Personal Learning Environments on Social Semantic Web

Abstract. Today's students, being used to constant activity and multitasking in their everyday life, need a high level of social and creative engagement in order to learn; for them, highly interactive learning environments which allow for communication, collaboration, and authoring, are a must. In addition, modern learning theories stress the importance of interactivity and engagement of students for successful learning processes, whereas recent empirical studies provide evidence and confirm this. In this paper, we present how the integration of Social and Semantic Web technologies, often referred to as the Social Semantic Web (SSW), along with the Linked Data paradigm can improve the interactivity of today's learning environments, while putting students in control of their learning process spanning across different tools and services. We identify the main principles on which such SSW-supported personal learning environments are based, and illustrate them thorough the design, implementation, analysis, and evaluation of DEPTHS (DEsign Patterns Teaching Help System) – a SSW-based interactive personal learning environment we have developed for the domain of software design patterns.

Keywords: Semantic Web, Social tools, Ontologies, Linked Data, Collaborative learning, Project-based learning

1 Introduction

Current e-learning practices are increasingly influenced by the fact that a huge number of students and teachers are members of at least one social network on the Web. In addition to being active on commonly popular social networks like Facebook, Twitter, and YouTube, many of them also actively participate in online networks specifically focused on education. For example, students typically use these education-oriented networks to share lecture notes and assignment materials with their classmates (e.g., NoteMesh, http://www.notemesh.com/). Similarly, teachers can exchange their lectures and slides on topics they present in class (e.g., SlideShare, http://www.slideshare.net/ and Connexions, http://cnx.org). Some online social networks are aimed at connecting students and teachers (e.g., BuddySchool, http://www.buddyschool.com/). Finally, other education-oriented networks support continuous development of one's portfolios through interactions with the members of the network (e.g., Elgg, http://elgg.net/, both as social network and social software platform).

The acceptance of social networking tools (and the broader category of social software tools) in education is primarily led by teachers enthusiasts who, trying to make their classes more engaging for students, turn to these popular online tools and make them part of their, often innovative, teaching practices. However, since evidence is still lacking as to whether and to what extent these tools are beneficial for education, different authors have different views on their usefulness in educational settings. Besides individual practitioners, the growing number of researchers (e.g., [Eisenstadt, 2007], [Minocha, 2009], [Ala-Mutkaet al, 2009]) and research projects (e.g., iCamp[1] and Horizon Project[2]) in technology-enhanced learning have been exploring the potentials of these tools and reporting the benefits of and challenges for their broader application. Some even consider that further development of social networking tools and Web in general will lead to serious disruptions in education [Christensen et al, 2008]. On the other hand, there are authors who are skeptical about these tools and their educational potentials (e.g., [Ziegler, 2007], [Bugeja, 2006]). Having done a deep exploration of the educational potentials of social software tools (as presented in the following sections), we believe that it is reasonable to expect that these tools will be increasingly present in educational practices. Accordingly, we follow such a perspective in our own exploration of this field.

To realize their full potential in the educational domain (as well as in many other domains), today's social networks have to evolve. Currently these networks are like isolated islands – knowledge and learning resources can be exchanged within the island (i.e., the network) but not across multiple islands, at least not without a lot of manual copy-and-paste effort. For example, consider a student learning about a certain domain topic and trying to consult related resources gathered by an expert or his/her peers. The resources maintained by these people may

1 http://www.icamp.eu/
2 http://www.nmc.org/horizon

be located on many different online social networks, and cannot be automatically imported in the student's current learning environment and context (e.g., described by her learning activities and goals).

However, content and human discovery is not the only important issue for an effective learning environment. Modern learning theories stress the importance of interactivity [Muirhead, 2004] and engagement of students [Caring, 2006] for successful learning processes, whereas recent empirical studies provide evidence and confirm this (see Section 2.4 for some background). Yet, widely used (e-)learning environments (e.g., Learning Management Systems) do not support students' interactivity across diverse learning systems, tools, and online educational networks that students turn to during the learning process. Even though some of them do support widely accepted online interaction paradigms and practices (such as bookmarking, tagging, commenting, and communicating via short messages), those interactions are confined to the "walls" of the learning environment.

Recognizing the weaknesses of the present social software and interactive learning environments, the e-learning community has come up with and already widely embraced the concept of Personal Learning Environments (PLEs) [Attwell, 2007]. PLEs let the learners control their learning environment while promoting interactive learning in distributed web contexts. As Section 2 demonstrates, there has been a considerable amount of research and development related to PLEs. Still, the problem of personalized and meaningful integration of distributed learning data/systems facilitating pedagogically sound interactive learning is an open research challenge. Moreover, there are no widely adopted principles that can provide developers with a set of systematic guidelines for building PLEs.

To address the above two open challenges of PLEs, this paper proposes a set of principles for designing PLEs based on both Social Semantic Web (SSW) paradigm and Linked Data paradigm. SSW has emerged recently as a new paradigm for creating, managing and sharing information on the Web [Mikroyannidis, 2007]. It is based on the idea of merging the best features of Social Web and Semantic Web, through combining the common formats for defining and structuring information with the social mechanisms for creating and sharing the knowledge. We argue that by using SSW technologies and following Linked Data paradigm and principles [Berners Lee, 2006], "walled garden" learning environments can be turned into open, interactive PLEs. To allow for a systematic development of such environment, we recommend a set of development principles (Section 3). By following these principles, we developed a PLE that allows for project-based and collaborative learning of software design patterns (Section 4). The implemented PLE enabled us to thoroughly analyze the recommended principles (Section 5) and evaluate the effectiveness of the approach in a real learning setting (Section 6).

2 Social Semantic Web and Interactive PLEs – State of the Art

In this section we give a brief literature overview of the research areas relevant for our work – Social Semantic Web, Personal Learning Environments and Interactivity in Learning – aiming to present the state-of-the-art in these areas and thus set the stage for the principles for designing interactive PLEs which we propose in the next section (Section 3).

2.1 Social Semantic Web in e-learning

The Social Semantic Web (SSW) stands for a new paradigm for creating, managing and sharing information through combining the technologies and approaches from the Semantic Web and the Social Web (Web 2.0). The former aims at giving information a "well-defined meaning, better enabling computers and people to work in cooperation" [Berners-Lee et al, 2001] through the definition of ontologies [Allemang & Hendler, 2008]. The latter is a platform for social and collaborative exchange [O'Reilly, 2005] where users meet, collaborate, interact and most importantly create content and share knowledge through, e.g., wikis, blogs, photo- and video sharing services. SSW emerged by merging the best of these two worlds, through combining the common formats for defining and structuring information with the social mechanisms for creating and sharing knowledge [Mikroyannidis, 2007]. On SSW, socially created and shared knowledge leads to the creation of explicit and semantically-rich knowledge representations [Gruber, 2008]. This novel paradigm has already started making its way into e-learning and education, as shown, e.g., in [Jovanovic et al, 2009a] and [Tiropanis et al, 2009]. Specifically, SSW has already shown as beneficial for: i) on-demand assembly of course content from existing learning objects [Westerski et al, 2006]; ii) learning and knowledge sharing in collaborative e-learning environments [Auer et al, 2006], [Zacharias et al, 2009], [Schaffert et al, 2006], [Bajanki et al, 2009]; and iii) provision of highly informative feedback for educators [Jovanovic et al, 2007]. Below we present how it has been leveraged for the realization of PLEs, and further on in the paper (see Section 4.3) how it enabled us to develop advanced, context-aware educational services that support and foster interactivity in a PLE.

2.2 PLEs – a common denominator of modern e-learning approaches

Different authors provide somewhat different definitions of PLEs. However, common features of these learning environments did emerge and include (but are not restricted to) the following[3]:

- Facilitate online interaction: interaction with content and interaction with other individuals around the shared content;
- Put the control over the learning process in the hands of learners;
- Bring together all the disparate resources of the learner's interests and simplify their management;
- Allow for creating new meaning through interaction with (annotation, linking and aggregation) disparate existing resources.

Accordingly, a PLE can be considered as a facility for an individual to access, combine, configure and manage digital resources (content and services) related to their present learning needs and interests. In addition, it provides means for seamless communication and collaboration among individuals involved in a learning process. PLEs are often associated with informal learning, but are also entering the formal learning scene mostly through the efforts of PLE researchers who are also educational practitioners (i.e., teachers)[4].

The notion of PLE recognizes the importance of interaction for learning – interaction with content as well as social interaction with members of a learning community or/and the Web in general. In order not to alienate learning interactions from those that today's students are well accustomed to, most PLEs adopt the widely accepted online interaction paradigms and practices, such as bookmarking, tagging, commenting, communicating via short messages, status updating, and the like.

Related to the notion of PLE is the metaphor of "Teacher as DJ"[5], introduced by Wiley in 2005. This metaphor has recently been revitalized and even put into practice under the name "Open Educator as a DJ"[6]. It demonstrates how different kinds of Social Web tools can be applied (by teachers) over open, publicly accessible (learning) content to produce new, contextualized teaching/learning content. However, this metaphor and practice can be further generalized so that not only teachers are the ones who do content sampling, (re-)mixing and presentation, but also learners can and should perform these activities as a part of their learning process.

Wild et al.'s view on PLEs, presented in [Wild et al, 2009], somewhat differs from the 'mainstream' view presented above. They consider learning environments, their construction and maintenance as the crucial parts of both the learning process and the expected learning outcome. Accordingly, learning environment is not a stage where the learning activities are taking place, but it is something that is created during the learning process and is considered as its most crucial result. The notion of learning environment is also extended to include not only tools, but also artifacts, and different actors involved in the learning process (learners, teachers, and experts). This novel perspective on learning environments is accompanied by a novel approach to learning environment design which is technically supported by a domain-specific language allowing learners to easily construct and maintain their PLEs. This approach can be considered a part of the broader area of end-user development.

2.3 Educational Mashups: the Materialization of PLEs

From a technical point of view, a PLE can be viewed as a self-defined collection of services, tools, and devices that help learners build their Personal Knowledge Networks, encompassing different kinds of learning resources (content, services, people) [Chatti et al, 2009]. Since most often PLEs are realized through combination of various Web 2.0 sources, they are also called Mash-Up Personal Learning Environments or MUPPLEs [Wild et al, 2008]. There are two types of MUPPLEs:

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3 http://www.deliberations.com.au/2006/12/present-and-future-of-personal-learning.html
4 One of the most prominent example is Prof. Michael Wesch from Kansas State University (http://mediatedcultures.net/ksudigg/)
5 http://opencontent.org/blog/archives/227
6 http://edtechpost.wikispaces.com/Open+Educator+as+DJ+%28Final%29

- Mashups by aggregation: most of the state-of-the-art mashup PLE solutions fall into this category; these mashups mainly support learners in putting together content from different sources (mainly feeds and widgets) into a single interface. Personal dashboards, like iGoogle, NetVibes and PageFlake are typical examples.
- Mashups by integration: allow for combining data from different sources and exchanging data among the tools and services integrated into the PLE; the integrated data can serve as an excellent bases for adaptation and personalization of PLEs through the provision of advanced context-aware services [Jeremic et al, 2009]; however, mashups of this type (still) require programming skills and thus have not been that widely accepted among end users (learners and teachers).

Since our research work, as well as the work of the MUPPLE research community in general, is primarily focused on the MUPPLEs of the latter type, in what follows we present different approaches to their implementation, categorized based on the major technology they rely upon. However, as some of the presented solutions combine two or more technologies, we classify these based on the technology that we perceived as dominant for the particular solution.

2.3.1 PLEs based on Web 2.0 APIs

Most of the proposed mashup PLE approaches fall into this category. Common features of these approaches include [Chatti et al, 2009]: (1) pulling data from external (RSS or Atom) feeds, (2) filtering, sorting, and combining many feeds into one, (3) exporting results as RSS, JSON, XML, and other formats, and (4) creating a widget for seamless integration of the results in other Web sites.

PLEM [Chatti et al, 2010] is a mashup driven aggregator and filter of diverse kinds of learning resources (e.g., learning content, activities, experts, communities). Inspired by the aforementioned David Wiley's concept of "the learner as DJ", PLEM allows one to create a personalized space, where she/he can easily aggregate, manage, tag, rate, and share learning resources of interest. Learning resources are made accessible through social media APIs that allow for the access to and retrieval of open educational resources (via MIT OCW[7] and OUNL OpenER[8]), blogposts (via Google Blog Search and Technorati), videos (via Google Blog Search and YouTube), books (via Google Book Search), images (via Google Image Search and Flickr), and presentations (via Slideshare). PLEM harness the collective intelligence of its users to provide them with a mechanism for ranking and recommending learning resources. Specifically, users' actions, such as commenting, saving, liking, rating, viewing, and sharing, are considered as votes for respective learning resources and are used for ranking and recommendation purposes.

As previously mentioned, Wild et al [2009] suggested a novel approach to learning environment design in which learners empowered by a domain-specific language (Learner Interaction Scripting Language – LISL) construct and manage their PLEs. Their prototypical implementation, called MUPPLE (Mash-UP Personal Learning Environment), allows for the reuse of different existing tools and their presentation to the user (learner) in an integrated manner (like personal dashboards). However, these tools do not communicate and their data cannot be interchanged, integrated and/or combined.

ReMashed is a system that recommends learning content by using the collective intelligence emerging in a PLE [Drachsler et al, 2009]. The PLE is realized through the aggregation of popular Web2.0 services, such as Flicker and Delicious. ReMashed uses collaborative filtering to offer recommendations; it matches together learners with similar opinions about learning resources. Ratings and tags of like-minded users are used to create personalized recommendations for the current learner.

2.3.2 PLEs based on Social Semantic Web and Linked Data paradigm

Talis Aspire[9] is aimed at enhancing the process of authoring resource lists by allowing user to easily discover appropriate content that can be re-used and remixed [Clarke, 2009]. In addition, by harnessing the existing work it can provide recommendations to authors of new lists within comparable subject areas. Recommendations are primarily based on the identified patterns of resource usage (e.g., which resources were often used together, or whose contributions were most often re-used). In addition, students votes for resources, both explicit (e.g., ratings

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7 http://ocw.mit.edu/OcwWeb/web/home/home/index.htm
8 http://www.opener.ou.nl/
9 http://www.talis.com/aspire

and stated intensions regarding resource usage) and implicit (e.g., number of accesses and downloads of a particular resource), are also used as a valuable source of data for generating recommendations. The Talis Aspire system is completely based on Linked Data principles [Berners Lee, 2006] and makes use of several ontologies to fully semantically describe the resources so that they can be easily combined and remixed. Even though this system cannot be consider a typical PLE, its features related to pulling content from different sources, reusing and remixing the content, and allowing for seamless collection of users' (learners') feedback do fit into the "Teacher as a DJ" metaphor.

The GroupMe![10] system combines Web 2.0 and Semantic Web technologies to provide personalized content management in a group (social networking) context [Abel at al., 2010]. Hence, it can be considered as a personal learning environment of a specific group of learners, often gathered around the same learning objective. From the Web 2.0 side, it leverages intuitive user interfaces that allow users to create groups of resources (Web pages, videos, images). Creation of groups, addition of resources to the groups, and any other operation related to the groups are all saved as RDF triples compliant to a set of ontologies that GroupMe! uses. By leveraging Semantic Web technologies for storing data about group-related (content and knowledge management) activities, GroupMe! allows for the integration, sharing and better (re-)use of resources relevant for a group of users. In particular, this eliminates the problems of ambiguity and improves the ranking of the discovered resources.

The Ensemble project[11] is exploring the potential of semantic technologies to support and enhance teaching and learning in higher education, with special focus on learning settings where some kind of case based learning is the pedagogy of choice. The adopted research approach assumes the combined usage of digital repositories, Semantic Web technologies, and features of 'social software' in order to allow for reuse through reconfiguration, adaptation, and collective action. This implies that the project is following SSW paradigm in building learning environments that bear a lot of resemblance to PLEs.

2.3.3 PLEs realized on SOA principles

Chatti et al. [2009] proposed a mashup PLE framework, called PLEF-Ext, which allows for mashing-up RESTful services and makes use of semantic approaches to deal with service integration and mediation within mashup PLEs. Specifically, PLEF-Ext leverages semantic description of learning services, expressed using Service Mapping Description language, to enable finding, sharing, integrating, managing, reusing, and remixing the services with minimum effort.

2.4 Interactivity in e-Learning

Interactivity in e-learning assumes learners' active participation in the learning process, rather than passive consumption of the content server by instructors [O'Connell, 2007]. It implies 'doing' as opposed to 'being' (present) [Downes, 2007], and could be equated with social and creative engagement, that is, communication, collaboration and authoring.

Today's students and teachers are citizens of the Social Web where the notions of social interaction, human computing, and collective intelligence are major assets. They are well accustomed to interaction paradigms and practices of Social Web, such as bookmarking, tagging, commenting, communicating via short messages, status updating, and the like. Accordingly, in order to be broadly accepted by students and teachers, the solutions for enhancing the interactivity in e-learning should be based on these already widely accepted forms of interaction which are currently (in everyday life) well supported by diverse kinds of social software tools. However, we believe and have already shown [Jovanovic et al, 2009a] that the integration of Social and Semantic Web technologies has potential to offer even better solution. Specifically, in our previous work [Jovanovic et al, 2009a], we have explored the potential of the SSW paradigm for improving present and developing new forms of interaction along each dimension of the "interactivity triangle" [Anderson & Garrison, 1998]. Our research work has been grounded on the "interactivity triangle" since it is a widely accepted model of interactivity in learning settings which has students, teachers and content at its vertices, and where each vertex is related with the other two and with itself (so that, for example, students are in interactions with teachers and content, but they also interact among themselves). We have indicated the potential of the SSW paradigm for: i) introducing new and improving existing

10 http://groupme.org/GroupMe/

11 Ensemble: Semantic Technologies for the Enhancement of Case Based Learning, http://ensemble.ljmu.ac.uk/wp/

forms of Interaction; ii) supporting interactivity across different systems and tools; and iii) integrating interaction data to allow for advanced forms of adaptation and personalization in e-learning [Jovanovic et al, 2009b].

2.5 (Semantic) Social Software Tools in e-Learning: State of the Practice

We have conducted a small-scale study in order to investigate the tools and services that leverage the Social Web and/or SSW paradigm for educational purposes, and get a better understanding of what kinds of tools/services have actually been used in practice and to what extent. The ultimate aim of the study was to find out whether and to what extent the tools that are currently in use could actually be employed for the realization of interactive PLEs.

The applied methodology included three primary steps: 1) identification of potentially relevant tools[12], 2) analysis of candidate tools with respect to a predefined set of criteria, and 3) selection of representative tools. Since social software tools and their semantically enhanced counterparts differ with respect to the underlying technology and the general level of maturity, we had to apply somewhat different approaches when reviewing and analyzing the tools from these two categories. To keep the narration clear and avoid any potential ambiguity, in the rest of the paper we refer to the former category of tools as social software tools and the later as SSW tools.

To select potentially relevant tools, we made use of both scholarly publications (i.e., journal, conference, and workshop papers), and Web content (content of, e.g., blogs, wikis, and discussion forums) generated by learning professionals worldwide. The latter source, even though less formal, is continually growing in both quantity and relevancy and offered us with great insights into educators real-world experiences with diverse Web-based tools. We also explored published surveys (e.g. SemTech Survey[13] and [Tiropanis et al, 2009]), tools listings (e.g., Sweet Tools[14]) and ratings (e.g., The 100 Tools for Learning[15]) of Web-based tools used for learning purposes.

The common criteria we used for the analysis of both kinds of tools are: 1) the ability to support, or even foster, interaction within an online community; and 2) the tool's applicability for educational purposes. Our choice to focus on interactivity of the considered tools was motivated by the fact that (as explained above) interaction is one of the key characteristics of the PLE concept; additionally, its pedagogical value is stressed by the major modern learning theories [Jovanovic et al, 2009a]. The criterion related to interactivity was further narrowed down to: interactions among members of an online learning community, and interactions with learning content. An additional third criterion, defined only for SSW tools, was the use of Semantic Web technologies for achieving advanced functionalities.

Even though social software tools have not yet become part of educational technology mainstream, they have reached a high level of maturity and have been increasingly adopted in educational practices worldwide. On the other hand, SSW tools are still quite immature and there is a scarce evidence of their application in real-world educational settings. Therefore, we had to use different approaches when eliciting representative tools of these two categories of tools. The social software tools were chosen based on the documented experience of their usage in learning settings, as well as their ratings in the previous studies. For example, the yearly report on the 100 Tools for Learning produced by Centre for Learning and Performance Technologies[16] provides practitioners' (i.e. teachers') perceptions of and opinions about each tool included in the list. Likewise, interviews and panel discussions with educational professionals and practitioners[17] provide insight into their experience with different social software technologies and tools. For the other category of tools – SSW tools – we present all the tools we identified that 'passed' the first (support for interactivity) and the third (advanced functionalities achieved through the use of Semantic Web technologies) criteria of the analysis phase. We did not strictly consider their successful application in educational settings (as the evidence of their usage is generally lacking), but considered their potential for use in education (mainly based on their features).

Our results are summarized in Table 1, given in Appendix, where we present the selected representative sets of both social software tools and SSW tools. Both kinds of tools are grouped into two broad categories based on the kind of interaction they (primarily) support: 1) interaction among members of an online learning community; and 2)

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12 In order to reduce the clutter and make the text easier to read, we use the term 'tool' as generic term when referring to different kinds of tools, systems and services.

13 http://semtech-survey.ecs.soton.ac.uk/

14 http://www.mkbergman.com/new-version-sweet-tools-sem-web/

15 http://www.c4lpt.co.uk/recommended/top100.html

16 http://www.c4lpt.co.uk/

17 Available as podcasts on, for example, http://www.educause.edu/podcasts, and http://cider.athabascau.ca/CIDERSessions/

interaction with (learning) content. Each of these categories is further narrowed down into subcategories reflecting the primary functionality offered by the tools within that subcategory (e.g., social networking, collaborative authoring, etc). It is important to stress that this is not a strict classification of tools since a significant number of them could be placed into more than one of these subcategories.

3 Principles

Having analyzed the state-of-the-art in the domains of PLEs and (support for) interactivity in e-learning, as well as the state-of-the-practice in the application of social software and SSW tools in e-learning, we set ourselves on the task of identifying the requirements for the realization of interactive PLEs. We looked into the requirements originating from: i) the concept of PLE; ii) the concept of interactivity in e-learning; iii) the identified strengths and weaknesses of the existing PLE implementations; and iv) the general trends in web-based (social) interactions and education, which includes, e.g., the use of numerous distributed and heterogeneous web-based applications, huge quantity of available content that is increasingly difficult to deal with, interactions with peers around the shared content, trust in the peers' recommendations, etc. Having analyzed these requirements we came up with a set of principles that could serve as a reference when developing software architecture of an interactive PLE. We present these principles in Table 1 and give below the rational for each one of them. The principles are highly mutually connected and reinforced; some of them, e.g., Principle 7, depend on other principles for their successful realization. Please note that the number associated with each principle is not aimed at indicating its relevancy.

3.1 Principle 1: Integration

The need for a PLE is based on the fact that learning is increasingly occurring in different places and situations and is not necessarily tied to one institution (e.g., school, university) [Attwell, 2007]. Accordingly, one of the basic premises of the PLE concept is the ability to integrate resources from disparate software tools and services that individuals use in their daily learning practices. In the previous section (see Section *Educational Mashups: the Materialization of PLEs*) we presented the existing approaches and technical solutions for realizing mashups of content and data originating from different tools/services an individual makes use of, and emphasized the advantages of mashups by integration (over mashups by aggregation). Mashups of this kind could be most effectively realized through the combined use of ontologies and Linked Data principles as they allow for seamless integration of data and knowledge originating from different, often dispersed sources [Allemang & Hendler, 2008]. In addition, the structure and semantics that ontologies add to the captured, stored and interlinked data/ knowledge provide an excellent basis for the development of advanced learning services, as demonstrated in [Jovanovic et al, 2007], [Jeremic et al, 2009], [Zablith et al, 2011]. Furthermore, by facilitating the integration of data about all learning activities and learning-related artifacts from different contexts and sources of learning, ontologies and Linked Data paradigm enable the creation of very comprehensive and dynamic e-portfolios. These portfolios can be further enhanced through semantic annotation of different kinds of content being used/created/shared by an individual, as well as her/his undertaken or planned learning activities. The Linked Open Data cloud[18] offers plenty of vocabularies (ontologies and datasets) that could be leveraged for semantic annotation of all kinds of learning-related resources; services such as DBpedia Spotlight[19] already enable this kind of advanced content annotation. This further enables semantic interlinking (i.e., connecting based on meaning) of diverse kinds of components of a learning process (e.g., activities, knowledge objects, people) and facilitates the provision of advanced search, discovery and recommendation services for learners.

3.2 Principle 2: Openness

This principle refers to: open standards, open content and open source software. Its first component, open standards, is quintessential for the realization of the above mentioned integration principle, since it is the key prerequisite for applications and data interoperability and integration. All Semantic Web technologies have been developed as open, community driven initiatives coordinated by the WWW Consortium (W3C)[20]. This trend is entering the Social Web as well, and there are emerging open standards, such as OpenID[21] and Activity

[18] http://linkeddata.org/

[19] http://dbpedia.org/spotlight

[20] http://www.w3.org/

[21] http://openid.net/

streams[22]. However, more rapid uptake of open standards on the Social Web is hampered by the interests of big enterprise players aiming to establish their own dominance over the Social Web space.

According to the latest, 2010, Horizon Report[23] [Johnson et al, 2010], our second component of openness – open content – can be characterized as one of the key trends in education in the last few years, promoted and led by the leading world universities and accepted by numerous educational institutions and practitioners worldwide. This yearly report suggests that the open content movement reflects the change in the perception of education in academia, and the recognition that learning is more about activities around the content than the content itself. Besides professionally authored open content (available through, e.g., MIT's Open Courseware Initiative[24] or Open Knowledge Foundation[25]), a significant source of educationally valuable open content are (social) Web users who share their knowledge and experience through wikis, blogs, Q&A forums, micro-blogging platforms and other online communication channels. For the realization of advanced PLEs (i.e., mashups through integration), the open datasets that are part of the Linked Open Data (LOD) Cloud are of special importance as they offer data that can be easily combined (mashed-up) and thus used to "fuel" diverse educational applications. Among many relevant LOD datasets, of particular importance are those comprising (meta)data about courses and learning resources published by universities. Current leaders in linked data publishing are UK universities: Open University (http://data.open.ac.uk), University of Southampton (http://data.southampton.ac.uk) and Oxford University (http://data.ox.ac.uk). In addition, (meta)data stored in learning content repositories have started being exposed as linked open data [Sicilia et al, 2011]. Educational semantic social networks, such as Metamorphosis+[26] are exposing data about shared learning resources as linked open data [Kaldoudi et al, 2011]. The principles of linked data also have a significant potential to increase integration of different educational/learning systems of interest (e.g., as shown in our case study later in the paper).

The continuously growing quantity of diverse and constantly evolving educational content opens up unprecedented possibilities for both teachers and learners, but also imposes a new challenge – how to make effective use of the available content. The previously mentioned "Open Educator as a DJ" metaphor has a potential to address this challenge and enable effective use of the available open content. Following the interactivity principles, we generalize this metaphor to include also learners. In other words, we suggest that all participants in the learning process could effectively use open content through the cycle of content sampling, (re-)mixing and presentation. Since this practice requires combined use of different kinds of software tool (integrated in a PLE) and interaction with both content and other participants in the learning process, an interactive PLE provides an excellent environment for its realization.

The third kind of openness – open source software – has made such significant contributions in so many domains, education being just one of them that we decided to include it in the list of principles for successful realization of interactive PLEs. If made open sourced, a software solution for e.g., data integration across diverse tools, could be reused and further developed (by either individual developers or groups/organizations), thus contributing to the improved implementation of interactive PLEs.

3.3 Principle 3: Distributed identity management

This principle is essentially about the users' ability to control and manage their 'identities' and online presence across different tools/services that are part of their PLEs. It includes the users' ability to seamlessly access different tools/services that are part of their PLEs; to pull together their profile data from those tools/services; and regulate the use of their data within tools/services that from their PLEs.

The first component of this principle, seamless access to web applications, is in the center of interest of open web initiatives, such as OpenID and WebFinger[27] for user identification, and OAuth[28] for user authentication. An increasing number of social software and SSW tools (e.g., significant portion of those mentioned in Table 1, in Appendix) is using some of these protocols to provide their users with easy access points. In addition, some recent research work has been directed towards devising methods for unique identification of users on the Social

22 http://activitystrea.ms/
23 Annual report that identifies and describes emerging technologies that are expected to have significant impact on higher education practices
24 http://ocw.mit.edu/
25 http://www.okfn.org/
26 http://metamorphosis.med.duth.gr/
27 http://code.google.com/p/webfinger/
28 http://oauth.net/

Web by using the people's public profile data on diverse online applications (mostly social networks). For example, Carmagnola et al have presented the preliminary results [Carmagnola et al, 2010] of their research work aimed at uniquely identifying users on the Social Web and retrieving the data stored in their profiles across Social Web applications. The suggested approach does not require the provision of user's authentication data and user identification is performed by using the public data available on the Web. Even though it offers promising results, this approach needs to be further worked on in order to become really usable.

The second component of this principle – seamless integration of users' profile data - is related to and can benefit from the research work done in the area of distributed user modeling (e.g., [Vassileva, 2001][Brusilovsky et al, 2005]). From the inception of this research challenge, i.e., the recognition of the need for integrating users' profile data from different online applications, ontologies have played a significant role in the proposed solutions (as shown in e.g., [Dolog & Schäfer, 2005] [Heckmann et al, 2005]). As one of the key representatives of the SSW trend, and one of the most widely used ontologies on the Web today, the FOAF (Friend of a Friend)[29] ontology has become the basis for building domain/application specific ontologies for user modeling. In addition, it has served as a common data format for mapping to and thus integrating user's profile data from popular Social Web applications (as shown, e.g., in [Rowe & Ciravegna, 2008]). While FOAF is about static user profiles dealing mostly with user's persistent characteristics, the notion of Online Presence is about dynamic and changeable characteristics (e.g., status messages, availability for chat, etc) that are related to user's current appearance in the online world. The Online Presence Ontology (OPO) enables the integration, exchange and common interpretation of Online Presence related data [Stankovic, 2008]. Thanks to the shared understanding of the online presence, tools/services of a PLE can adapt their interaction with the learner by considering social factors such as who is online, who to contact, who is nearby, and how to contact. This further leads to the provision of advanced peer, expert, and teacher finding services, and thus benefits student-student and student-teacher interactivity [Jovanovic et al, 2009c].

Finally, the third component of the Distributed Identity Management principle – the user's ability to seamlessly regulate the use of their data in different online applications – can be realized through the definition/configuration of various types of policies, primarily those related to privacy and access control. Ontologies have proved as beneficial technology in this domain as well. For example, Kruk et al [2006] have used the FOAFRealm ontology for letting users define fine grained access rights for their resources. FOAFRealm ontology [Kruk, 2004] is an extension to the FOAF ontology which allows users to express how well one person knows, or trusts, another. Access control is based on the distance and the friendship level between users which is expressed using FOAFRealm. However, in this domain, ontologies are even more advantageous if they are used in combination with policy languages such as Ponder, KAoS, Rei, PeerTrust, and XACML [Bonatti et al, 2006]. Typically defined over ontologies, policy languages provide a reliable mechanism for (rule-based) reasoning in open environments, such as PLEs, where the use of roles and institutions the users may belong to is not applicable [De Coi et al, 2008]. Current policy languages allow for context-based reasoning where one can only leverage the knowledge coming from the shared vocabulary (i.e., ontology) of a community and the individual's reputation in the community. However, management of policies today requires a lot of technical knowledge, which prevents wider adoption of policy-based approaches in educational settings. Accordingly, there is a need for the development of user-friendly interfaces for policy management. Moreover, one cannot expect that end-users will define a policy for all the different ways they want to regulate the use of their data. Accordingly, there is a need to develop mechanism for automatic, context-aware detection of situations that potentially violate users' requirements/preferences regarding the usage of their data, by leveraging the ontology-based definitions of contexts. To make the policy-based approach even more applicable in educational settings, there is a need to investigate policy languages that allow for reasoning over socially constructed knowledge, in addition to the formally defined ontologies.

Finally, it should be noted that this principle is tightly related to the User Centricity principle and e-portfolio approach; actually it is a prerequisite for these two. Also, it is strongly related to, and dependent on the Integration principle.

3.4 Principle 4: Context-awareness

The abundance of resources (content and services) available over the Internet, makes it difficult for learners to find specifically those resources that would be relevant for their learning task/objective; hence the need for an

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29 http://xmlns.com/foaf/0.1/

assistance by the learning environment. Context-aware software environments offer a solution as they attempt to improve the efficiency of the user's interaction with the environment through capturing and making use of data about relevant aspects of the user's current situation (i.e., context). The improvement in the interactivity typically originates from improved quality of search results, proactive recommendations, and mediation of communication, among other things [Braun et al., 2007].

Despite the diversity in interpretations of the notion of learning context, researchers seem to agree that it is about the environment, tools, resources, people (in terms of social networking), and learning activities [Siadaty et al., 2008]. Being more specific, context in learning is mostly characterized by the learners, learning resources (content and tools) and a set of learning activities that are performed in the light of a specific pedagogical approach. Due to their flexibility, expressiveness and extensibility, ontologies have been accepted by many researchers as the most suitable mean for context modeling (e.g., [Schmidt, 2006] [Ghidini et al, 2007] [Jovanovic et al, 2007]). Ontologies ensure that different entities that use the context data have a common semantic understanding of that data. They also come with reasoning mechanisms over the available context data, making it possible to extract inferred knowledge out of the implicitly stated situations. Through the context awareness, learning environments can also provide adequate pedagogical support (e.g., guidance or instruction).

In our previous work, we have developed LOCO (Learning Object Context Ontologies) as a comprehensive ontological framework aimed at formally representing diverse kinds of learning contexts (i.e., learning situations), as well as diverse kinds of interactions that occur during a learning process (i.e., students' mutual interactions and their interactions with the learning content) [Jovanovic et al, 2007]. LOCO allows one to formally represent all particularities of a given learning context: the learning activity, the learning content that was used or produced, and the student(s) involved. Accordingly, the framework integrates a number of learning-related ontologies, such as learning context ontology, a user model ontology, and domain ontologies. The ontologies are designed to harness the value of Linked Data paradigm by reusing and being based on ontologies such as Friend of a Friend (FOAF) and Socially-interlinked Online Communities (SIOC). Moreover, they are also designed to be compatible with the relevant e-learning standards such as IMS Learning Design. These ontologies allow for preserving the semantics of any given learning context in a machine interpretable format and thus provide the foundation for the development of context-aware learning services (as we show in the subsequent sections). We have integrated LOCO with the aforementioned Online Presence ontology in order to enrich the LOCO-based definition of learning context with the online presence data [Jovanovic et al, 2009c]. This was motivated by the fact that the inclusion of social software tools/services in online learning environments, PLEs not being an exception, has made users' online presence an integral part of any learning situation (i.e., context). Finally, in the scope of the IntelLEO EU (FP7) project, we have evolved this framework to secure support for context-aware learning and knowledge building in workplace learning settings [IntelLEO D3.2, 2010].

In the following sections we present how context-awareness, achieved through the use of semantic web technologies, lead to the development and deployment of advanced learning services within the DEPTHS PLE and positively influenced different interactivity dimensions (student-student, student-teacher, student/teacher-content) of this PLE.

3.5 Principle 5: Modularity

This principle refers to the ability to seamlessly "configure" a PLE for any given purpose (i.e., learning goal), by adding new and/or replacing existing content, tools and/or services. Currently, this principle is realized in aggregation-based educational mashups (e.g., personal dashboards) which allow learners to put together content from different sources (mainly feeds and widgets) into a single interface. Some online learning systems, Haiku[30] being a notable example, allow learners to incorporate well-known social software tools/services by choosing them from a wide selection of available tools/services (e.g., Haiku offers over 80 social software tools ready to be embedded with just a simple drag-and-drop). The drawbacks of such mashups include the user's low level of control over what and how is present (e.g., there is no support for setting custom filters for the data supplied by a service), and their static nature (the data sources are predefined and cannot be dynamically changed).

From the modularity perspective, an advanced PLE could be realized through dynamic service composition based on standardized description of services deployed within a service-oriented architecture [Dietze et al, 2007]. Furthermore, if services' descriptions are enriched with formal semantics (i.e., annotated with concepts coming

30 http://www.haikuls.com/

from ontologies), service composition could be partially automated thus facilitating the creation and maintenance of a PLE and improving user's experience. An initial work in this direction is presented in [Chatti et al., 2009].

An alternative solution for data modularity, that is, for the realization of dynamic data mashups is to use SPARQL [Harris & Seaborne, 2010] queries on top of linked data to integrate data originating from potentially different sources, and filter the resulting data stream based on personal preferences. Even though advantageous in terms of the offered functionality (over the current static and non-adaptive mashups), this approach is presently not applicable in educational settings since it is still overly complex for non-technical users. However, semantic web interfaces have been significantly evolving (as shown, e.g., in the series of workshops on Semantic Web User Interaction[31] and summarized in a recent presentation by D. Degler [2010]) and we can expect that it is not far away when these advanced solutions become usable in educational settings.

3.6 Principle 6: Ubiquitous data access

This principle emerges from the proliferation of mobile devices which made numerous aspects of our lives, education included, ever more mobile. Accordingly, individuals increasingly need the ability to have access to their data from whatever device they are using in the given moment. In addition, web-based applications are having even higher growth rate, resulting in a huge number of available online applications, among which a significant number can be used for educational purposes (see section (Semantic) Social Software Tools in e-Learning: State of the Practice). The challenge with respect to this trend is to provide users (learners and educators) with access to all relevant resources regardless of the application they are using at the given moment. Specifically, this implies the need for letting users access and integrate their profile data scattered across diverse applications they use. Additionally, it assumes the learners' ability to access data about their learning activities and achievements (e-portfolio). These requirements are tightly related to the previously discussed Integration and Distributed identity management principles, and the solutions presented there address the requirements stemming from the above described challenges.

In addition, this principle is related to the users' ability to ubiquitously access and manage artifacts they have (co-)authored as well as their work in progress. This is currently supported by online Office-like environments (also known as "office in the cloud"), such as Google Docs or Zotero. These authoring environments, equipped with constantly increasing number of collaboration features and accessible through web browser, offer users any-time and any-place access to their documents, and all the advantages of modern collaborative authoring tools. However, the problem is that these environments are (still) like "wall gardens" enabling users to do many things within the "walls", but not letting their data/content cross the "walls" (e.g., it is not possible to open in Zotero a document created in Google Docs in order to use some advanced feature of Zotero not available from Google Docs). As indicated in the discussion about the Integration principle, the technology is available, and even though it is maybe not mature enough, the real challenge is not technical. Instead, the challenge is in making a shift in the ownership of data and content – switching it from companies, to users [Yeung et al, 2009].

3.7 Principle 7: User centricity

The notion of PLE recognizes the role of an individual in organizing his or her own learning [Attwell, 2007]. It assumes an active learner who is in control over his/her learning process, by taking initiative in learning and responsibility for managing his/her knowledge and competences. This makes PLE closely related to the concept of Self Regulated Learning (SRL) [Zimmerman, 2002] and the portfolio approach [Osterloch, 2007]. Through the different tools and services they integrate, PLEs allow learners to plan and document their personal learning processes, to store personal reflections, self-produced artifacts and other evidences of acquired competences. This could be effectively enabled by using the linked data principles that allow for seamless integration of data about learning activities in various systems and connecting them through the different learning contexts. In addition, a PLE can further support a self-directed learner by offering the content and learning tasks appropriate for the learner's present learning context. It is obvious that this non-technical principle is closely related to and depends upon all the above described technical principles (1-6).

[31] http://swui.webscience.org/

Table 1 Principles for the development of Interactive PLEs

Principle 1: Integration	Integration of distributed and heterogeneous data sources, tools and services Quintessential for the realization of all other principles, and thus development of advanced PLEs, i.e., PLEs offering context-aware and personalized learning, as well as ubiquitous data access
Principle 2: Openness	Open standards => application and device independence, long-term access to content and services, interoperability Open source software => cost-effective customizations to the users' needs, Open content => more diverse and constantly evolving and improving educational content
Principle 3: Distributed Identity Management	The users' ability to: seamlessly access different tools/services that are part of their PLEs; pull together their profile data from those tools/services; regulate the use of their data within tools/services that from their PLEs.
Principle 4: Context-awareness	Improved efficiency of user's interactions with the environment through capturing and leveraging data about the user's learning context; Improvements: higher quality of search results, proactive recommendations, mediation of communication/collaboration
Principle 5: Modularity	The ability to seamlessly "configure" a PLE for any given purpose (i.e., learning goal), by adding new and/or replacing existing content, tools and/or services Support for standardized and light-weight approaches for the development of dynamic (e-learning) mashups.
Principle 6: Ubiquitous data access	Seamless access to and integration of profile data, data about learning activities and learning resources Ability to access and use relevant resources regardless of the system/tool/service the user is currently using
Principle 7: User Centricity	The 'user at the centre' paradigm – student is responsible for managing his/her individual knowledge and competences The learning system is the facilitator: it identifies the appropriate resources, adapts them to the user's learning context, and suggests the most appropriate learning strategies

We have further explored the principles shown in Table 1 during the development of DEPTHS (DEsign Patterns Teaching Help System) – an interactive collaborative learning environment in the domain of software design patterns [Jeremić et al, 2008].

4 Case study: Development of the DEPTHS Personal Learning Environment

DEPTHS is designed as a PLE. Its architecture and implementation is based on the SSW and Linked Data paradigm and the use of ontologies as a common base for the integration of different learning systems and tools in a common environment. Moreover, it is developed to be fully compliant with the principles identified in the previous section.

4.1 Pedagogical Approach

Having in mind that effective learning of software DPs requires a constructivist approach to be applied in the teaching process, we have identified two important theories in this field: Project-based learning (PBL) and Engagement theory. PBL is a teaching and learning model that organizes learning around projects. Projects comprise complex tasks and activities that involve students in a constructive investigation that results in knowledge building. The engagement theory is based upon the idea of creating successful collaborative teams that work on tasks that are meaningful to someone outside the classroom [Kearsley & Schneiderman, 1999]. Based on the guidelines for teaching Software Engineering to students (e.g., [Jazayeri, 2004]), and our own teaching experience, we believe that the presented theories provide a solid base for effective learning of software DPs. Accordingly, we based the DEPTHS framework on them.

A typical scenario for learning software patterns with DEPTHS assumes a problem-based learning approach with collaborative learning support. In particular, a teacher defines a specific software design problem that has to be solved in a workshop-like manner. A workshop is a peer-assessment activity with a huge array of options, such as allowing students to review and assess each other’s solutions. Students’ engagement in solving the problem and the support provided by DEPTHS are presented in Figure 1. Specifically, based on a student’s current learning context, DEPTHS suggests other students, experts and/or teachers who can be contacted for additional support (via the Experts, teachers and peers discovery service) (A). Using the Web resource finding service and the Service for discovery of relevant internally produced resources, DEPTHS will also suggest the learning content which might be useful for the student’s task at hand (B). The system does this both proactively and on the student’s request. Finally, it lets students to collaboratively annotate and comment on the learning resources during the problem solving process (C). As DEPTHS provides seamless integration of all of its tools, students are able to communicate and collaborate regardless of what specific tools of the DEPTHS environment they are using at that moment.

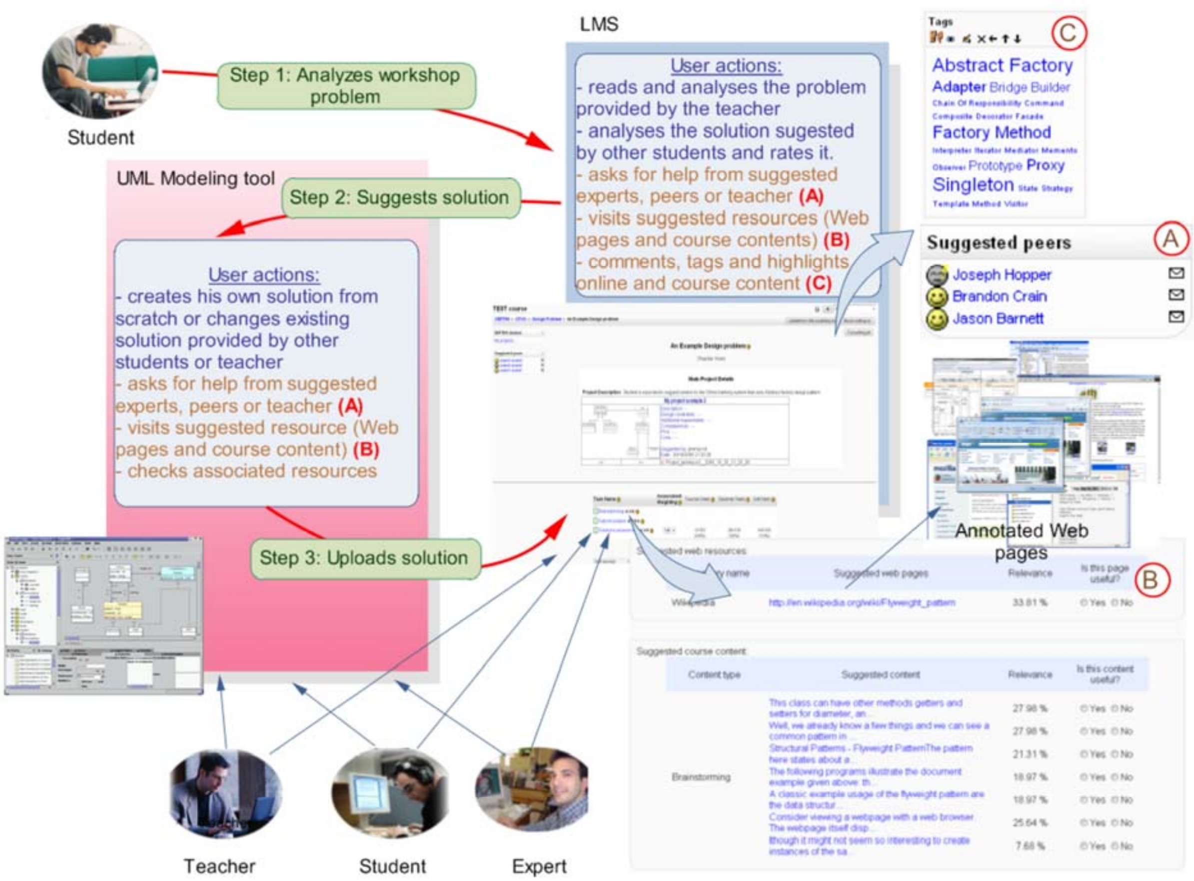

Figure 1. A typical learning scenario for the DEPTHS environment

It is possible to develop many other learning scenarios where DEPTHS would prove as beneficial for the learning process. For example, let us suppose that a student, who uses DEPTHS, is experiencing problems with his assignment related to the Composite design pattern. He would like to ask some of his classmates for help, but he does not know who have already done that assignment and how to reach them in that moment, so he decided to rely on the system's recommendation. Having analyzed his current learning context, the system recognizes that some of his classmates have already mastered Composite design pattern and would be able to help. However, the two of them whom the system recommends as the most appropriate 'helpers' are currently not using the same learning tool (e.g. LMS) as the student requesting help. Luckily, they are using another tool integrated in DEPTHS (e.g., modeling tool) and thus, can be contacted. The contact could be initiated through chat (yet another tool that is a part of the DEPTHS environment) and further developed through any of the tools integrated into DEPTHS.

4.2 Architecture

Figure 2 illustrates the architecture of DEPTHS. It integrates existing, proven learning systems, such as a Learning Management System (A), a software modeling tool (B), a feedback provisioning tool for teachers (C), a collaborative annotation tool (D) and online repositories of software patterns (E). This integration is achieved through the use of ontologies that comprise the LOCO framework (F). Specifically, the LOCO ontologies serve as the basis for storage and exchange of data among DEPTHS components.

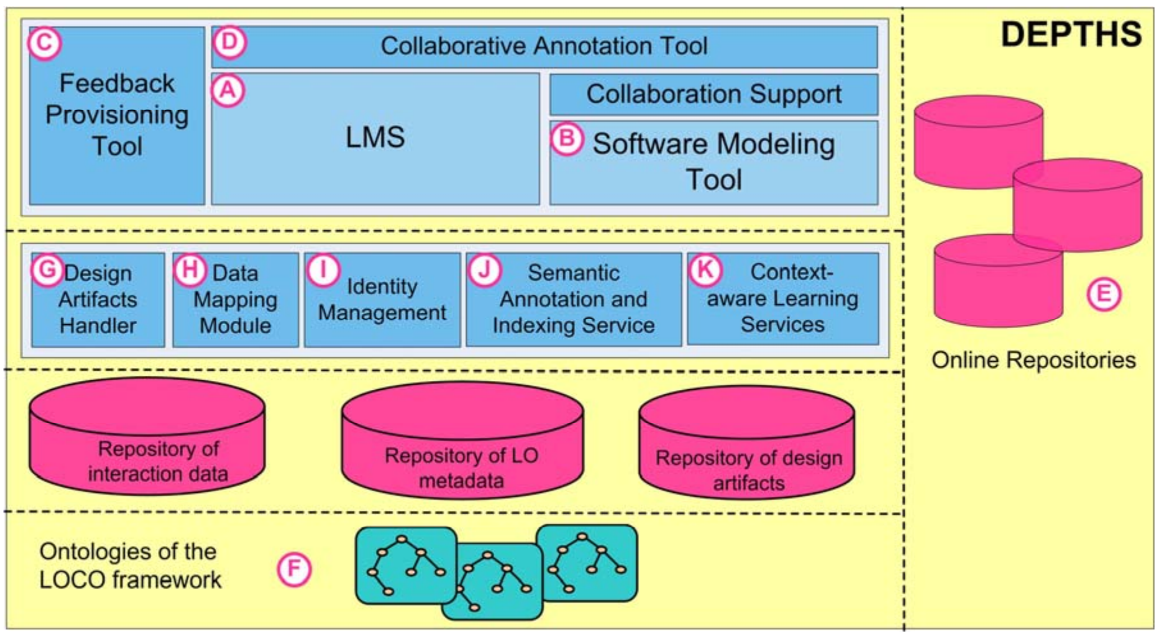

Figure 2. The architecture of DEPTHS learning environment

LOCO (Learning Object Context Ontologies) (Jovanovic et al, 2007b) is a generic ontological framework capable of formally representing all particularities of the given learning context. We define learning context as a specific learning situation, determined by: the learning activity that was performed (e.g., reading, posting, or discussing), the learning content that was used or produced (e.g., lesson, Web page, or forum posting), and the user(s) involved (student(s) and/or teacher(s)). The ontologies integrated within this framework (e.g., user model ontology, content structure ontology, and domain ontology) allow one to formally represent all the details of any given learning context, thus preserving its semantics in a machine interpretable format and allowing for the development of context-aware learning services. The ontologies of the LOCO framework were developed by following the Linked Data Principles and Best Practices [Dodds & Davis, 2010]. Accordingly, linkages were established (primarily through subclass relationship) with well-known Web ontologies such as the Dublin Core vocabulary (http://dublincore.org/documents/dces/), FOAF (Friend-Of-A-Friend, http://xmlns.com/foaf/0.1), and SIOC (Semantically Interlinked Online Communities, http://sioc-project.org). These ontologies provide a suitable infrastructure for implementing most of these principles of SSW-based learning (as explained in the Compliance to the Principles section).

DEPTHS currently makes use of two ontologies of the LOCO framework: the Learning Context ontology and domain ontology. The Learning Context ontology allows for semantic representation of the data about student's overall interactions with learning content and other students during different learning activities. This ontology was extended to allow for the representation of learning contexts specific to the systems, tools and services often used in software engineering education and thus integrated into DEPTHS. For example, the kinds of learning activities recognized by the Learning Context ontology (e.g., reading a lesson, posting a chat or forum message and doing an assignment) were not enough to meet the specific needs of the DEPTHS environment. Therefore, we have extended this ontology with a set of classes and properties for modeling project-based collaborative learning. Moreover, the Learning Context ontology has been extended with additional types of learning content (i.e., subclasses of the ContentUnit class), namely DesignProblem, Task and Diagram (Figure 3). Based on the data captured by the (extended) Learning Context ontology, DEPTHS can perform context-aware retrieval of resources on software design patterns (DPs) from online repositories and its own repository of software artifacts (which may also contain artifacts produced by other students and shared by the community, Figure 2).

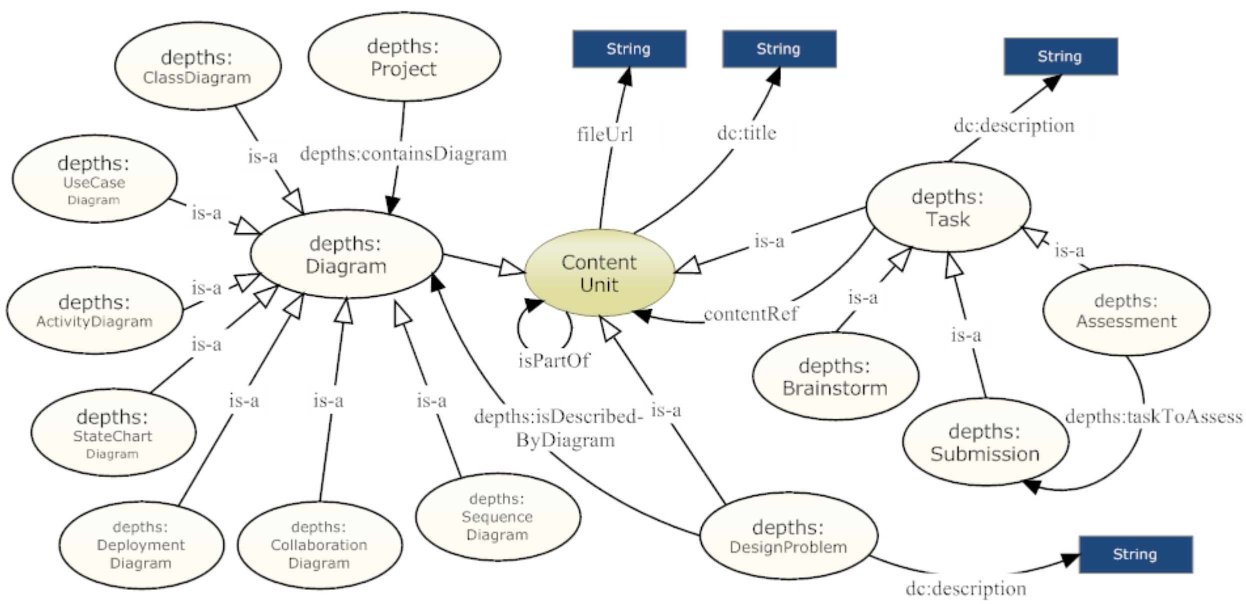

Figure 3. The extension of Learning Context ontology: the ContentUnit class and its DEPTHS-specific subclasses

Since DEPTHS is devised as an environment for teaching/learning software DPs, we needed a domain ontology that formally represents the domain of software DPs. Rather than developing a new ontology from scratch, we (re)used an existing ontology. Specifically, we have chosen the set of ontologies suggested in [Henninger, 2007] as it provides a very intuitive and concise way to describe DPs and pattern collections, and to offer more information on usability of DPs in software architectures. These ontologies are used by the Semantic annotation service to semantically annotate learning content (see section Implemented Architecture).

The above presented LOCO ontologies are used as the basis for storage and exchange of data among DEPTHS components. In particular, these ontologies underlie two DEPTHS repositories:

Repository of interaction data stores data about students' interaction with learning content, as well as their mutual interactions in the learning environment. It actually stores learning context data in the form of RDF triples compliant with the (extended) Learning Context ontology.

Repository of LO metadata stores semantic metadata about all kinds of learning objects (LOs) used in the courses under study: lessons and resources available from online repositories, as well as user generated content, such as software design diagrams, discussion forum and chat messages. We refer to these metadata as semantic metadata, as they formally define the semantics of the learning content they are attached to. This is done by relating LOs with the appropriate concepts in the ontology of software DP, in the following manner: {loco:LearningObject} loco:hasDomainTopic {depths:DesignPattern}.

DEPTHS also includes a Repository of design artifacts that stores software artifacts created by students, such as UML class diagrams. These artifacts are maintained in two open standard formats: XMI (XML metadata interchange) format that is appropriate for reuse latter, and SVG (Scalable Vector Graphics) that is suitable for presenting the artifacts in the Learning Management System. In addition, they are suitable for semantic annotation with domain ontologies. This repository is maintained by the Design Artifacts Handler (G in Figure 2).

Since different learning systems, tools and services use different formats for representing and storing interaction data, DEPTHS integrates a Data Mapping Module (H in Figure 2) that performs the mapping of the native data formats into RDF triples compliant with the LOCO's learning context ontology (i.e., interaction data are transformed into LOCO context data). The resulting (RDF) data are stored in the Repository of interaction data. Data mapping is performed throughout each learning session in order to keep the semantic repository updated (with data about the interactions occurring during that session).

Identity Management Component (I in Figure 2) enables learners to seamlessly access all learning systems/tools integrated in the DEPTHS environment in spite of the fact that they all may require different access accounts. More importantly, this allows for ubiquitous access to the data available within the DEPTHS environment regardless of the system the data was originally created and stored in. In our present implementation, we opted for the use of OpenID due to its simplicity.

Semantic Annotation and Indexing Service (J in Figure 2) is used for semantic annotation and indexing of documents from publicly-accessible repositories of DPs, as well as the learning content created by students and teachers (e.g., exchanged chat messages, discussion forum threads, or assignments). This module automatically assigns topic-related metadata to a learning object (e.g., a Web page from an online repository or a lesson) based on the ontology of software patterns. It uses Information Retrieval techniques to resolve what the primary topic of a learning object is and to determine its relevance for a specific software DP.

Context-aware Learning Services (K in Figure 2) are accessible to all systems and tools integrated in the DEPTHS environment and are exposed to end users (students) as context-aware learning features.

4.3 Context-aware Learning Services

These services use the data from DEPTHS repositories to provide students with additional, context-aware learning support. They include (but are not limited to) the following:

Web resource finding. Based on the student's current learning context, this service finds potentially useful Web resources. DEPTHS uses relevant, publicly accessible repositories of software DPs as the source of potentially relevant Web resources. In particular, it currently makes use of Yahoo! Design Pattern Library[32], Portland Pattern Repository[33], and Hillside.net Pattern Catalog[34]. The service uses the semantic annotations of the resources available from these repositories (generated by the DEPTHS's Semantic Annotation and Indexing Service) to identify those resources that are relevant for the given learning context. The relevance of a resource is calculated according to its relatedness to the domain ontology concepts (i.e. software patterns) relevant for the current learning context, and the students' previous ratings of the resource [Jeremic et al, 2009]. All resources found to be relevant are sorted based on their relevance for the current context.

Discovery of relevant internally produced resources. This service suggests internally created resources (e.g., discussion threads, brainstorming notes, and project descriptions) that could be useful to a student when solving a problem at hand in the given learning context. The computation of relevancy for the internally produced resources is done in a way similar to the one used for external Web resources [Jeremic et al, 2009].

Discovery of experts, teachers and peers. Based on the current learning context, this service suggests other students or experts as possible collaborators. Collaborators are selected and sorted using an algorithm which considers their competences on three different levels: same content (i.e., the current software problem), similar or related learning content (i.e., a similar software problem) and broader content (i.e., a software problem in the

[32] http://developer.yahoo.com/ypatterns/index.php
[33] http://c2.com/ppr/
[34] http://www.hillside.net/patterns/onlinepatterncatalog.htm

same course). Estimation of a peer's competence on each level is performed through assessing three types of competence indicators [Jeremic et al, 2009]:

- participation in learning activities (e.g., brainstorming, submitting a solution to the software problem or assessing peers' solutions). Each activity has a different impact factor on the system's estimation of the student's competences. This factor is defined in the system but could be changed by the teacher.
- knowledge level estimated by the teacher and obtained through the peers' evaluations, including projects evaluations and idea ratings. However, not all ratings have the same influence on the knowledge level estimation. For example, a high mark given by a student with high competences on the given topic has more impact on the final knowledge level appraisal than a high mark given by a student with average or low competences.
- social connections with the peer asking for help - the stronger the social connection with a specific person, the more suitable that person is for providing help. It has been shown (e.g., in [Richardson & Swan, 2003]) that an already appointed social connection could be much more successful and effective than new connections with people one does not know.

Context-based semantic relatedness. This service is used by all other services, as it allows for: i) computing context-based semantic relatedness between tags that students define and/or use in the given learning contexts with appropriate concepts of the domain ontology (i.e. disambiguation of the tags with the domain concepts [Gasevic et al, 2011]); and ii) resolution of students' queries containing both tags and domain concepts relevant for the given learning context.

4.4 Implemented Architecture

The DEPTHS learning environment is implemented through the extension and integration of open-source learning system and tools. The open access to the source code of those system and tools enabled us to extend them with Semantic Web technologies and to integrate them according to the requirement of the DEPTHS architecture.

We use Moodle (http://moodle.org), a popular open-source Learning Management System, with a variety of learning tools and features. However, to effectively support collaborative learning in the domain of software DPs, we have extended it with additional modules. In particular, we have developed a module that supports activities typical for collaborative project-based learning, such as brainstorming, software artifact exchange, evaluation of peers' projects based on teacher-defined criteria, and rating and commenting ideas. We have also extended the Moodle's block called "Tags" in order to support collaborative tagging within the DEPTHS's project module, as well as within discussion forums which lack this feature in the current Moodle release (release 1.9.2). Of course, given the openness and flexibility of DEPTHS' architecture, other general-purpose collaborative tagging, highlighting, and note-taking systems can be used. In our experiments, we have used OATS (Open Annotation and Tagging System) [Bateman et al, 2006]. We have also extended Moodle with support for capturing interaction data in the form of RDF triples compliant with the Learning Context ontology of the LOCO framework. All these data are stored in the Repository of interaction data and could be accessed from all tools integrated in DEPTHS. Finally, our context-aware learning services are available from within Moodle.

For semantic annotation of learning content we deploy semantic annotation services of the KIM platform (http://www.ontotext.com/kim/). These services allow us to annotate learning content (e.g., lessons, resources from online repositories of software patterns and artifacts produced by students) with the concepts from our domain ontology (i.e., the ontology of software patterns). The resulting metadata is represented and stored in the standard format for educational metadata storage (i.e., as IEEE LOM profile encoded in RDF).

As a software modeling tool, we have integrated ArgoUML (http://argouml.tigris.org/), an open-source tool that supports the design, development and documentation of object-oriented software applications. ArgoUML has also been extended with support for working with the LOCO ontologies, so that it can exchange learning context data with all other integrated systems/tools. We have also provided support for describing software solutions and collaborative work (e.g., chat and messaging) that were lacking in this tool. Most importantly we enabled it to make use of the DEPTHS context-aware learning services.

Finally, we integrated LOCO-Analyst, a tool that uses learning context data (based on the ontologies of the LOCO framework) to provide teachers with learning analytics about all kinds of activities their students performed during the learning process (e.g., feedback about students' online interactions, or feedback about students' comprehension of domain topics based on their collaborative tags) [Jovanovic et al, 2007].

5 Analysis

Having developed DEPTHS as a novel SSW learning environment, we analyzed how compliant it is to the principles that we have identified (Table 1) and how such architecture improves interactivity in the learning process.

5.1 Compliance to the Principles

The integrative approach (Principle 3) applied in DEPTHS is completely opposite to the currently prevalent, 'fragmented' approach that assumes individual use of systems and tools for teaching/learning software DPs. The major advantage of this novel approach is the seamless exchange of interaction data (i.e., data about the students' interaction with learning content and other members of the online learning community) among different systems, tools and services that students typically use when learning about software DPs. The integration of students' interaction data (Principle 3) allows for the deployment of context-aware learning services (Principle 2) that offer a personalized learning experience to students (Principle 7). In addition, it allows for ubiquitous access to relevant data and resources (Principle 5). Through the use of OpenID (http://openid.net/), we support identity management between systems and services integrated in DEPTHS (Principle 6).

DEPTHS integrates open-source learning systems and tools and assumes the (re)use of open learning content, that is learning content available in publicly open content repositories (Principle 1). It also uses open software standards for storage and exchange of software artifacts that students produce during the learning process.

DEPTHS modularity (Principle 4) stems from its reliance on the ontologies of the LOCO framework for data capturing and integration, as well as on the encapsulation of context-aware learning services relying on loose coupling and interoperability. In particular, DEPTHS context-aware learning services are fully based on the LOCO-based data, so the functionalities they provide are not coupled to any particular learning system or tool (i.e., to their native format for interaction data). This further means that these functionalities would be available to any new system and/or tool added to DEPTHS. The only thing that needs to be done is the mapping between the interaction data format of the new system/tool and the LOCO's learning context ontology (i.e., an extension of the DEPTHS's Data Mapping Module). Similarly, resources from new online repositories can be included (i.e., considered for recommendation), after they are semantically annotated (by the Semantic Annotation and Indexing Service) with the concepts of the domain ontology.

Table 2. Compliance of the DEPTHS's architecture with the proposed principles of SSW-based Learning Systems and Tools

Principle	**Short Description**	**DEPTHS Component(s)**
1	(Re-)use of open learning content	Semantic Annotation and Indexing Service
2	Context-aware learning services	Context-aware Learning Services
3	Integration of heterogeneous tools and the users' interaction data	LOCO ontologies and Data Mapping Module
4	Modularity	LOCO ontologies
5	Ubiquitous access to relevant data and resources	LOCO ontologies and Data Mapping Module
6	Ubiquitous identity management	Identity Management
7	Personalized learning experience	Context-aware Learning Services and Semantic Annotation and Indexing Service

5.2 Challenges (Experiences) and Lessons learned

Based on our experience, including the above case study, we can state that DEPTHS' foundation on the SSW Linked Data paradigm has introduced a new quality to the learning experience. However, providing support for all the identified principles (see Section Principles) was not an easy task. We have found several difficulties caused by the technology limitations that prevent a wide adoption of PLEs consisting of different learning and educational tools. In what follows, we reflect on the difficulties related to some of the identified principle.

Integration. One of the basic aspects of learning in DEPTHS is integration of different learning resources both from internal sources (tools integrated) and external sources (web repositories). In order to provide appropriate recommendation of web pages originating from different web sites, DEPTHS needs to have knowledge about their content; accordingly, it has to annotate those pages and collect important metadata. DEPTHS integrates a Web crawler, a tool for collecting links of all processable web pages inside a specific online repository. However, some websites do not allow Web crawlers to process the pages inside the site, which makes such a site unavailable for DEPTHS. In addition, there is a problem of semantic annotation of the crawled pages and learning content in general. Even though, DEPTHS makes use of the state-of-the-art services for semantic annotation, the results (i.e., annotations) are not always on the level of quality (due to missing, imprecise or even wrong annotations) that would be required for linking content based on its semantics. Even if we disregard this problem, there is still an important impediment associated with this kind of semantic annotation; it is the need to extend the knowledge base of the annotation services with the concepts relevant for the subject domain of the resources to be annotated. In the case of DEPTHS (Section 4.2), this has been done by extending the KIM's knowledge base with the concepts from the domain ontology used by DEPTHS (ontology of software design patters). However, the need for hand-crafting domain ontologies for different subject domains (i.e., different courses, in the considered context of education) and importing them into knowledge bases of annotation services could be bypassed and thus the whole process could be significantly facilitated by making use of DBPedia and/or subject-specific datasets of the Linked Open Data cloud.

Openness. To facilitate an effective access to the content and addition of new tools in a PLE, we considered the tool's support for representation and annotation of the used content. For example, ArgoUML is compliant to the UML XMI standard, so that the produced software models can be easily shared with other tools. In addition, we use SVG format to share UML models between ArgoUML and Web applications (e.g. Moodle). Furthermore, the DEPTHS environment is also open in its compliance to the broadly adopted Linked Data ontologies (e.g., SIOC and FOAF), which allow for sharing the data produced and used in the DEPTHS services and tools with other external systems.

Distributed identity management. None of the LMSs we have considered to integrate in DEPTHS supports any of the open web initiatives, even though they can have identity management regulated via more heavy-weight identity management approaches (e.g., LDAP). Even more, domain specific tools (e.g., ArgoUML) most often do not support any kind of user authentication. As DEPTHS builds user profiles based on their activities in different tools, it is very important to provide common user identification for all the tools integrated within the environment. In order to deal with this problem, we implemented mapping of the user authentication data from the integrated LMS (i.e., Moodle) to the common ontology. All other tools, integrated within DEPTHS use this information to authenticate user. However, these tools needed to be extended to support this. Tools that already contain authentication module are extended to check user identity against the user profile stored in the ontology, while tools that do not contain authentication module had to be extended with the module that supports authentication.

Modularity. From the modularity perspective, none of the tools we integrated within DEPTHS could be described as highly modular application. We had to extend all these tools in order to support their integration within the DEPTHS environment. Developing additional module that maps data between integrated application (i.e., its database) and common ontology was not a challenging task. However, extending applications to track user activities and export them to the ontology was not so easy in case of ArgoUML due to its quite complex design and lack of modularity; the same task in Moodle demanded much less work. This extension of the tools allowed us also to get both Moodle and ArgoUML tools *aware of learning contexts*, so that they can proactively advise learners.

5.3 *Improving* Interactivity

To analyze the impact of the proposed architecture on interactivity in learning environments, we decided to use widely-adopted model – the interactivity triangle [Anderson & Garrison, 1998]. The interactivity triangle has students, teachers and content at its nodes; each node is related with the other two and with itself, so that, for example, students are in interactions with teachers and content, but they also interact among themselves.

DEPTHS uses ontologies to define learning context unambiguously. It also relies on and even fosters extensive social interactions and user engagement for facilitating knowledge creation and sharing. These features enable DEPTHS to locate relevant learning artifacts or collaborators for the given learning context regardless of the system being used and the specificities of the learning community.

Student-student interaction is stimulated in DEPTHS as students are not limited to peers directly involved in their course or school. As such, they may find even more dedicated "study-buddies" in their social network, as per their relevance for the actual learning context and the reputation they gained during their previous learning activities. In addition, context-aware data sharing enables seamless building of shared knowledge and common understanding of domain concepts (i.e., software design patterns). More importantly, as students perceive the ownership over the content they create within their (software patterns) learning community, they are continually motivated to maintain their learning portfolio, which is constantly reviewed by members of their social network.

DEPTHS students constantly create and share learning-relevant content with their peers. This content comes in the form of software design artifacts, blog posts, Web pages, stories, screen recordings, videos, and the like. Being constantly provided with feedback on their content, students are motivated to continually improve their work through the interaction with their peers and other content, thus advancing their student-content interaction. This activity then goes also in the content-student direction. Through aggregation of context-relevant content coming from the social networks and online repositories on software DPs, the content itself is interacting with the students and continuously motivating them for self-reflections and further learning activities.

Besides their peers, students supported by SSW technologies may also locate and interact with experts and practitioners, which can take a role of either their informal instructors or study buddies. In addition to the increase of this student-teacher (student-expert) interaction, DEPTHS also enables indirect and transparent increase of teacher-content interaction. By integrating non-intrusive tools that analyze the progress of students through the software patterns learning resources, DEPTHS provides teachers with useful context-aware feedback [Jovanović et al., 2007] that further stimulates teachers to interact with content. For example, the feedback may indicate the content that students have difficulties with and thus requires qualitative improvements. These improvements can be further reflected in improved student-content or student-student interactions (e.g., if they use action-oriented learning design strategies).

6 Evaluation

The evaluation of DEPTHS was conducted in February 2009, in the context of a course that the first author of this paper taught at the Department of Computer Science of the Military Academy in Belgrade, Serbia. DEPTHS was evaluated with a group of 13 students from the fifth year of the computer science program who took part in our course on software development. This size of the class (13) is typical for most of computer science programs in the senior years of study, i.e., the study sample is a representative for the target audience of our research. The students already had some elementary knowledge in the domain of software DPs, but they were not familiar with the particular software DPs used in this experiment (Facade, Adapter, Strategy, Composite, Visitor and Decorator).

The students were divided into 4 groups (3 groups with 3 students and 1 group with 4 students), based on the instructor's subjective opinion about their knowledge in the domain of software development and their previous results in the courses related to software engineering. The size of the groups is based on our belief and teaching experience that work in small size groups (3 or 4 students) is a necessity for effective education of software engineers.

The aim of the evaluation was to determine how effective DEPTHS is for learning DPs. Specifically, we wanted to evaluate the perceived usefulness of the integrated learning environment, tools, services and distributed data sources (Principle 3). Moreover, we wanted to check if active students' involvement in real world problems (Principle 7) and the employment of context-aware educational services (Principle 2) could ensure a more effective way of imparting knowledge in the domain of software development. Finally, we wanted to check if the ability for right-in-time access to relevant resources and the sharing of information within a community could provide for more effective learning (Principle 5).

Before the experiment started, a demonstration of DEPTHS's functionality along with some training using a task similar to the one later used in the experiment, were performed with students. For the experiment, each group was assigned a different task (i.e., a software design problem); students were asked to suggest solutions and evaluate each others' solutions within one week period of time. Actually, project organization used in the experiment was based on the learning workflow described in the section Pedagogical approach.

We used a questionnaire to collect data about the students' satisfaction with and attitudes towards learning with the DEPTHS system. The questionnaire was also supposed to reveal the students' perceptions regarding the effectiveness of learning with DEPTHS. Based on the data we wanted to collect, we divided the questionnaire into three sections: questions related to the students' previous experience with computer-assisted learning, questions related to the DEPTHS system and questions related to the learning program on software DPs offered by DEPTHS system. Most of the questions (33) were multiple-choice questions based on a five-point Likert-scale, and there were six open-ended questions.

Having analyzed the students' responses, we found that the majority of students have experience in: i) using Internet to find relevant information (84.62%), ii) collaborating with colleagues on solving common tasks (53.85%), and iii) using tools for message exchange and online discussions (84.62%). However, they have far less experience with online learning tools (only 23.07% are familiar with e-learning tools) and in using the Web to find peers for solving problems (only 38.46% answered positively).

The DEPTHS system received high marks from the students. The majority of them (53.85%) reported they have learned as effectively as in traditional way, and 30.77% reported that they have learned more than via the traditional way. The students also reported that the system was intuitive and very easy to use (76.92%). They felt that educational services provided within DEPTHS are very helpful: Web resource finding service - 92.30%; Service for the discovery of relevant internally produced resources – 84.61%; and Experts, teachers and peers discovery service – 76.92% (Principles 2, 3 and 5, respectively). They also thought that the activities provided within the learning tasks considerably contributed to the outcomes of the learning process (brainstorming – 76.92%, and evaluating each other's works – 100%).

Furthermore, our analysis has shown that majority of the students (76.92%) were encouraged to take responsibility for their learning in DEPTHS. Most of them (76.92%) reported that they had a great deal of choice over how they are going to learn in the given project task (Principle 7).

In order to check the impact of the proposed architecture on interactivity, we used the interactive triangle (described in the previous section). Specifically, we used a set of questions to check how DEPTHS has affected/improved interaction between students and content, as well as between students themselves. However, the design of the experiment (students worked in small groups without a teacher involved in collaboration) made it impossible to analyze the impact on interaction between students and teachers.

As already stated, students reported that educational services for recommending Web resources and internally produced content were very useful. Having analyzed DEPTHS's logs, we found that students have frequently used these services during the experiment. Moreover, resources suggested by DEPTHS as most relevant in the current context, have also been voted as relevant by students (94.15%) in DEPTHS itself. These results gave us a solid evidence that DEPTHS has a very positive impact on the student-content interactions. We have also recognized a positive attitude toward student-student interactions. Students reported that they found the other students' ideas have been very useful for them (84.61%). In addition, majority of the students believe that they have learned from other students' works (92.31%).

We can conclude that students involved in this evaluation were not familiar with e-learning tools. Rather, they were educated using a traditional, system-centered approach. DEPTHS provides prerequisites for user centricity (Principle 7), and makes students responsible for the development of their individual knowledge and competences. Moreover, even though the students were used to using the Web for information access and online tools for collaboration, they did not used them in an integrated way. However, they found that when integrated (like in the DEPTHS environment), these tools are even more useful (Principle 3). Based on the students' answers to the questions about educational services and tools provided within DEPTHS, we can conclude that context-awareness (Principle 2) and ubiquitous data access (Principle 5) are promising to create the learning experience more productive and effective.

Finally, we have identified 27 variables' pairs that have significant association through the use of Pearson's chi-square (we used standard level of significance p<0.05). For example, there is a significant association between the students' answers on the question if they used tools for sending messages and discussions, and the question if they think that the other students' ideas were useful. Many useful conclusions could be drawn from these associations about the extent of some of the variables on student achievement. For example, we found that students' satisfaction with the educational services for recommending relevant Web pages and course content affected their later satisfaction with their learning results using this program. We believe that this association is related with the students' level of adoption of these services as very important and useful part of a learning system. However, a deeper analysis of these results is out of scope of this paper and will be reported in our future work.

7 Conclusion

The seven key principles for interactive PLEs have been identified and verified in the architecture of the DEPTHS PLE. The principles can be considered a first step towards the materialization of the concept of interactive PLE built on Social Semantic Web paradigm and Linked Data principles. The presented implementation of the DEPTHS environment demonstrates how this synergetic mix of social and semantic technologies and Linked Data paradigm advances the learning process in a very concrete domain of software engineering education. DEPTHS goes beyond narrow goals of individual courses and serves as a basis for managing life-long learning. While the benefits of the use of the Social Semantic Web and Linked Data are obviously present, two major questions still need to be solved: privacy preservation and data ownership in education and learning. This requires further research of the perception of privacy and data ownership in this new networking (learning) context and an engagement of the overall Web community, not only educators. Until these important issues are resolved, Linked Data inspired local data clouds [Dimitrova, 2011] will most probably dominate in the educational domain.

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9 Appendix

Table 1 An overview of the state-of-the-practice in social software and SSW tools/services, and their contribution to the interactivity of online learning environments.

Interactivity types	Tool types	Social software tools	Social Semantic Web tools
Interaction among members of an online learning community (student-student, student-teacher, teacher-teacher)	Social networking tools: (online discussions, content sharing, tagging, commenting, content/peers recommendations)	Special focused learning groups within general online social networks, like Facebook, Orkut, YouTube Specialized online social networks: - for students: CollegeRuled (http://collegeruled.com/), NoteMesh (http://www.notemesh.com/) - for teachers: Curriki (http://www.curriki.org/), Connexions (http://cnx.org/), EdTechTalk (http://www.edtechtalk.com/) - for students and teachers: Mixxer (http://www.language-exchanges.org/), BuddySchool (http://www.buddyschool.com/) VoiceThread (http://www.voicethread.com)	Special focused learning groups within general online social semantic networks, like Innoraise (http://innoraise.com/) GroupMe (http://groupme.org/GroupMe/) Learning-focused social semantic network: Metamorphosis+ (http://metamorphosis.med.duth.gr/)
	Collaborative authoring tools	Online office tools: - Google Docs (http://docs.google.com/), - Zoho (http://www.zoho.com) Wiki tools, like Wikispaces (http://www.wikispaces.com/), Wetpaint (www.wetpaint.com/)	Semantic Desktop office tools KOffice (http://www.koffice.org/) Semantic wikis, like Semantic Media Wiki (http://semantic-mediawiki.org/), IkeWiki (http://ikewiki.salzburgresearch.at/)
	Expression and exchange of opinions	Blogging tools, like Blogger (http://www.blogger.com/), Wetpaint	Semantically enhanced blogging tools, like Wordpress (http://wordpress.org/)[35], Livejournal (www.livejournal.com/)[36], or any blog powered by Zemanta (http://www.zemanta.com/)
	Reviews and ratings	Education focused: Rate My Professors (www.ratemyprofessors.com/)	General purpose: Revyu (http://revyu.com/)
Interactions with learning content (student-	Social bookmarking and annotation tools	delicious.com, diigo (http://www.diigo.com), StumbleUpon (http://www.stumbleupon.com/)	Faviki (http://www.faviki.com) Bibsonomy (http://www.bibsonomy.org/)

35 SparqlPress plugin (http://wiki.foaf-project.org/w/SparqlPress) is required for providing Semantic Web functionalities
36 FOAF export plugin is necessary to provide Semantic Web functionality

content, teacher-content)	Data visualization and exploration tools	ManyEyes (www.many-eyes.com) mSpace (http://mspace.fm/) Choosel (http://code.google.com/p/choosel/)	Exhibit (http://simile.mit.edu/exhibit/) Freebase Parallax (http://mqlx.com/~david/parallax/), Potluck (http://simile.mit.edu/potluck/) RKBExplorer (http://www.rkbexplorer.com/explorer/)
	Tools for creating mash-ups	NeedleBase (http://www.needlebase.com/) Google Fusion Tables (http://www.google.com/fusiontables) Personal Dashboards, e.g., http://www.google.com/ig, http://www.pageflakes.com/, http://www.netvibes.com/	Potluck (http://simile.mit.edu/potluck/) Sigma (http://sig.ma/) Paggr (http://paggr.com/)
	Services providing data for mash-ups	Socrata (http://www.socrata.com/), Factual (http://www.factual.com/), Infochimps (http://www.infochimps.com/)	DBpedia (http://dbpedia.org/), and the continuously growing Linked Open Data Cloud (http://richard.cyganiak.de/2007/10/lod/)
	Tools for manipulating RSS feeds	Yahoo! Pipes (http://pipes.yahoo.com/)	DERI Pipes (http://pipes.deri.org/)