

# Ontology-Based Personalised SQA e-Learning System

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**Abstract.** Developing quality software requires well trained graduates with high SQA skills. Unfortunately, experience shows that most institutions are unable to graduate software engineers to meet manufactures expectations. With the new technological advances and the use of e-learning techniques, ontologies play key role in supporting semantic knowledge representation and thus enhancing e-learning experience. It allows structural annotation of electronic resources with semantic information providing machine-understandable contents. In this paper an ontology-based e-learning prototype was designed and implemented to guide students and practitioners about SQA process required in the software development.

**Keywords.** Software Quality Assurance, Ontology, Context-aware e-Learning

## 1 Introduction

Studies show that software companies can make more money through increased customer satisfaction and improved product quality [1]. Therefore, Software Quality Assurance (SQA) becomes one of the most important objectives of software development and maintenance activities and as a result within an area of Software Engineering (SE) there are developed standards related to the SQA.

A well-defined, complete and disciplined SQA process can be helpful to improve communication and collaboration among project participants and can serve as a standard when there is a disagreement.

Software quality is a rather complex concept; some authors have defined the entire discipline of SE as the production of quality software [2]. Therefore, adopting software management and SQA standards,

as well as training highly qualified software engineers became critical for developing high quality software.

Ontologies provide a common understanding and sharing of knowledge by using a general agreement on terminology among all interested people.

SE domain ontologies are very useful in developing high quality, reusable software by providing an unambiguous terminology that can be shared through the development processes. Ontologies also help in eliminating ambiguity, increasing consistency and integrating distinct user viewpoints [3; 4; 5; 6].

Using ontology to model the SE knowledge shortens the development time, improves productivity, decreases cost, and increases product quality. Ontologies provide better understanding of the required changes and the system to be maintained [7].

In addition, SE ontologies can be used to support the translation between different human languages when different users need to exchange information. Software developers with different backgrounds and viewpoints working on the same project can be helped by ontologies in the requirement specification process by offering a declarative specification of the system, its components and the relationship between the components [7].

This paper presents an ontology-based e-learning system aims to guide learners through the necessary SQA practices by providing resources that deal with all SQA related aspects of the software process at hand. The rest of the paper is organized as following: Section 2 presents the merits of ontologies in education and e-learning applications. Section 3 presents the development of the SQA ontology while Section 4 shows the architecture and implementation of the SQA e-learning system. Section 5 presents the context awareness of the system with examples. Conclusion of the work is presented in Section 6.

## 2 Ontologies in Education

Developing quality software requires well trained graduates with high SQA skills. Unfortunately, experience shows that most institutions are unable to graduate software engineers to meet manufactures expectations. This is mainly due to: (i) the fast changing discipline; (ii) inability to deal with large complex problems in a limited educational setup; and (iii) the variety of methods, techniques, and technological tools used in this field [8; 1].

One problem in teaching software engineering as a discipline, considered as a set of topics and subtopics that are studied sequentially, is the use of textbooks. The discipline may be studied as separate modules/courses that may be not coordinated in terms of consistency and completeness. Moreover, educators in this area have different backgrounds, programming language preferences, and usually use different jargons which lead to a variety of understanding and overlapping of meanings of the same software engineering term or concept. This often results in lack of communication between the same team members and ambiguity in understanding requirements and defining system specifications.

We, as educators, believe that we share part of the responsibilities for the gap between the software engineering graduates' knowledge and what is required in practice by software industries. Therefore, to improve the way of learning and teaching software quality, we will use an ontological approach to model SQA knowledge area [9].

To our knowledge, there is no software quality ontology available for teaching and learning purposes. Having the opportunity to build operational ontology will provide a unique insight in teaching software quality in an e-learning environment. Ontology can be used as a tool for the representation of a specific domain knowledge which offers a consensual shared understanding of the domain knowledge to be exchanged and reused among people and organizations. In addition, the great expressiveness of the knowledge in the domain ontology supports the teaching and learning of the domain as it is machine-readable, and thus, can be used for e-learning purposes.

According to Stojanovic and colleagues [10] ontologies in e-learning can be used to describe the content, the context, or the structure of the learning materials. For instance, when searching for a learning material, the content refers to what the learning material is about (the topic) and the context refers to the form in which this learning material is presented. Learning material can be presented in a variety of learning or presentation context. However, structure ontologies breaks down learning materials into small bits of information (or chunk of knowledge) that can be connected to each other in order to build up a complete course. In this thesis, we adopted the

approach based on the first and second category (i.e. the content and context ontologies)

Ontologies can support teachers in the course construction phase in the analysis and annotation of the learning objects where the course can be seen as a path over the ontology model of the course contents. In addition, ontologies can support students to follow the suggested learning path or dynamically modify it according to their needs [11].

### 2.1 Domain Ontologies for Learning

In an attempt to create meaningful and effective learning strategies in teaching C programming [12] accumulate their experience in teaching several C-related programming courses to present an educational ontology that reflects their vision on what is important in studying C programming.

Another educational ontology created by Jakkilinki and colleagues [13] for their Multimedia Design and Planning Pyramid MUDPY model. MUDPY is being built to guide novice through the multimedia design and planning process by answering queries on the MUDPY elements and their relationships.

For better software engineering education, a project-based collaborative learning environment was developed for learning software design patterns (DPs) [14].

### 2.2 Ontology-Based Context-Aware Learning

As there is no fix learning path that can fit all learners' needs, most systems in the e-learning literature have combined more than one knowledge source to contextualize the learning sequence and the learning content aiming to provide the best personalized learning or what is called context-aware e-learning. Context is defines as any information that can be used to characterize the situation of an entity. An entity is a person, place, or object [15]. In such e-learning environment, the system responds differently according to the learner characteristics (i.e. learner's needs, learning style, preferred presentation formats, learner's previous knowledge of the subject domain, etc.) and performance (gathered in user profile) [16].

LOCO-Analyst, an educational tool built on top of the LOCO framework, an ontological framework that captures necessary information for personalization learning process, aimed at providing teachers with feedback on the learning process taking place in a web-based learning environment [17]. In the field of personalized learning, Henze and Dolog [18] proposed an approach for a dynamically generated personalized educational system powered by reasoning mechanisms. The system uses three types of ontologies: a user ontology (describing user characteristics), an observation ontology (modeling

different possible user interactions with the system), and a domain ontology (describing the concepts covered in the knowledge domain and the relationships among concepts).

CRES DUP [19] is a personalized recommendation system that collects, mines, and discovers user data in order to update a Dynamic User Profile (DUP). The system then uses DUP to identify user preferences and deliver preferred resources to interested users. Also, the Portable Personality (P2) [20] integrates data mining methods and management algorithms to handle multiple profiles and personalized recommendations based on distributed (portable) profiles. In the same area, Chen [21] proposes a novel genetic-based personalized learning path generation schema to provide near-optimal learning path for individual learner. The schema based on an ontology-based concept map able to simultaneously consider the course material difficulty and the concept-relations of the prior and posterior knowledge between course materials in generation personalized learning paths.

Berri and Benlamri [22] have developed context-aware e-learning system consists of a rule-based ontology and a search engine. Extracted knowledge from the source ontology is used to recommend a learning path by firing a set of rules based on the learner profile.

A similar approach has been adopted by Anand and colleagues [23] who proposed an e-learning system that enhances the quality of generated recommendations. Their work is based on a similarity computation that integrates an ontology item with user rating data to generate recommendation tailored to the user's context.

Yu et al. [24] have developed an infrastructure for context-aware e-learning services based on semantic knowledge representation, learning context processing, and adaptive content recommendation.

Another similar context-aware e-learning system was developed by Das and colleagues [25]. This system uses standardized context parameters to build the context models, which in turn are used by a content management component to create learning resources that are dynamically composed into basic learning objects based on the learner's context.

### 3 SQA Ontology

Even though, domain ontologies are developed for education, none of these ontologies is useful for the scope of this research as each of them represent a different domain and hence cannot be re-used in the development of the SQA ontology.

There are various vocabularies to describe the software quality domain knowledge. There is no single standard which embraces the whole software quality knowledge.

The primary source of the SQA ontology is the SWEBOK guide [26] in addition to above-mentioned ISO and IEEE standards (ISO 9126, IEEE 12207, IEEE 610.12, IEEE 00100, PMBOK 2008, CMMI v1.2) and research proposals.

Basics concepts of the SQA domain are represented by OWL classes that are the roots of various taxonomic trees. The root class of any OWL ontology is the *owl:Thing* where every individual of the OWL world is a member of that class.

the main class in the domain ontology is class *SQAConcept*, a subclass of *owl:Thing*, is the upper class of all other classes of the SQA ontology that is used to conceptualize and to represent the knowledge of the SQA domain.

Fig.1 shows the general structure and concepts of the domain ontology among with the relationships among concepts. The property *makeQuery* relates keyword input by the learner to the most related ontology concept. The property *consumedLearningObject* track previously consumed LOs by a specific learner. The property *isMappedTo* relates the SQAConcept class to the learning object class.

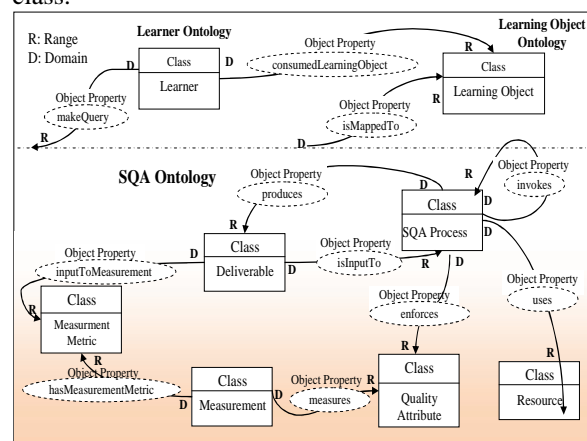


Figure1. SQA Domain Ontology

The conceptual model of the SQA ontology was presented. The consistency and conciseness of the developed ontology were automatically validated during the implementation process using the Protégé consistency checker tool. Ontology assessment questionnaire was developed to evaluate the quality of the SQA ontology. The discussion and findings of the evaluation was also presented in [27].

### 4 Architecture of the SQA e-Learning System

Ontology as a promising technology plays an important role in the development of enhanced and effective learning by providing machine-readable content [10; 28; 29]. Unlike the linear organization of

textbooks, access to learning resources in an e-learning course using ontologies is continuous

The main components of the SQA e-learning system (SQAES) are: the learning recommendation generator, the process discovery unit and the ontology reasoning unit as illustrated in Fig.2 [9].

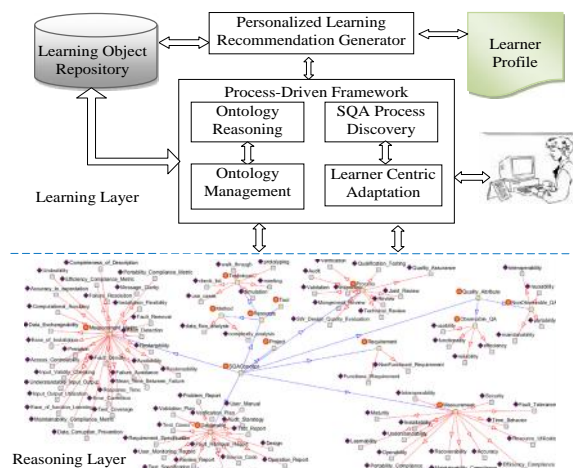


Figure 2. SQAES Architecture

### 4.1 Learning Scenario in SQAES

In this section we present an overview of the main steps in a typical learning scenario while using SQAES. Ontology reasoning is used to personalize learning services based on the learner’s context. This learner centric adaptation is based on the Learner and the SQA domain ontologies. A set of ontological rules is applied to infer metadata that can be used to customize the learning recommendation [30]. Typical learning scenario has the sequence of steps illustrated in Fig. 3:

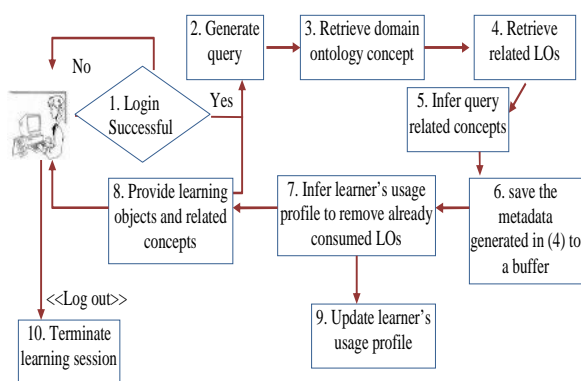


Figure 3. Processing Steps of a Typical Learning Scenario

For example if the learner queries about the Validation process. The system retrieves unconsumed learning objects that are directly associated to the term Validation (already consumed LOs are presented

for the user for re-learning). The system will then use the reasoning rules, given in step 4, to infer other concepts related to the validation process. For example: a Validation process enforces quality attributes such as Functionality and Efficiency and invokes the Review and Audit processes. It also uses the Testing and Prototyping as resources. The system then saves these related concepts in a buffer. Associated LOs and related concepts are then displayed as recommendations to the learner for investigation.

### 4.2 Implementation of SQAES

As shown in Fig.4, in the center of the system is Web-based server which read the ontology model and retrieves queried concepts. Other related concepts are inferred using ontology reasoning mechanism of the defined ontology reasoning rules. Each SQA concept is mapped to several learning objects. The system retrieves those learning objects that are associated with the queried concept from the LOs repository. Retrieved LOs are saved in a buffer to be filtered based on the learner profile and then provided to the learner.

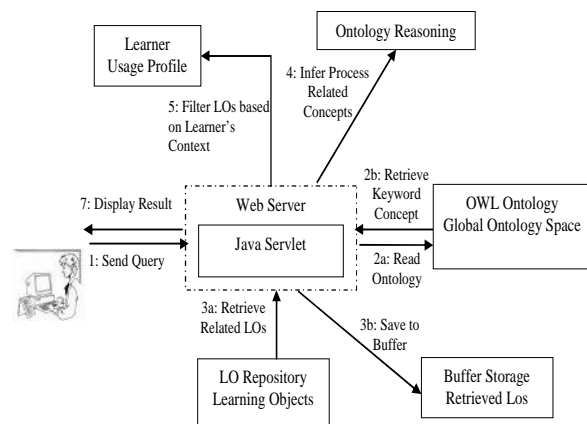


Figure 4. Logical Diagram of SQAES Software Components

For SQAES implementation is used a set of tools and libraries already developed for the Java programming language and the integrated development environment (IDE) such as Eclipse Software Development Kit (SDK). All components are free open source and platform independent software. The main components and processing steps are shown in Fig.5 [9] and the Java code of the implemented prototype is presented in Appendix I.

As a server software, ApacheTomcat 7 [31] allows to develop the container with a few servlets has been chosen. Here servlet means a software component which is providing service to other software components.

Jena [32], a Semantic Web framework for Java, is used to extract data from and write to the developed

OWL ontology model. The Jena framework offers a convenient way to work with ontologies and in particular for integrating ontologies into applications. The Jena framework is used to read the ontology and to create prerequisite individuals. The system uses the SWRL Tab of Protégé to build SWRL rules for ontology reasoning.

RacerPro [33] is a Description Logic (DL) reasoner used as an interactive tool for manipulating the ontology and the SWRL rules.

Finally, JDOM [34] is XML framework for Java used to process XML files of developers' usage profiles.

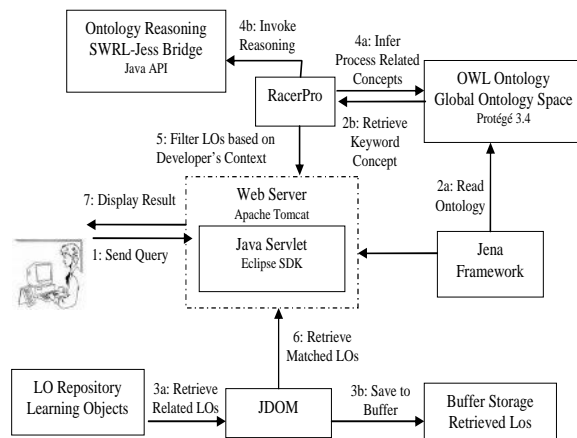


Figure 5. Implementation-specific Diagram of SQAES Software Components

## 5 Context-Aware SQA e-Learning System

Various context parameters are considered in existing e-learning system such as: learner personnel profile, expertise level, learning preferences, learning situation, network, device...etc. [25]. The e-learning prototype of this

### 5.1 Learner Centric Adaptation

The prototype system aims to guide learner through the necessary SQA practices by providing resources that deal with SQA related aspects of the current SQA process at hand. This is achieved by sensing the learner's current activity and suggesting relevant LOs (e.g. recommendations for good practices, example code, and graphical description of a related methodology/process) that deal with all SQA aspects related to the current SQA process. The aim of the learner centric adaptation is to construct personalize learning recommendation based on the learner's usage profile. The system responds differently according to the learner performance (already consumed LOs) and the SQA process at hand. The learner centric adaptation achieves its functionality in two steps:

First: The reasoning unit of the proposed e-learning system infers the core LOs that are directly related to the queried concept through the object property isMappedTo using the CoreLearningObject rule:

$$\text{Learner} (?L) \wedge \text{MakeQuery} (?L, ?C) \wedge \text{IsMappedTo} (?C, ?LO) \wedge \text{Consumed} (?L, ?LO) \rightarrow \text{CoreLearningObject} (?C, ?LO)$$

For implicit query expansion, related concepts are then inferred based on the relations among the ontology classes and the user defined SWRL rules. The output is a sequence of LOs and related topics that are generated as learning recommendations.

Second: recommendations generated from the previous step are then semantically refined and adjusted according to the learner's profile where the system distinguishes LOs objects that have already been consumed by the developer.

Besides the OWL ontology reasoning rules (subClassOf, subPropertyOf, inverseOf, etc...), the SQA knowledge base is extended with a set of user defined rules in first order logic to allow inferring higher-level conceptual context from relevant low-level ones [30].

The property isMappedTo(?C, ?LO) maps the learner's query related concept to a corresponding learning object. The property  $\neg$  consumed (?L, ?LOj) relate a learner to a learning object that has not been consumed so far. It should be noted that the system automatically establishes relation of  $\neg$  Consumed (?L, ?LOj) for all those learning objects that have not been consumed by particular learner.

### 5.2 Learner Usage Profile

According to Das [25] context is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that are considered relevant to the interaction between a user and an application including the user and the application themselves. Context-aware learning or personalized learning provides learning contents according to learner's needs, preferences, style and previous knowledge of the subject domain.

Various context parameters are considered in existing e-learning system such as: learner personnel profile, expertise level, learning preferences, learning situation, network, device, etc. [25]. The system proposed in this research takes into consideration already consumed learning objects that are stored in the learner's profile. The learner usage profile is automatically updated according to his/her performance. A new learning session is initiated each time the user logged into the system. Information about the starting time of the session, queried concepts, and consumed learning resources is stored in the learner's usage profile. JDOM (Hunter, 2008) will be used to manipulate users' profiles which are stored in XML format. A sample user profile is shown in Fig. 6.

```

<?xml version="1.0" encoding="UTF-8"?>
<sessions numOfSessions="2">
  <UserName>Nada</UserName>
  <Session>
    <id>1</id>
    <time>2011-12-14 14:44:36</time>
    <Query Concept="Validation">
      <Consumed_LO>
        Software Validation Tools
      </Consumed_LO>
      <Consumed_LO>
        SW Validation in Accredited
        Laboratories
      </Consumed_LO>
      <Consumed_LO>
        Seven Keys for Successful SW
        Validation
      </Consumed_LO>
      <Consumed_LO>
        Software Validation
      </Consumed_LO>
    </Query>
    <Query Concept="Measurement">
      <Consumed_LO>
        Software Measurement 2
      </Consumed_LO>
    </Query>
    <Query Concept="Prototyping">
      <Consumed_LO>
        What is SW Prototyping
      </Consumed_LO>
      <Consumed_LO>
        Successfully Building SW
        Prototype
      </Consumed_LO>
    </Query>
  </Session>
  <Session>
    <id>2</id>
    <time>2011-12-14 14:46:51</time>
    <Query Concept="Testing" />
  </Session>
</sessions>

```

Figure 6. Sample Learner's Usage Profile

### 5.3 Context Reasoning

The prototype system provides the learner with a recommendation list based on the initial query. However, this list may include some overwhelmed LOs or unnecessary content. Ontology axioms, a declaratively and rigorously represented knowledge which has to be accepted without proof, were added to prevent unnecessary knowledge. In ontology representation, axioms can be used to represent the meaning of concepts carefully, and to answer questions on the capability of the built ontology using the ontology concepts.

Consider the case when the user queries the *Verification* concept, which is a process according to the SQA ontology, the system retrieves the core LOs associated with the *Verification* concept from the LO repository. Related concepts represent the list of recommended SQA concepts to be provided to the user for further investigation. However, this list may include some overwhelmed or unnecessary contents. In the example of *Verification*, by firing the *Invokes*

rule, LOs associated with all SQA processes will be added to the list of recommendation as illustrated in Fig. 7.

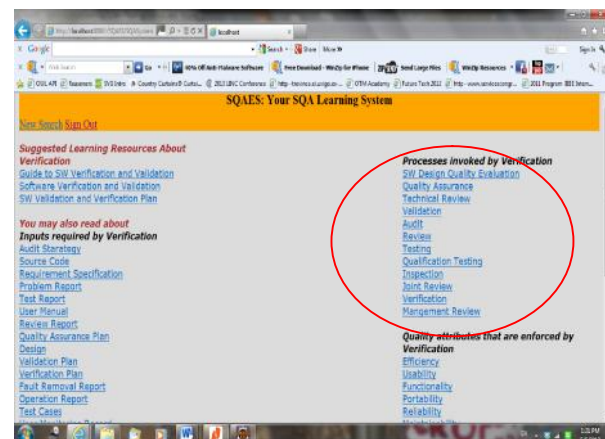


Figure 7. System Response without Using Axioms

In theory (i.e. as per IEEE 12207 standard), only those processes that are associated with *Review* and *Audit* should have been added to the list (Fig. 8).

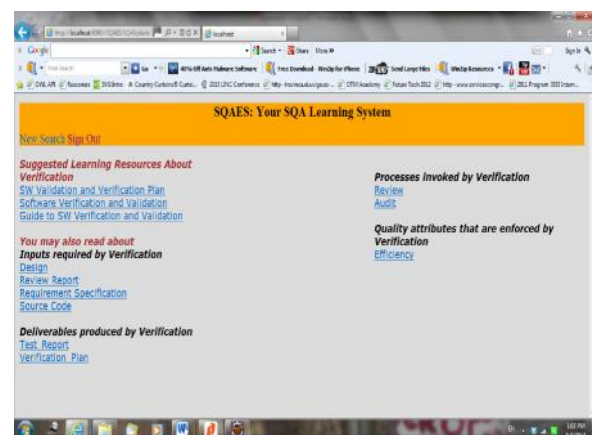


Figure 8hu7. System Response Using Axioms

To prevent such situation, recommendation refining is guaranteed by adding ontology axioms to the ontology model. By referring back to our example related to *Verification* concept and according to ISO/IEC 9126 standard, a *Verification* process produces *Test Report* and *Verification Plan* and requires *Requirement Specification*, *Source Code*, *Review Report* and *Design* as inputs. In addition, *Verification* has *Efficiency* as quality attributes. The above knowledge can be represented with the following axioms added to the *Verification* concept of the SQA ontology model:

$\forall$  produces only (Test\_Report or Verification\_Plan)

$\forall$  invokes only (Review or Audit)

$\forall$  ensuresQA only Efficiency

$\forall$  uses only (Use\_case or Measurement or Prototyping)

$\forall$  hasInput only (Requirement\_Specification or Source\_Code or Review\_Report or Design)

## 6 Conclusion

In this paper the design and structure of a process-driven e-learning system that senses learners' current activity and guide them through the necessary SQA practices is presented. First, a general system architecture and design was introduced followed by the main software components used to build the system.

Context-awareness is achieved through a set of reasoning tools that take into account user's profile and learning history to recommend SQA resources needed for the task in hand. Reasoning axioms based on international standards have been added to the ontology to prevent retrieving unrelated concepts. The system updates the learner's profile with consumed learning resources each time the learner logged in the system.

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