solutions for building complex adaptive learning applications by reusing distributed learning functionalities. Moreover, Knight et al. (2006) base their work entirely on IMS LD and thus, it does not envisage to bridge between different metadata standards.

Baldoni, Baroglio, Brunkhorst, Henze, Marengo and Patti (2006) follow the idea of using a dedicated personalization Web service which makes use of semantic learning object descriptions to identify and provide appropriate learning content. Neither is the integration of several distributed learning services within the scope of this research, nor is the allocation of services at runtime. Further related research on a Personal Reader Framework (PRF) introduced in Henze (2006) and Henze, Dolog, Nejdl (2004) allows a mediation between different services based on a so-called ”connector service”. However, the composition of complex learning applications based on distributed services is not within the scope of the PRF.

The work described in Schmidt and Winterhalter (2004) and Schmidt (2005) utilizes Semantic Web as well as Web service technologies to enable adaptation to different learning contexts by introducing a matching mechanism to map between a specific context and available learning data. However, neither it considers approaches for automatic service discovery nor it is based on common standards. Hence, the reuse and automatic allocation of a variety of services or the mediation between different metadata standards is not supported. These issues apply to the idea of ”Smart Spaces” for learning as well (Simon, Dolog, Miklos, Olmedilla, Sintek, 2004).

Apart from these research efforts, even the specifications of existing E-Learning metadata standards such as IMS LD or ADL SCORM provide facilities for context-adaptive behavior. For instance, IMS LD Level B properties (IMS Global, 2003) and the sequencing elements of IMS Simple Sequencing, utilized by ADL SCORM enable the description of strategies for conditional selection of learning resources. However, since these facilities still rely on a manual pre-selection of learning resources at design-time, the issues described in Section 2 are not finally solved.

Whereas the majority of the described approaches enables context-adaptation based on runtime allocation of learning data, none of them enables the automatic allocation of learning functionalities or the integration of new functionalities based on open standards. Nevertheless, all approaches do not envisage mappings between different learning metadata standards to enable interoperability not only between learning contexts but also across platforms and metadata standards.

10 Conclusions

In this paper, we proposed an approach aimed at bridging the gap between learning contexts and learning resources based on Situation-driven Learning Processes (SDLP), which abstract from learning data and services – the actual resources - as well as learning process metadata. By introducing semantic descriptions of contextualized learning processes, which are aligned through SWS to learning resources on the one side and learning process metadata descriptions on the other side, our approach finally enables the context-aware composition of learning processes and their accomplishment by automatically allocating learning resources for a given learning need within a specific learning situation.

To support this vision, we provided the semantic representations to support SDLP, respectively an ontology which represents the SDP metamodel (SDPO) and another which derives SDP for the E-Learning domain (LPMO). Given a specific learning situation, a semantic learning process based on LPMO is composed dynamically and is accomplished in terms of SWS Goal achievements, utilizing the gradual derivation of learning goals within a learning process from WSMO Goals. Furthermore, an implementation architecture to support reasoning on these semantic layers was introduced based on the Semantic Execution Environment IRS-III. IRS-III serves as central reasoning environment and SWS broker, hosting ontological descriptions of available learning resources as well as semantic conceptualizations of situation-driven learning processes. Thus, IRS-III is able to compose and deliver appropriate resources to satisfy a given learning objective within a specific learning situation. Consequently, by addressing L1-L4 described in Section 2, neither manual design and composition of learning processes nor manual allocation of resources is required in contrast to traditional E-Learning applications.

Apart from that, the authors would like to highlight the openness of the described approach: additional resource providers can be integrated into the application framework by simply providing semantic descriptions of available resources and publishing these to the Semantic Execution Environment. By utilizing dedicated mediation facilities, heterogeneities related to data formats or terminologies used by distinct providers, can be solved to ensure the autonomy of all integrated resource providers.

It is apparent that the approach described in this paper requires a preliminary effort, to provide the semantic facilities described in the previous sections as well as comprehensive semantic descriptions of learning resources and that their maintenance may be a challenging task. However, given these facilities - as exemplarily provided for the described prototype - our approach represents a generalisable framework which can be applied and reused across distinct E-Learning application scenarios to enable context-adaptive learning process composition and accomplishment.

Moreover, the authors are aware, that the E-Learning community may be suspicious about trusting a reasoning engine based on semantic knowledge representations instead of manual process design and resource allocation. This is of particular concern as there may not be the one and only point of view on the semantics of a resource or a situation and distinct philosophies and perspectives are common on the question, which resource may be most appropriate for a given learning situation. To take this aspect into account, we particularly foresee the provision of distinct semantic descriptions of one learning entity, such as a learning resource, and of a variety of Web services which compose and transform learning processes. The most appropriate Web service is selected at runtime as this is a key feature of the Semantic Execution Environment IRS-III.

To enable the high applicability of our approach, future work will consider the development of semantic mappings to a wider variety of metadata standards. Furthermore, it may be beneficial, to consider further SWS standards, such as OWL-S and their alignment to the SWS layer (Section 3). Nevertheless, as we attempt to provide a domain-independent metamodel for SDP, the consideration of further process domains is within the scope of our work, to enable a mapping of learning processes to additional process domains – for instance business processes – and their conjoint support through a unique SWS based application framework. We are strongly convinced that applying the idea of SDP in further process domains is feasible, since processes across several domains share similar notions and concepts and have to deal with related issues, such as process design, process resource allocation, and context-sensitivity.

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