Representation of an Electrical Engineering Curriculum using an Ontology of Controlled Quality

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ABSTRACT

A curriculum is a complex system that includes a set of core competencies, objectives, contents, methodological and evaluation criteria, regulation among other things. In order to represent a curriculum taking into account the deep and complex relationships among its elements, a representation of an engineering curriculum using ontologies has been developed. This paper presents the construction of an ontology for undergraduate Electrical Engineering Curriculum domain at Universidad Nacional de Colombia, which aims to represent, organize, formalize and standardize the knowledge of this domain, so that it can be shared and reused by different groups of people in the field of education and engineering. The ontology includes four Curriculum aspects: Knowledge in Electrical Engineering, skills in Engineering, Electrical Engineering Curriculum and regulation. For the ontology development, Methontology was selected as methodology and Protégé as implementation tool. In addition, there is a proposal of documentation for this methodology, based on principles of Quality Management Systems. This ontology is designed in order to be used in any field of engineering.

Keywords: Curriculum, Methontology, Ontological Engineering, Protégé, Quality Management Systems.

1. INTRODUCTION

This paper presents an ontology of a Curriculum and the strategy of quality assurance used in its construction. The construction methodology is Methontology (Gómez-Pérez et al., 2004). This methodology has been complemented with elements of Quality Management Systems (ISO, 2008) to ensure the quality of the process. The ontology is about the Electrical Engineering Curriculum from Universidad Nacional de Colombia.

A Curriculum is used by educational institutions as one of the basic resources in their academic processes. There are common tools for the representation of a curriculum domain as a piece of software, consisting of databases, trees and lists of courses, among others. However, none of these tools allow capturing the deep and complex relationships between its elements. We propose the use of ontologies to enrich the data and capture those complex relationships.

Ontologies define the terms used to describe and represent an area of knowledge and are used by people, databases and applications that need to share specific information about a particular subject (or domain). Here, we show an ontology that represents a specific Engineering Curriculum (Electrical Engineering at Universidad

Nacional de Colombia); however, it has been designed with the purpose of making this application a helpful reference for any Engineering Curriculum at any university.

Methontology is a methodology for building ontologies from scratch. This methodology was selected for the construction of our ontology because it employs a clear and orderly set of activities organized as an iterative process of development (Gómez-Pérez et al., 2004). However, Methontology does not specify the tasks to perform during the process of "quality control" proposed in the management activities. We set out a strategy for implementing a documentation system based on Quality Management Systems as a novel complement to Methontology. The purpose of this system is to ensure that the outcome obtained during the development process of the ontology fulfils the minimum specifications and gets an "ontology of controlled quality".

The foundations of Quality Management Systems, and the terms related with them, are the subject of the family of standards ISO 9000, created by ISO (International Organization for Standardization) (ISO, 2008). A Quality Management System can provide the framework for continuous improvement in order to increase the satisfaction of stakeholders.

This paper presents in section 2 an overview of ontologies, including some methodologies and tools for their development. Section 3 includes the documentation proposal for Methontology applying Quality Management Systems (QMS). The ontology created to represent the Electrical Engineering Curriculum is described in Section 4. Finally, in Section 5, conclusions about the construction and the potential uses of the ontology are presented.

2. OVERVIEW OF ONTOLOGY

There are several definitions about the concept of ontology. Gruber's definition has evolved into one of the most cited in the literature and the ontology community. "An ontology is an explicit specification of a conceptualization" (Gruber, 1993). Gómez-Pérez et al., provides another definition that includes the more relevant definitions of the ontology word: "Ontologies aim to capture consensual knowledge in a generic way, and to be reused and shared across software applications and by groups of people. They are usually built cooperatively by different groups of people in different locations" (Gómez-Pérez et al., 2004).

The ontologies components vary by domain, but usually consist of classes (set of objects that describe the domain concepts), relationships (to represent the interactions between classes), instances (to represent particular objects of a class), taxonomies (hierarchical organization of the set of concepts), axioms (used to modeling sentences that are always true and allow, along with the legacy of concepts, to deduce knowledge) and attributes (to describe objects) (Gruber, 1993).

With the knowledge stored in ontologies, software agents can interpret and process the data in Web pages, get conclusions, make decisions and negotiate with other agents or persons. As the ontologies development grows, developers of these use different tools and languages; as a result of this growth, it must be possible to find and compare existing ontologies, reuse complete ontologies or their parts, and maintain different versions (Noy and Musem, 2004).

2.1 METHODOLOGIES FOR BUILDING ONTOLOGIES

Until the mid 90's, the process of ontology building was more an art than an engineering activity, due to the absence of structured and common guidelines for developing this process. Each development team usually uses its own criteria to construct manually the ontology.

Among the most representative methodologies for developing ontologies are: Grüninger & Fox (Grüninger and Fox, 1995), On-To-Knowledge (Staab et al., 2001) and Methontology (Gómez-Pérez et al., 2004).

For this work, Methontology was selected because it is one of the most comprehensive methodologies for ontology engineering, allowing the construction of ontologies from scratch, by reusing existing ones or by a reengineering process. This methodology developed within the Ontology Engineering Group of Universidad Politécnica de Madrid, proposes a life cycle based on evolving prototypes. Additionally, it provides guidelines on how to carry out the development of the ontology through the activities of specification, conceptualization, formalization, implementation and maintenance (Corcho et al., 2005).

Although Methontology proposes to carry out a quality assurance in its management activities, it does not provide the guidelines of how to implement this activity. For this reason we have created a documentation proposal for Methontology applying Quality Management Systems (QMS), which is explained in section 3.1.

2.2 ONTOLOGIES DEVELOPMENT TOOLS

Among the ontologies development tools characterized by having an open architecture, which allows simple integration and extensibility with other applications, we can include: Protégé (Noy et al., 2000), Onto Edit (Sure et al., 2002), WebODE (Arpírez et al., 2003) and KAON (Maedche et al., 2003).

For the development of the Ontology of Electrical Engineering Curriculum, Protégé was used. This tool is a free, open source, ontology editor created by the Stanford Medical Informatics (SMI) group from Stanford University. Protégé allows achieving interoperability with other systems of knowledge representation and it is a tool for knowledge acquisition, which is easy to use and configure (Noy et al., 2000).

3. DOCUMENTATION PROPOSAL FOR METHONTOLOGY APPLYING QUALITY MANAGEMENT SYSTEMS

In order to facilitate understanding and application of Methontology, we have designed a processes diagram, which shows the sequence of activities during the construction of an ontology. Given that the methodology chosen for the construction of the ontology does not include specifications to obtain a quality-controlled ontology, we have designed the diagram shown in Figure 1, including principles of quality management (see section 3.1) and documentation control, with the purpose of ensuring that the outcome of this process accomplishes minimum specifications.

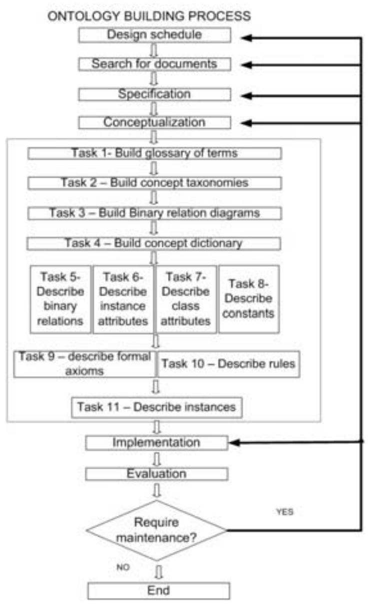

Figure 1: Processes Diagram for Methontology

3.1 QUALITY MANAGEMENT SYSTEMS

Quality is a concept that has changed over the years, there are a variety of ways of conceiving it in organizations. Some representative authors in the field of quality management who have defined the concept of quality are: Deming (The W. Edwards Deming Institute, 2012), Juran (JURAN The Source for Breakthrough, 2012) and Ishikawa (Ishikawa, 1985).

For the International Organization for Standardization (ISO), Quality Management is a set of coordinated activities to direct and control an organization with regard to quality. This concept is defined within the International Standard ISO 9000 (ISO, 2008), which distinguishes between systems requirements for Quality Management Systems (QMS) and product requirements. The requirements for QMS are specified in ISO 9001 standard.

Quality Management Systems can help organizations to increase customer satisfaction by providing a framework for continuous improvement. Some of the benefits of QMS are: confidence in the ability of the processes and the quality of the products or services, transparency in the development of processes, ensuring compliance with targets, increased benefits and work organization (ISO, 2008).

The implementation of a QMS ensures proper operation of processes. For an effective operation in organizations, they must identify and manage several interrelated processes. The identification and systematic management of organization processes and in particular the interactions between such processes are known as "approach based on processes". Often the result of a process becomes the input for the next.

3.2 Manual of Processes

From an approach based on processes and taking into account the processes diagram of Methontology, we have created a manual of processes. It enables to organize different activities taking place during the building of ontologies, in order to ensure an efficient implementation and the compliance of initial objectives.

Each of the processes involved in the manual is described taking into account: code and name of the process, input, procedure and final product required. As an example, Table 1 shows the model scheme used to describe a process.

Table 1: Description of Process 001

Code Process:	001
Name Process:	Design schedule
Input:	Activities to develop
Product:	Schedule
Procedure:	- Identify tasks to develop - Identify order of tasks - Identify time and resources required for compliance

3.3 Proposed Model applying Methontology

Following the implementation of Quality Management Systems and considering that Methontology is based on development of prototypes, we designed a diagram that contains the support activities carried out during the development of each ontology building process.

These activities are: Knowledge acquisition, Integration, Evaluation, Documentation and Configuration management. The name of the prototypes is given by the word ***iteration***, followed by an ascending sequence of numbers beginning with ***0***. For each iteration, we used the model diagram of support activities shown in Figure 2.

Each of the columns of this diagram is explained below:

- **Knowledge acquisition**: Sources of knowledge acquisition may be experts, books, manuals, figures, tables and even other ontologies. They can be combined with other techniques such as brainstorming, interviews and analysis of formal and informal texts.
- **Integration**: It relates to the reuse of definitions already built into other ontologies instead of starting from scratch.
- **Evaluation**: This activity carries out a technical judgment of the ontologies, their software environment and documentation with respect to each iteration and between iterations of their life cycle.

- **Documentation**: There are not consensuated guidelines on how to document ontologies, therefore documentation activity follows the guidelines explained in section 3.4.
- **Configuration Management**: In this activity, documents or files that are the result from the execution of the process are included.

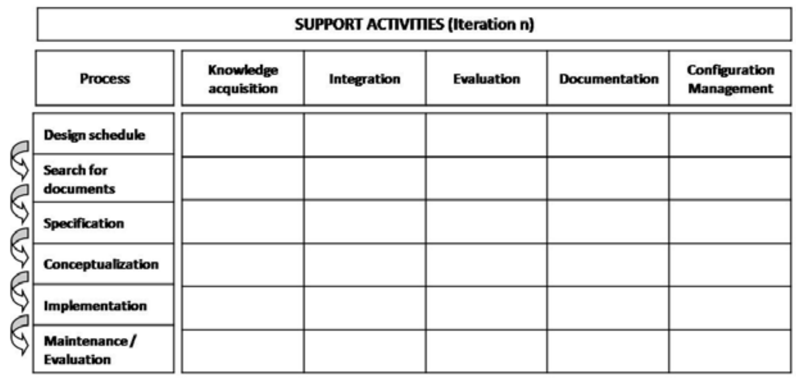

Figure 2: Model Diagram of Support Activities

The following is the description of how the processes of Figure 2 were developed:

- **Design schedule:** The schedule represents the tasks performed at each iteration, their execution order and identification of time and resources required for compliance.
- **Search for documents**: It was the result of the collection, filtering and selection of references.
- **Specification**: In this process the purpose of building the ontology, level of formality and its scope was determined.
- **Conceptualization**: Tabular or graphical representations were used to organize and convert an informal perception of the domain in a semi-formal specification that can be easily understood by domain experts and ontology developers. The result of this activity was the conceptual model of the ontology.
- **Implementation**: In this process, the OWL ontology language for the construction of computer models was used.
- **Maintenance / evaluation**: In this process, the compliance of tasks outlined in the schedule was verified and aspects for improvement, if necessary, were established.

During the building of the ontology to represent the Undergraduate Electrical Engineering Curriculum from Universidad Nacional de Colombia, we developed 4 iterations named as: ***iteration 0***, ***iteration 1***, ***iteration 2*** and ***iteration 3***.

Over the course of the activities proposed in the manual of processes, ontologies evolve in relation to the number of terms, concepts, binary relations, instances and file sizes. The values that describe this evolution are represented in Table 2.

Table 2: Ontology Evolution in Quantity and Size

	Iteration 0	**Iteration 1**	**Iteration 2**	**Iteration 3**
Number of terms	0	204	950	962
Number of concepts	0	60	55	62
Number of binary relations	0	17	42	49
Number of instances	0	95	840	929
File size .owl (KB)	0	190	1302	1368

The documentation system proposed ensures traceability of the process of ontology construction. This makes quality control easier to perform by filling out diagrams of support activities for these iterations. The content of these diagrams allows differentiating significant changes between iterations.

3.4 REGISTRATION OF PROCESSES

The documentation related to registration of processes is performed following the format presented in Table 3. The construction of these records is supported by static HTML pages created with the plug-in of Protégé OWL '***OWLDoc***'.

Table 3: Registration of Processes Format

DOCUMENTATION PROCESSES ITERATION n		**Code:**
		Date of preparation:
		PAGE 1 OF 1
Name Process:		
Domain:	Electrical Engineering Curriculum	
Developed by:	Carolina Sarmiento	
Reviewed by:	Oscar Duarte	
Procedure:		
Product:		

Documentation takes into account the processes described in the manual and developed for each iteration (0, 1, 2 and 3). The format contains among others, the process code (defined in the manual), date of preparation, procedure developed and the final product. During the documentation process, we obtained a total of 122 records.

4. ELECTRICAL ENGINEERING CURRICULUM

4.1 BASIC SOURCES OF CONCEPTUALIZATION

Acquisition of knowledge is one of support activities included in ontology construction. Knowledge contained in the ontology of Electrical Engineering Curriculum was acquired through meetings with experts, collection and classification of documents related to the domain and analysis of texts to get concepts related with the domain.

Creation of ontology conceptual model begins with the results obtained in the knowledge acquisition stage and presents the concepts with their properties and relationships with other concepts through intermediate representations. Four basic sources of conceptualization were selected to create the conceptual model: knowledge in Electrical Engineering, skills in the Engineering area, curriculum of Electrical Engineering and regulation. Each of these sources is described below.

4.1.1 ENGINEERING KNOWLEDGE

The concepts that represent this source of conceptualization are selected with the assistance of experts in electrical engineering and taking into account some contents of the Electrical Engineering Manual proposed by IEEE (Dorf, 1997). Currently, we are working to include more detailed information.

4.1.2 SKILLS

Universidad Nacional uses a methodology to determine the skills that an engineer must have at the time of graduation. This methodology is based on the structure and content of the CDIO Program of Massachusetts Institute of Technology (MIT) (Crawley, 2001).

The Department of Electrical and Electronic Engineering from Universidad Nacional created the CDIO Syllabus document (Department of Electrical and Electronic Engineering, 2008). This document presents the skills to be developed for programs in Electrical and Electronic Engineering and all its content is included in the ontology developed for the Electrical Engineering Curriculum.

CDIO Program of MIT developed a new educational concept which aims to improve the training process, and its premise is to graduate engineers capable to Conceive - Design - Implement and Operate in the context of engineering education (Crawley, 2001). This objective forms the base for the rational design of curricula and a comprehensive evaluation system, which become a useful tool in the process that is taking place at Universidad Nacional de Colombia.

4.1.3 CURRICULUM

Knowledge of Electrical Engineering Curriculum is obtained from Resolution 181 of 2009 by the Council of the Faculty of Engineering from Universidad Nacional de Colombia (Council of the Faculty of Engineering, 2009). It specifies number of credits, groups and subjects of the Electrical Engineering Curriculum from Faculty of Engineering. All courses contained in Resolution 181 are included in the ontology developed, taking into account characteristics such as number of credits, requirements, prerequisites and groups to which the subject belongs to.

4.1.4 REGULATION

This source of conceptualization is supported by regulations issued by the University Superior Council, the Academic Council, the President and the General Secretary, as standards of interest for Universidad Nacional de Colombia, which have been issued by authorized agencies or organizations outward of the institution.

The ontology created to represent the Electrical Engineering Curriculum allows consulting the contents of Resolution 181 of 2009 (described above) and the Agreement 033 of 2007 of the Superior Council from Universidad Nacional, which sets basic guidelines for vocational training of students through their curricula (Superior Council, 2007). Although the ontology created includes only regulation related to the domain, its structure allows the inclusion of several types of regulation.

4.2 PROCESS FOR BUILDING THE ONTOLOGY OF THE ELECTRICAL ENGINEERING CURRICULUM

A curriculum is defined in the Agreement 033 of 2007 of the Superior Council from Universidad Nacional (Superior Council, 2007) as an open and dynamic system composed of activities, processes, resources, infrastructure, teachers, students, graduate students, evaluation mechanisms and joint strategies with the society.

Given the above definition, we began the analysis and establishment of the elements that will be part of the ontology that represent the Undergraduate Electrical Engineering Curriculum from Universidad Nacional de Colombia.

On the basis of activities proposed by Methontology, we created a manual that describes the processes to be accomplished in each iteration. This manual was prepared according to parameters of quality management, with the purpose of ensuring proper implementation of the processes and getting a product with controlled quality.

Based on the life cycle proposed by Methontology, we began a series of four cycles called, in order, *iteration 0*, *iteration 1*, *iteration 2* and *iteration 3*. Each of these iterations is developed following the processes described in the manual: design schedule, search for documents, specification, conceptualization, implementation and maintenance/evaluation (see section 3.2 and section 3.3).

As a result of the implementation process in iterations 1, 2 and 3, Protégé generated files in OWL language (Web Ontology Language), a markup language that allows publishing and sharing data using ontologies. Additionally, we used a Protégé plug-in which creates static HTML pages for publishing on the Web, with a dynamic view that allows navigation within Protégé.

Parallel to the development of the iterations, we carried out a set of support activities (described in section 3.3), following guidelines established by the Quality Management System, in order to achieve quality of the final product. These activities were made for each process developed in the iterations, and they include knowledge acquisition, integration, evaluation, documentation and configuration management.

With the implementation of processes and support activities, an ontology of the Undergraduate Electrical Engineering Curriculum was obtained. This ontology represents the domain knowledge organized and standardized, with the aim to be shared and used by people interested in education and engineering areas. Figure 3 shows a general outline of the work described above.

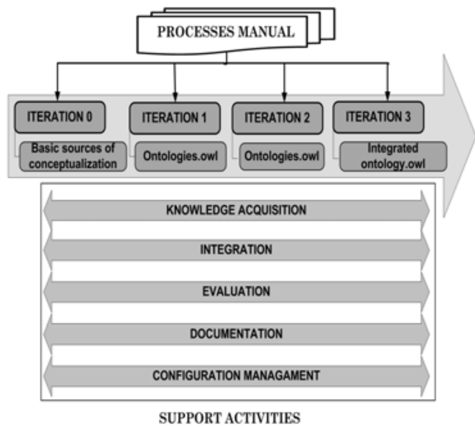

Figure 3: Process for Building the Ontology of Electrical Engineering Curriculum

4.3 ONTOLOGY STRUCTURE

The final ontology structure is given by the following:

- Glossary: The glossary consists of a total of 962 terms, which include 55 concepts, 840 instances, 56 class attributes and 11 instance attributes.
- Concepts Taxonomy: The taxonomy is defined by the combination of the hierarchy of concepts of each ontology (engineering knowledge, CDIO skills, curriculum and regulation) created previously. Figure 4 shows an excerpt this hierarchy.

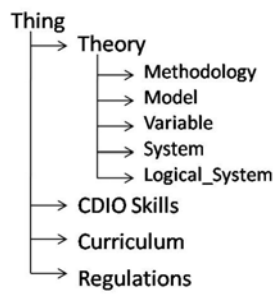

Figure 4: Excerpt of the Hierarchy of Concepts

- Binary Relations: For each binary relation, we specify its name, source and target concepts and inverse relation. An excerpt of relationships established between the taxonomy concepts is presented in Table 4.

Table 4: Excerpt of the Description of Binary Relations of Knowledge Engineering Ontology

Relation name	Source concept	Target concept	Inverse relation
represents	Model	System	is represented by
analyzes	Methodology	System	is analyzed by

4.4 Scope of the Ontology

The actual scope for each ontology reaches the following concepts:

- Ontology of Knowledge Engineering: It includes terms related to circuit theory.
- Ontology of CDIO Skills: It consists of all contents of CDIO Syllabus, developed by the Department of Electrical and Electronic Engineering from Universidad Nacional de Colombia.
- Ontology of Curriculum: This ontology contains all the curriculum courses of the Electrical Engineering Curriculum.
- Ontology of Regulation: The ontology has a structure that allows entering knowledge related to regulation of different types.

4.5 Aplicability

The potential of the knowledge stored in the ontology of the Electrical Engineering Curriculum can be exploited through the use of software agents that support different educational processes. For example, an agent can facilitate academic mobility processes through comparison of curriculum in a program or institution, as well as between different educational institutions.

A software agent as a support tool for students when taking proper decisions about the direction of their curriculum, so that they can be agents of their own training. The representation built for the curriculum provides understanding of different course contents, skills to be developed and the knowledge to be gained, with the purpose of helping strengthening the student autonomy.

The modeling of a complex curriculum allows teachers or administrative staff to plan and carry out more precise guidance to students on issues related to their vocational choice, by shaping the curriculum and academic processes. An agent can use the available relations between elements of the Electrical Engineering Curriculum to support academic management processes, such as shaping the students curriculum as they develop their training, orientation for future vocational decisions by students and creation or modification of curricula.

5. Conclusions

The ontology developed to represent the Electrical Engineering Curriculum provides the community interested in this domain, a well-structured, standardized and formalized knowledge, acquired from experts in the field of Electrical Engineering. It permits to share specific information of the area and make knowledge reusable.

The creation of a manual of processes based on quality management systems facilitated the work done in each iteration, ensuring efficiency and compliance with established procedures. By following the guidelines outlined in this manual, the purposes set out initially are achieved with the creation of a model that represents the concepts involved in the Electrical Engineering Curriculum, using ontologies and based on four sources of conceptualization.

The development of registration of processes allows tracking the evolution of the ontology and verifying the compliance of all stages of Methontology.

During construction of the ontology to represent a curriculum, the complexity in this domain was clear, due to its large number of components and the complex relationships between them. This complexity can be evidenced when carrying out accreditation processes in higher education and mobility of professionals in various parts of the world, for which simplified models are used or there are not common standards of procedures to follow.

This work has allowed defining the terms used to describe and represent the Electrical Engineering Curriculum domain, considering the scope described previously. Currently, we are working to complete the knowledge represented in this domain and creating software tools that strengthen educational processes, related to student support to achieve certain learning objectives.

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