Semantic wiki for learning and teaching computer science

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This paper discusses the use of a collaborative learning environment, specifically designed for computer science education. In particular, we investigate how students (may) meaningfully learn computer science and how web technologies (may) support them in this process. For a comprehensive view of the problem, different instructional theories are considered, as well as specific requirements for computer science education, driving the research to the adoption of semantic technologies and to the definition of a specific semantic-wiki-based framework. In this scenario, the authors present an on-going research project, named Semantic-WikiSUN, which aims to investigate innovative strategies for learning and teaching computer science in the context of higher education. It is based on the use of semantic-wiki to support the sharing and acquiring of knowledge in this specific knowledge domain, enabling the application of basic pedagogical principles.

1 Introduction

How can we support our students in the development of their Computer Science (CS) expertise, in the acquisition of new knowledge, skills, and meta-competencies? How can web technologies facilitate CS education? In order to find out the answers to such questions, we started a research project based on: (i) an instructional theoretical framework, (ii) an analysis of requirements for this specific subject matter and (iii) the design of a specific tool, based on a semantic wiki platform. The general objective is to stimulate semantic learning (Vivanet, 2011), intended as a meaningful learning process, supported by ontology-based technologies, that is founded on the co-construction of the knowledge model underlying the course content.

The remainder of the paper is structured as follows: after the description of the theoretical framework, a discussion on requirements for learning CS is presented as well as the role of semantic web and available technologies. Then, the Semantic-WikiSUN project is introduced. Finally, a brief description of related works and a discussion concerning criticalities and future perspectives of this study are proposed.

2 Theoretical framework

According to Ausubel (1963), meaningful learning, in contrast with rote learning, refers to the process enabling students to obtain a deep understanding of what they are learning. To learn meaningfully, students should deliberately establish a relation between the new knowledge they are acquiring and what they knew before, and thus incorporate new concepts into their existing cognitive structure. Basically, Ausubel proposes a learning strategy that can be summarized as follows: (i) presentation of higher order inclusive concepts (defined as *advance organizers*); (ii) presentation of learning resource/activity; and, finally (iii) strengthening the cognitive organization.

Besides, on the basis of the Ausubel's theory, Novak and Gowin (1984) proposed the use of concept maps for representing meaningful relationships between concepts and propositions. Accordingly, concept maps must be developed on the basis of a hierarchical structure, which puts in evidence the taxonomical structure: then it is possible to explore the transversal relationships among concepts.

Many studies share this model and, recently, the connectivism theory (Siemens, 2005) was grounded on the idea that knowledge should be distributed in a network of connections and that learning would be the ability of constructing and navigating through this network.

In a similar way, Spiro *et al.* (1988) proposed the flexibility cognitive theory,

according to which, students should be encouraged to represent knowledge from different conceptual perspectives, for example by means of nonlinear hypertext systems.

Furthermore, learning is not independent from the surrounding cultural and social context. Socio-cultural variables influence the cognitive development. Conforming to this, Bruner (1996) advanced an idea of culture as a social construct, like a kind of encyclopedia that is elaborated several times by several interpretations, where people define meanings in a collaborative way.

3 Requirements for teaching and learning Computer Science

Any branch of knowledge implies specific learning issues that teachers should take into account in both the design and delivery of courses. Moreover, the above section has highlighted the role of structure and organization in the definition of the learning content. In this paper we take into account CS education. It is worthwhile noticing that CS education is not only addressed to informatics and engineers and that technology plays a twofold role: it is the target of the learning process and it is also the means students nowadays use to acquire it. Hall *et al.* (2009) presented the motivations driving software engineers to the choice of a particular theory, while Zendler (2010) highlighted the need of developing content together with the learning process and involving students in the lessons (Adorni *et al.*, 2008). As a consequence, the first candidate model for an effective CS education is constructivism (Ben-Ari, 1998), exploiting a peer-to-peer interaction model. In addition, cognitive information processing and behaviorism can be profitably applied (Quevedo-Torrero, 2009). Besides, Ben-Ari (2004) considers the existing communities of CS (e.g., open source software developer groups) and concludes that CS educators should base their activity on the emerging behaviors in professional CS communities of practice and design educational activities accordingly.

In addition, we observe that collaborative methodologies push the creation and the sharing of materials, best practices and learning objects in open source communities, putting in evidence the need of common repositories and standard for effectively sharing knowledge (Bianchi *et al.*, 2010; Coccoli *et al.*, 2011). Hence, as a final consideration, we underline that the success of these learning methodologies can be improved through the design of cognitive models enabling easy access to notions and information, which extends the field of investigation beyond mere education techniques, towards the field of knowledge management and organization. Especially, Semantic Web technologies have demonstrated to take advantages in education, owing to their potential to express meaning for learning resources, teaching resources, individuals, and learning objectives with the help of ontologies and annotation (Millard, 2012), which

can strongly empower interoperability and the discovery of learning resources as well as the matching with the individuals' needs. Semantic technologies are gaining consensus, also driven by the annotation mechanism and habits introduced within the Web 2.0 and by the linked data approach. In this respect, Tiropanis *et al.* (2009) discriminate between hard and soft semantic technologies. On one hand, the formers allow expressing the meanings of resources and their relationships in machine-understandable languages, and provide inheritance, based on the above meanings. On the other hand, the latters enable expressing resources' meanings in a human understandable language, or in formats based on domain-specific information structures. In their work, they also define a categorization of semantic technologies targeted to higher education. With more than thirty tools and services identified, they restricted the classification to four main typologies, based on functionalities: (i) collaborative authoring and annotation tools, (ii) searching and matching tools, (iii) repositories and virtual learning environments (VLEs) that import and export their data using semantic technologies and that can expose metadata in RDF, and (iv) infrastructural tools and services that enable exposing databases or integrating data sources within or across organizations in interoperable semantic formats.

4 The Semantic-WikiSUN project

As renown, a wiki is a web site that allows users to create pages in a collaborative fashion, by means of a web browser and, usually, using a simplified markup language. However, as highlighted in previous works (see, e.g., Coccoli *et al.*, 2012), in the authors' opinion, wikis suffer from some limitations in terms of knowledge sharing, mainly due to the fact that wiki contents are not easily machine understandable. Such limitations can be overtaken by the semantic support introduced within the semantic-wiki.

Based on considerations in the previous sections, applying general theory to the specific case of CS education, the authors started the Semantic-WikiSUN (Semantic Wiki-based Student's University Notes) project, launched on the 2010-2011 academic year and currently underway. It is the semantic-enriched version of a previous project, called WikiSUN, which was carried out at the University of Genoa to provide students with the ability of developing a repository of their lecture notes in a collaborative way, by means of a wiki system (at the end of 2006, more than one thousand pages were composed).

During the last two years of semantic wiki experimentation, around 150 students of the "Operating Systems" class – Degree Course in Communication Sciences – were involved (70 students in the 2010-2011 and 80 in the 2011-2012).

According to commonly recognized learning design models (Merrill, 2002;

Gagne & Briggs, 1979), the instructional design started from a clear definition of learning goals describing what learners should know or be able to do at the end of the instruction. One of the most widespread models for defining them was provided by Bloom *et al.* (1956) and it is known as the Taxonomy of Educational Objectives. Put simply, it is a framework for classifying statements of what we expect or intend students to learn as a result of instruction. We inspired the design also to Anderson and Krathwohl (2001), which proposed a revision of the Bloom model that is based on two dimensions: the *Cognitive Dimension* (an action expressing what is to be done with or to the instructional content) and the Knowledge Dimension (a noun expressing some instructional content). In other words, the definition of any learning goal is composed by a verb and an object, where the former refers to the cognitive process, while the latter identifies the knowledge that students are expected to acquire.

The Cognitive Dimension (see Table 1) is composed by the following categories: remember (retrieving relevant knowledge from long-term memory); understand (determining the meaning of instructional messages); apply (carrying out or using a procedure in a given situation); analyze (breaking material into its constituent parts and detecting how these parts are related each other); evaluate (making assesments based on criteria and standards); and create (putting elements together to form a novel, coherent whole or make an original product).

Table 1
THE COGNITIVE DIMENSION

Lower order thinking skills ⟶ Higher order thinking skills					
remember	understand	apply	analyze	evaluate	create
recognizing recalling	interpreting exemplifying classifying summarizing inferring comparing explaining	executing implementing	differentiating organizing attributing	checking critiquing	generating planning producing

The Knowledge Dimension (see Table 2) is composed by four types of knowledge: factual (the basic elements that students must know to be acquainted with a discipline or solve problems in it); conceptual (the interrelationships among the basic elements within a larger structure that enable them to work together); procedural (how to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods); and, finally metacognitive (knowledge of cognition in general as well as awareness and knowledge of one's own cognition).

Table 2
THE KNOWLEDGE DIMENSION

Concrete Knowledge ⟶ Abstract Knowledge			
factual	conceptual	procedural	metacognitive
- knowledge of terminology - knowledge of specific details and elements	- knowledge of classifications and categories - knowledge of principles and generalizations - knowledge of theories, models, and structures	- knowledge of subject-specific skills and algorithms - knowledge of subject-specific techniques and methods - knowledge of criteria for determining when to use appropriate procedures	- stragegic knowledge - knowledge about cognitive tasks, including appropriate contextual and conditional knowledge - self-knowledge

As depicted in Table 3, we defined the Semantic-WikiSUN outcomes as the intersections between the Cognitive Process and the Knowledge Dimension with respect to our goals.

Table 3
LEARNING OBJECTIVES IN THE SEMANTIC-WIKISUN PROJECT

Knowledge Dimension	Cognitive Process					
	remember	understand	apply	analyze	evaluate	create
factual	x	x		x	x	
conceptual	x	x		x	x	
procedural			x			
metacognitive						

In our opinion, the learning objectives - for CS teaching in an introductory course about Operating Systems (OS) - must mainly cover *concrete aspects* (factual and conceptual categories) rather than abstract ones; then, we must take into account that students tend to acquire skills on applying specific procedural knowledge with "learning-by-doing" techniques, regardless of general functioning principles of OS, generating a frustrating knowledge gap. To reduce this gap, semantic wikis are interesting for at least two reasons: ease of use as encyclopedic factual knowledge base, and the semantic browsing features of the linked documents. These aspects fit well with the contents of a typical OS course.

As an example, in an OS course, if you would state that "paging" is a

memory-management scheme (using an inheritance relationship), semantic-wiki would be able to automatically generate a list of memory-management schemes, simply by listing all pages that are tagged as belonging to the semantic category "memory-management". Moreover, further semantic tags in "paging" page could indicate other data about this strategy, including definition, implementation in current and historical OS, references, and so on.

Such semantic features, used in combination with traditional wiki features, like, e.g., the possibility of adding categories for each page, allow users defining a model of the knowledge described in wiki pages, using both hierarchical (e.g. IS_A property) and associative (e.g. PART_OF and IS_RELATED_TO) relations.

Since their origin, the use of semantic-wikis in learning and teaching scenarios has been investigated (Schaffert *et al.*, 2006). In particular, researchers focused on the semantic annotation process as a way to wonder about the knowledge domain. But the definition of a formal model requires structured contents. Consequently, learners are forced to redesign the wiki content organization after a deep analysis. Moreover, changes recorded in the chronology can support teachers in the assessment phase, to evaluate the achievement of learning goals. Furthermore, the collaborative strategy gives teachers and learners the opportunity to share their different perspectives, co-constructing a common knowledge domain model.

In the Semantic-WikiSUN project, students have been asked to classify wiki articles (each page refers to a concept in the subject matter) by means of categories that they also must define (hierarchical organization) and to identify semantic relationships (properties) among concepts in the wiki pages.

In order to do this, group and individual activities have been organized as follows:

1. Sandbox Phase: each student must create a set of wiki pages syntactically (not semantically) interrelated, starting from a concept suggested by the teacher;
2. Weaving the net: each student (individually) was encouraged to wonder about wiki pages content and to assign tags to them in order to develop a sort of primitive folksonomy, a kind of informal, social categorization;
3. Peer-review Phase: students were invited to peer-review wiki pages both for pages content and the folksonomy developed by means of Discussion feature provided by the wiki platform;
4. Conceptual Net: students were invited to identify semantic relationships among concepts inside wiki pages by means of properties according to the syntax previously cited;
5. Homogenization Phase: students were encouraged to revise the classification schema by both pruning and merging categories and properties

(e.g., repeated) in order to define a coherent conceptual structure and to uniform terminology.

5 Related works

Semantic technologies, wiki-based system for education and a mix of these are considered, putting in evidence how the adoption of a semantic support in learning environments can improve search, as a first step, and enhance the management of learning processes, as a secondary result. Firstly, we would like to highlight that, although there are various studies on the use of semantic-wiki in instructional context, only a limited number of projects specifically related to the CS education are reported in the literature.

The use of semantic annotation in learning environments has been recently reviewed by Weal *et al.* (2012), which showcase a variety of prototypal systems, implemented to investigate (and to learn) how students learn. Also, an exhaustive bibliography can be found in their work, reporting many projects in the specific educational context and in professional activities as well. Another interesting contribution is given by Martinez-Garcia *et al.* (2012), which cope with the specific context of case-based learning to achieve pedagogical innovation through semantic technologies. For what concerns the adoption of semantic wiki environments in education, we mention, among the others, the works by Bratsas *et al.* (2009) and Kontotasiou *et al.* (2011), which present a specific tool for medical education, based on a learning environment that enables medical students to easily access, evaluate, organize and reuse content, and collaborate. Moreover, the system exploits the valuable features offered by the Semantic Web technology for exchange between different systems and tools (mEducator web site, 2013).

Besides, Wei-Tek Tsai *et al.* (2010) describe a specific case study of using a Wiki in collaborative learning activities for computer science undergraduate education. This work also reports a rich bibliography and a related work section in which the authors underline that basic concepts of Web 2.0, and thus of e-learning 2.0 (Downes, 2005), are intrinsically belonging to software engineering, reflecting in open source, design patterns, object oriented programming, which strongly encourage cooperation and sharing, as well as peer-evaluation (Georgouli *et al.*, 2012; Cen Li *et al.*, 2011). Finally, Naismith *et al.* (2010) propose experimentations on different sets of students (different ages and courses), putting in evidence topics related to the assessment too. Another interesting project is Triple A (Triple A website, 2013), a Semantic MediaWiki site that provides IT architecture information for educational organizations.

Conclusions

In a preliminary study, results of students' activity in Semantic Wiki-SUN have already been published (Coccoli *et al.*, 2012); currently a deeper experimentation is still running. In this paper, we have sketched the theoretical framework, the motivations and the design issues to justify our semantic wiki approach in teaching and learning in CS education. At this stage of the project, on the basis of this analysis and the preliminary data available, we are confident that our current system should better refined, allowing the definition of a general purpose collaborative learning environment for different disciplines – not only CS - based on wikis and semantic technologies.

In a general educational perspective, future releases of the system should take more and more advantages by using social, learner-driven, semantic annotation/relations, which will enhance the straightforward role of semantic browsing as "enabler" for students. In this social context, each learner should take benefit through the continuous evolution of her/his own socially merged network of concepts about the specific knowledge domain. To do this, semantic-wiki based learning platforms like Semantic-WikiSUN should better exploit two semantic features: (i) a usable, structured visualization of the internal ontological structure of the knowledge domain by means of a better visual interface and (ii) a more social-oriented collaborative structure of platforms making "discussion pages" more appealing from the educational point of view.

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