

## **AC 2008-1449: ONTOLOGIES AND WEB-SEMANTICS FOR IMPROVEMENT OF CURRICULUM IN CIVIL ENGINEERING**

### **Jean-Pierre Bardet, University of Southern California**

Jean-Pierre Bardet is Professor of Civil and Environmental Engineering and Chair of the Sonny Astani Department of Civil and Environmental Engineering. He received his Ph.D. from the California Institute of Technology.

### **Dennis McLeod, University of Southern California**

Dennis McLeod is currently Professor of Computer Science at the University of Southern California, and Director of the Semantic Information Representation Laboratory at USC. He received his Ph.D., M.S., and B.S. degrees in Computer Science and Electrical Engineering from MIT. Dr. McLeod has published widely in the areas of data and knowledge base systems, federated databases, database models and design, and ontologies. His current research focuses on dynamic ontologies, user-customized information access, database semantic heterogeneity resolution and interoperation; personalized information management environments via cooperative immersipresence; information management environments for geoscience and homeland security information, crisis management decision support systems, and privacy and trust in information systems.

### **Gisele Ragusa, University of Southern California**

Gisele Ragusa is Associate Professor of Clinical Education, and Director of Undergraduate and Teacher Education Programs at the Rossier School of Education of the University of Southern California. She received a Ph.D. from the University of Southern California. Her research interests and areas of expertise include: teacher education and retention, literacy education, teacher education supervision, multimedia literacy, early childhood special education, deaf education, as well as bilingual elementary teacher education.

### **Nazila Mokarram, University of Southern California**

Nazila Mokarram is a Ph.D Student in the Sonny Astani Department of Civil and Environmental Engineering of the University of Southern California

# **Ontologies and Web-Semantics for Improvement of Curriculum in Civil Engineering**

## **Abstract**

The National Academy of Engineering (NAE) and the American Society of Civil Engineers (ASCE) recommended that engineering education becomes more responsive to continual changes in society. We propose to address these challenges of improving engineering education through the application of ontology and web semantics. These fields of information technology allow computers to interpret the vast body of knowledge dispersed throughout the web. The long term objective of our research is to develop an ontological approach for improving curriculum in civil engineering as well as other fields of engineering. In the future, we envision that the curriculum information on university websites will be interpreted by computers through ontological tools for the ultimate benefits of students, educators and engineers. This paper reviews the background and premises of our research and summarizes some preliminary results about the application of ontological concepts for describing, analyzing and improving undergraduate programs in civil engineering. Future work will enhance curriculum using ontological tools using best-practice educational evaluation and accounting for NAE and ASCE recommendations.

## **Introduction**

This paper reports on preliminary results of a research that aims at improving engineering education through the application of ontologies and web information semantics. These fields of information technology aims at interpreting the vast body of knowledge dispersed throughout the web. Currently, the information on engineering curriculum web sites is heterogeneously organized with different terminologies. Presently when users want to request information from web sites, they issue a search using a word-based search engine (e.g., Google or Yahoo). The essential problem here is that searches are word-based, and the information is not clearly meaningful on the web sites. This is where ontologies effectively and practically describe information on web sites using a meaning-based as opposed to word-based approach. The objective of our research is to support the understanding and querying of the contents, relationships, and practices in engineering education, and to develop analysis, advisement and student performance assessment tools that facilitate the improvement of engineering education, and explore alternative delivery and content packaging strategies. Following the introduction, the first section reviews the background about engineering education; the second section defines the concepts of ontology and reviews ontological examples; and the last section presents some preliminary results.

## **Background**

In two recent reports<sup>1,2</sup> on engineering education, the National Academy of Engineering (NAE) raised the following question about the future of engineering: “What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession of 2020?” NAE recommends that research be

carried out for documenting engineering education. NAE states that “although progress is being made in engineering education, much remains to be done in developing research base underlying best practices in engineering education<sup>25</sup> and faculty practice generally<sup>1</sup>.” The educational reforms recommended by NAE are so pervasive that their implementation requires non traditional research with innovative approach.

ABET aims at ensuring the quality of undergraduate engineering science and technology programs through rigorous review and monitoring, and promoting leadership in applied science, engineering and technology accreditation. In 2001, ABET required that graduates must possess a set of hard and professional skills, which extend beyond the minimalist standard of engineering practice to include professional standards of high quality, multidisciplinary, global and collaborative focus<sup>23</sup>. There is a definite need for developing modern information tools that maps the extensive breadth and depth of curricular content so that students meet the ABET requirements.

Professional engineering societies such as ASCE have constantly revised their curriculum guidelines to assist educational institutions in preparing graduates for an effective practice of engineering responsive to the needs of the Nation. The ASCE vision for the future of Civil Engineering<sup>4</sup> can be found in the report entitled “The vision for Civil Engineering in 2025.” ASCE is energetically engaged in efforts to create better alignment between academic experience and anticipated future workplace requirements. ASCE collaborates with other professional organizations (e.g., IEEE) to offer “Excellence in Engineering Education” teaching workshop for engineering faculty. ASCE<sup>3</sup> supports the attainment of a “Body of Knowledge” for entry into the practice of civil engineering at the professional level. ASCE recommends the adoption of the following engineering education and experience requirements as a prerequisite for licensure:

- a baccalaureate degree,
- a master's degree, or approximately 30 coordinated graduate or upper level undergraduate credits or the equivalent agency/organization/professional society courses providing equal quality and rigor, and
- appropriate experience based upon broad technical and professional practice guidelines which provide sufficient flexibility for a wide range of roles in engineering practice.

NAE and ASCE concur that reforms in engineering education are necessary but complex endeavors in view of rapid changes in world economy and society, e.g., globalization. So far most educational institutions have responded to these challenging tasks with traditional approaches, which unfortunately have produced incremental and slow improvements. Reformers face often tremendous difficulties and even resistance in their attempts of modifying curricula that have been gradually perfected through years of incremental revisions. There is an urgent need for new information-based tools that simplify and accelerate educational reforms and allow educators to analyze and modify curricula at all levels down to course contents, delivery, and assessment of student learning. These new tools should also embody quantitative assessments on students' learning as developed in educational psychology. Recognizing that each institution favors their own solution, these new tools should be also versatile enough to adapt to all types of curricular information. As means of accelerating and enabling educational reforms, we propose to use ontology and web-semantics.

## Ontologies and Web Information Semantics

In response to present limitations in analysis techniques for natural languages and images, the middle-ground approach is to specify the semantics of information (a web site) through an ontology, i.e., a collection of concepts and inter-relationships at multiple levels of abstraction. If a curriculum web site is described using an ontology, it can be explored and queried at much higher levels. For example, a civil engineering website may contain the concepts of bridges, with sub-concept suspension bridges. Through interfaces that allow probing ontologies, users can request the desired information. A key hypothesis is that such a higher-level of access can greatly increase the accuracy of the information obtained, as well as the discovery and exploration of conceptual connections across web sites for different departments within a single university, and even multiple universities.

The idea of specifying the semantics of information is a classic line of research in the areas of data-base systems and knowledge representation. In particular, relational database technology was devised in the 1970s, implemented in the 1980s, and is now the dominant manner of organizing structured information. Here, information is organized in tables with fields (i.e., columns), with common values in different columns of tables establishing inter-connections. While simple, and useful for structured data, relational technology has little support for describing the meaning of the data in a way that allows users to discover and easy query it. Object-based technology<sup>13,21</sup> goes a step further in specifying the meaning of data, by defining classes (kinds) of information units (objects) and their inter-relationships. It also supports such semantic notions as subclassing (specialization) and inheritance. (For example, if “suspension bridges” is a subclass of “bridges”, then since all suspension bridges are bridges, relationships are inherited from “bridges” to “suspension bridges”). Object-based technology along with knowledge representation techniques from Artificial Intelligence have led to the state-of-the-art of ontology specification – which is what we intend to utilize in this project.

Within the development of web technology, it was recognized that data/information/semantics had to be represented. A multi-level approach is used. The bottom level is the eXtensible Markup Language (XML) (<http://www.w3.org/XML/>), which has become a standard for exchanging data over the internet. XML is a meta-markup language that supports that syntactic structure of data elements, as well as inter-relationships among those elements. On top of XML is the Resource Description Framework (RDF), which provides for triple <subject, predicate, object> representation of semantics<sup>16, 7</sup>. OWL sits on top of RDF, provides additional modeling features, and in its full form also supports inferencing<sup>17, 19</sup>.

Key to this project is a tool that specifies evolving ontologies, and supports information discovery and queries, i.e., Protégé<sup>20, 11</sup>. Protégé is open-source software which can be extended with plug-ins. Protégé has visualization tools for web-ontology applications (e.g., TGViz and OWLViz), and exports data into various formats, e.g., XML, RDF, and OWL. Protégé also supports the design of forms and templates to input data and query subsets of data. Table 1 lists of few examples of ontologies developed using Protégé. Figure 2 displays the objects and relationships of the Science Ontology<sup>10</sup>, which models scientific and educational events, e.g., scientific conferences, research projects, and software development projects. As shown in Figure 2, a project relates to other objects, including people, organizations, products and events. In

addition to the examples of Table 1, there are several relevant ontology efforts. Ontologies were used for handling complicated construction management applications<sup>24</sup>, for improving communication between educational repositories<sup>8</sup> and for describing IT education goals<sup>14</sup>. However to our knowledge, ontologies have not yet been applied to describe, analyze and improve curricula and practices in engineering education.

Bardet et al.<sup>6</sup> proposed an ontology for describing the experimental processes in earthquake engineering in response to the needs of the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) of the National Science Foundation. NEES was created to improve our understanding of the effects of earthquakes. NEES is a national network of 15 experimental facilities, collaborative tools, and a centralized data repository. Together, these resources provide the means for collaborative discovery of the ways buildings, bridges, utility systems, and soils perform during earthquakes. A federation of ontologies was developed to access various geo-seismic information for simulating and forecasting programs<sup>9</sup>. Comparing and integrating ontologies created for different applications is an important and key problem<sup>5,12</sup>.

Table 1. Examples of ontologies created with Protégé  
(<http://protege.cim3.net/cgi-bin/wiki.pl?ProtegeOntologiesLibrary>)

- amino-acid.owl: amino acids and their properties.
- BreastCancerOntology: describe some features of Breast Cancer.
- fgdc-csdgm.owl: Content Standard for Digital Geospatial Metadata (CSDGM) of Federal Geographic Data Committee (FGDC).
- Infrastructure Product Ontology: utility infrastructure products, their attributes, mechanisms, and measures. Products span all five sectors of utilities (Water, Wastewater, Gas, Electricity, and Telecom).
- NCI Thesaurus: A huge ontology developed by the National Cancer Institute (NCI).
- OGC: Ontology for Geography Markup Language (GML3.0) of Open GIS Consortium
- Cardiology.owl: present various disease of cardiology, their symptoms, test and complication.

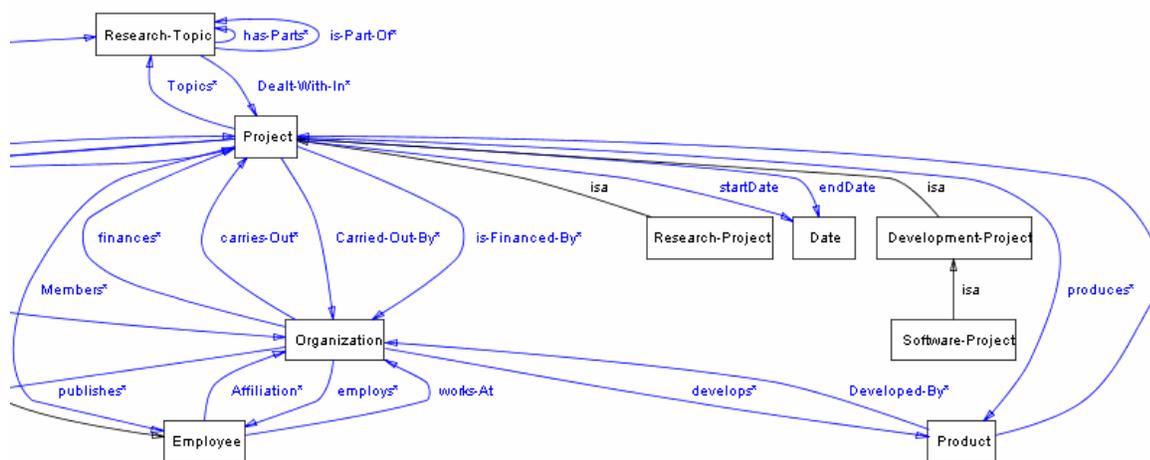


Figure 2. Representation of Science Ontology<sup>10</sup>

## Illustration of needs for ontological approach in engineering education

The need for developing an ontological approach for engineering education can be justified using a particular example relevant to engineering curriculum. The example, which is presented hereafter only for the purpose of illustration, consists of searching several university websites to answer the following question: “*What are the prerequisites for taking an introductory undergraduate course in dynamics?*” This question could be prompted by a group of faculty members during curriculum revision, or by students inquiring about their qualification for a particular engineering program. Table 2 shows the results of systematic searches using a leading search engine, e.g., Google. It contains the results of systematic queries through the academic websites of the top ten engineering schools. Advanced features of Google were used to restrict the search domain to the university domain as specified in Table 2. The keywords used in the search were “dynamics + course + catalog + prerequisite + civil.” Table 2 lists the number of pages that were found, sorted according to their relevance, and the number of pages that had to be visited subsequently to the Google search to access the desired information. All searches fail to get to the desired information in one step. Additional steps guided by subjective intuition were required to discover the pages or documents that had the most likelihood of containing the desired information. Table 2 also contains the time required to access the desired information. In summary, the information is available on university websites but can only be accessed through time-consuming manual navigation and guessing. It was found beyond the reach of automatic search engines.

Table 2. Examples of word-based search in university websites.

University Name	URL	Number of Results	Time Spent (min)	Number of Search Steps	Course Found	Prerequisites
Massachusetts Institute of Technology	mit.edu	68	10	4	1.053J Dynamics and Control I	8.01, 18.03
Stanford University	stanford.edu	38	>5	3	ENGR15 Dynamics	None
University of California–Berkeley	berkeley.edu	81	5	2	125 Structural Dynamics and Earthquake Engineering	122 or 123 and 121
Georgia Institute of Technology	gatech.edu	43	5	2	CEE2040 Dynamics	COE2001
University of Illinois–Urbana-Champaign	uiuc.edu	118	5	2	CEE472 Structural Dynamics	TAM212, MATH385, 360
Carnegie Mellon University	cmu.edu	35	10	3	24-351 Dynamics	None
California Institute of Technology	caltech.edu	56	5	2	AM/ME35 abc Statics and Dynamics	Ma1 abc, Ph1 abc
University of Southern California (Viterbi)	usc.edu	23	5	2	CE325 Dynamics	CE205
University of Michigan–Ann Arbor	umich.edu	69	>15	6	CEE211 Statics and Dynamics	Physics 140 I, II
Cornell University	cornell.edu	48	> 30	3	ENGRD 203/ T&AM 203 Dynamics	ENGRD202

## Potential advantages of ontological approach for engineering education

Users (e.g., faculty, current or prospective students) can get much more appropriate and complete results about particular inquiry on curricula when curriculum materials (e.g., in Civil

Engineering) is described using a “domain” ontology. There are essentially two ways for ontological information to yield more relevant and accurate information. First, user requests may be formulated through a word-based search engine (e.g., Google or Yahoo), and “enhanced” using the domain ontology, resulting in much higher accuracy in the results. Here, we can use a lexical ontology to accommodate synonyms, e.g., Wordnet. This approach was applied by Khan et al.<sup>16</sup> for a collection of closed-captioned audio clips; they showed 30%-70% increase in F-score (the harmonic mean of precision and recall – a common metric of retrieval accuracy). For example, if a user entered “dynamics + course + catalog + prerequisite + civil”, we would not utilize a Google/Yahoo type search, but rather use information in the domain ontology to modify the user request before presenting it to Google or Yahoo. By doing so, the accuracy of the result can be significantly increased. We will be conducting experiments with this approach for our curriculum information, and expect 30%-70% increase in result accuracy. A second way in which we can utilize the domain ontology is to conduct a “semantic search.” Here we provide a search interface in which the user does not enter a sequence of words, but rather is presented with a top-level view of the domain ontology (what information is available), and can look at the relationships between concepts and indicate which ones are of interest. The user can also traverse the ontology, for example looking at more specific concepts. A graphical interface is best for doing this, given that ontologies can easily be presented as semantic graphs. In our example, the user would look at the Civil Engineering curriculum ontology and see the concept course and that it has a relationship with other courses that are prerequisites. The user sees that course relationship with the topics concept. They then enter the topic “dynamics”, and a semantic search is performed, returning precisely the facts specifying the prerequisite courses for all courses whose topics include “dynamics”. This is essentially analogous to a structured database search, where the database is semantically structured by the ontology. In this case, we get a very significant increase in accuracy; so that accuracy would likely be in the high 90%. We plan to experiment with the above approaches, providing both and allowing users to try them, along of course with a traditional word-based search option. We will record the results (anonymously), and will analyze and compare the effectiveness of the two ontology-based approaches with the word-based approach, and with each other. In the past, this approach yielded successful results in many areas other than engineering curricula (<http://www.swoogle.com>).

## **Preliminary Results**

One of the advantages ontological tools is their ability of integrating concepts from educational psychology, such as embedded signature assignments/assessments (ESAs) and research based evaluation methods. ESAs are signature or primary assignments that address the essence and primary goals of each course in a comprehensive manner<sup>18</sup>. They combine an assignment with a quantifiable assessment that allows engineering educators to assess student learning. ESAs include course projects, concept inventories, vignette assignments, concept maps and comprehensive examinations.

Our research intends to develop an ontology for engineering education including curriculum (e.g., courses, topics and concepts), delivery techniques (e.g., advisement, ESAs including problem based vignettes, homework, exams, concept inventories, concept maps and course projects), and evaluation methods (e.g., grades, exit surveys, concept inventories, rubric judged projects, and course evaluations). The ontology is being designed using the open-source software

Protégé. The ontology will describe curriculum contents, educational practices, ASCE body of knowledge, students and instructors. At the present, we have considered the following kinds of objects:

- Programs, courses, topics, concepts, and lecture examples;
- Mechanisms of program and course delivery, e.g., schedule, advisement, lectures, laboratory, discussion, instruction, examination, and projects
- Grading systems, administrative monitoring, satisfaction survey, and EIT exam results
- Students going through a four-year BS program
- Instructors, advisors and administrators
- ASCE body of knowledge, and ABET requirements.

Table 3 and Figure 4 depict a preliminary ontological model for engineering education, which displays objects and relationships. This preliminary model, which is presented for the sole purpose of illustration, will be built up by trial and error to ensure it is logical, unambiguous, usable, and accepted. The preliminary model of Table 3 has 8 main object types, namely *Program, Course, Topic, Department, School, Instructor, Advisor* and *Student*. Each object type has specific attributes that characterizes objects instances. Table 3 lists only a few attributes, and is by no mean exhaustive. For instance a Program has goals and total number of units. The key components of the models are relationships; they enable connections between object instances, i.e., are bridges which support the traffic of queries. For instance, *hasForPrerequisite* and *isPrerequisiteOf* are two relations that apply to courses; they work in inverse direction of each other. These relationships would be extremely useful to define all the prerequisites, at different depths, of a particular course. The relations *hasForPart* and *isPartOf* would allow to ad to this search all the topics covered in the prerequisite of this course.

Table 3. Preliminary objects and relationships of proposed ontology

Object	Description	Relationship	Inverse Relationship	Attributes/ Properties
Program	A sequence of course with a specific goal	hasForCourses hasForTopics hasForRequirements isAdvisedBy	IsCourseOf isTopicOf isRequirementOf Advises	TotalUnits Goals
Course	A collection of topics	isTaughtBy hasForPrerequisite isEquivalentTo isStudiedBy isPartOf	Teaches isPrerequisiteOf Studies hasForPart	SemesterTaught Duration Schedule Units
Topic	Part of a course	isPartOf isEquivalentTo	hasForPart	Duration
Department	Academic unit	hasInstructors		
School	Group of departments	hasDepartment		
Instructor	A person teaching courses	Teaches isInstructorOf		HighestDegree YearExperience PersonAttributes
Student	A person taking courses	Studies sAdvisedBy		
Advisor	A person	Advises		PersonAttributes

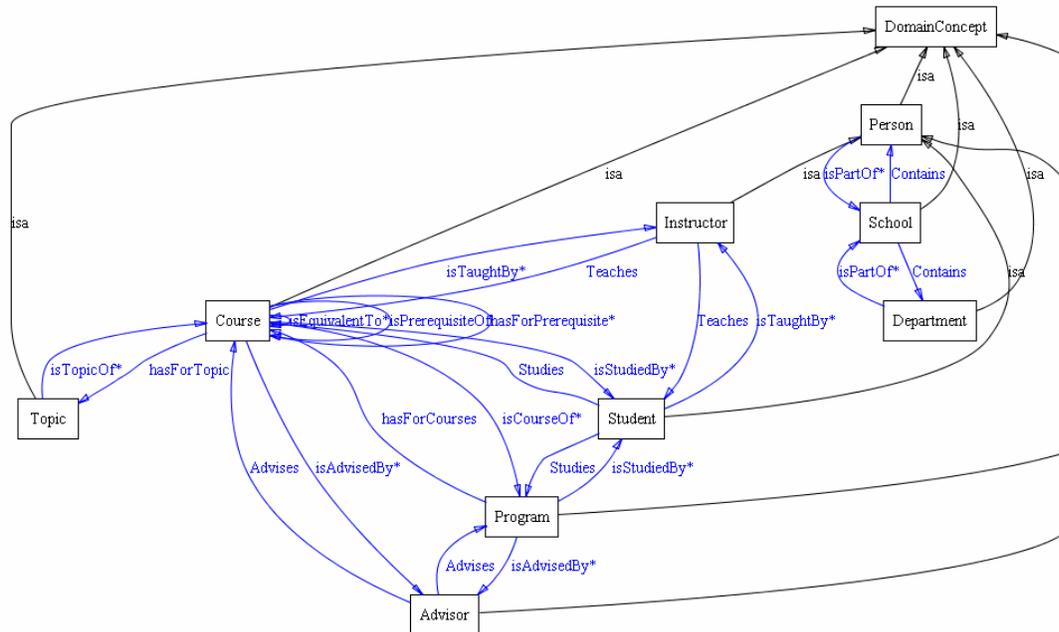


Figure 4. Preliminary ontological model of engineering education represented in Protégé (The symbol “\*” indicates inverse relations).

## Future Work

So far we have just started to populate the preliminary ontological model with instances. The course and program contents are being extracted from the information available from university catalogs, promotional brochures, course syllabi, advisement forms, curriculum change petitions, and other information posted on the CEE web site: [http:// www.usc.edu/cee](http://www.usc.edu/cee).

The next task includes developing Protégé software tools that depict comprehensively a Civil Engineering curriculum to students, instructors, advisors, and administrators. Protégé can be extended to visualize specific issues, e.g., course dependencies, prerequisites, and relation to ABET requirements. Specific Protégé adaptations will be carried by implementing widgets and plug-ins, i.e., Java extension to Protégé<sup>26</sup>. In this research, we specifically intend to support information access in several manners. (1) One can navigate through the ontology, and identify relevant kinds of objects and inter-relationships; specific instances can then be accessed – such instances will be presented with an associated measure of semantic relevance, determined by the degree to which the instances match the desired result. (2) One can issue a word-based information request, in which case the tools we develop will utilize the ontology to disambiguate the request, and do an ontology-enhanced word-based search; the results presented will again be presented with an associated estimate of semantic relevance. (3) The ontology can itself be used for study and analysis – it can be evolved dynamically to reflect new or modified ESAs, explore alternative delivery paradigms, etc.

## Conclusion

We have reported some preliminary results of a research that aims at improving engineering education through the application of ontologies and web information semantics. Using these

fields of information technology, we anticipate analyzing and applying the information on engineering curriculum web sites, which has been so far heterogeneously organized with different terminologies. Ontological tools will facilitate the (1) extraction and analysis of a large amount of complicated information dispersed through university websites, and (2) the incorporation of the knowledge of educational psychology about best-practice in curriculum development and delivery mechanisms (e.g., vignette), and assessment tools for measuring effectively students' learning (e.g., concept inventory).

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