Generic Educational Knowledge Representation for Adaptive and Cognitive Systems

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ABSTRACT

The interoperability of educational systems, encouraged by the development of specifications, standards and tools related to the Semantic Web is limited to the exchange of information in domain and student models. High system interoperability requires that a common framework be defined that represents the functional essence of educational systems. To address this need, we developed a generic model of educational systems that we called Cognitive Ontology of Educational Systems (COES) and we encoded it as functional reference ontology. It generalizes the educational system architecture, taking into account the cognitive perspective. This framework ranges from the usual e-learning systems to complex cognitive and adaptive hypermedia systems. This article describes the part of the COES related to domain knowledge representation and proposes an implementation called Generic Educational Knowledge (GEK). The GEK model is structured in a flexible way that allows the authors to codify instructional and semantic levels as needed. In order to test its feasibility, the model was applied in a distance learning course using two educational-knowledge models, GEK and ADL-SCORM, and two educational systems, a traditional Web-Based Adaptive Hypermedia System and a Rich Internet Application with dialog interaction and cognitive monitoring.

Keywords
Intelligent educational systems, Cognitive systems, Knowledge representation, Domain model

Introduction

The development of specifications, standards and tools related to the Semantic Web (Hendler, 2001; Dolog & Nejdl, 2007) has led to the development of ontologies with the objective of globally interconnecting knowledge. Applying this knowledge to education requires the development of browser technologies that automatically filter knowledge in order to generate an appropriate offer for each educational objective. Existing e-learning management systems (LMS) use instructional knowledge coded with different levels of granularity and associated with multimedia resources such as ADL-SCORM or IMS-CC. However, research and development centers propose adaptive models that range from basic instructional rules to implicit and complex representations related to the needs of each particular implementation. Currently, efforts are focused on the creation of models, specifications and standards that increase computational integration (Kozaki, Hayashi, Sasajima, Tarumi, & Mizoguchi, 2008; Dietze, Gugliotta, & Domingue, 2007; De Roure & Hendler, 2004) using ontologies (Gaeta, Orciuoli, & Ritrovato, 2009; Žitko, Stankov, Rosić, & Grubišić, 2009; Iositani & Mizoguchi, 2008; Boyce & Pahl, 2007; W3C, 2004) in what is called the Intelligent/Semantic Web (Devedzic, 2004; Zhong, Liu, & Yao, 2002) or Web3.0 (Zeldman, 2006).

This approach leads to the emerging paradigm of open-corpus knowledge (Sosnovsky, 2009). It offers a wealth of knowledge described at a semantic level to educational systems, which greatly improves the capabilities of automatic systems. However, the interoperability of learning platforms is restricted to the exchange of information in domain and student models that follow specifications. We believe that the interoperability of educational systems on the Grid requires a framework to facilitate interaction at a functional level and to overcome the limitations of the specifications. The LTI project (IMS, 2009) is an example of such efforts.

Work on Intelligent Educational Systems (IESs) is traditionally divided into two main paradigms (Nicholas & Martin, 2008): Intelligent Tutoring Systems (ITSs) (Murray, 1999; Wenger, 1987) and Adaptive Hypermedia Systems (AHSs) (Dolog, 2008; Brusilovsky, 1996). The former are designed to guide students in acquiring specific skills to complement the primary instructional method and use Constraint-Based Modeling from Ohlsson's theory. The system works by correcting the learner’s practice errors and guiding him/her to improve; the WETAS system is an example (Martin, Mitrovic, & Suraweera, 2008). AHSs, in contrast, are directed to a complete theoretical instruction through learning concepts. They use intelligent systems to adapt the sequence, presentation and contents according to the student model. New educational systems incorporate the latest advances in cognitive science. Some of them employ estimated cognitive parameters of learning, while others develop computing architectures that
simulate the mental processing of students. Cognitive control is the ability to integrate information from a multitude of sources and use that information to flexibly guide behavior. From the characteristics described above, we developed a framework for educational systems called the Cognitive Ontology of Educational Systems (COES) whose main objective is to provide functional interoperability. The teaching-learning process is a complete and indivisible entity in which numerous real and abstract elements are artificially bound together by functions in different areas: emotional, cognitive, instructional, behavioral, etc. The traditional IES architecture (De Bra, Houben, & Wu, 1999; Murray, 1998) has kept a functional division in which a processor uses the rules of a pedagogical/adaptive model to select content from a domain model. However, many systems encode pedagogical models through specific operational rules within the domain model. In the COES proposal, we group the two models into one domain called the educational domain. Within the architecture of the three domains shown in Figure 1, the interaction domain facilitates communication with the user and agglomerates the user interface and the control unit. The educational domain encodes knowledge involved in the teaching-learning process; and the personal domain estimates the characteristics and state of the student and simulates his behavior.

Figure 1: Domain division in COES

In section 2, we describe the part of the COES model related to the educational domain and propose a framework of the educational domain that is compatible with traditional models and that incorporates the cognitive point of view. In section 3, we analyze the different ways of encoding educational knowledge and propose a model called Generic Educational Knowledge (GEK), which is compatible with the COES framework. Section 4 describes the results of a distance learning course supported by two COES-compatible educational systems that use two ways of representing the educational knowledge: GEK and ADL-SCORM.

Educational Domain

The essential part of the teaching-learning model is the educational domain, which is responsible for the stimuli generated toward the student to properly modify his cognitive state. All intelligent educational systems incorporate an educational domain that determines its scope and the process effectiveness. Usually the educational domain is divided into two parts: one represents the target knowledge of the learning process and is called domain model, and the other defines rules or procedures governing the process and is called the pedagogical/adaptive/operational model. We elaborated on an ontology named the COES which aims to homogenize and generalize the architecture of IES into the cognitive point of view, extending models like AHAM (De Bra, Houben, & Wu, 1999), Munich (Koch & Wirings, 2002), GAF (Knutov, 2008), OMNIBUS (Hayashi, Bourdeau, & Mizoguchi, 2008) or ODAS (Tran, Wang, Lamparter, & Cimiano, 2008). In this regard, we have grouped these modules into one, because they are very strongly related, and in many cases, the representation is a single one. Figure 2 shows the class diagram of the COES educational domain.

The main part of the educational domain is the internal representation of educational knowledge. This knowledge is the perceptual-semantic device that teachers use to influence student cognitive states. Therefore, it will always be a structure of media resources linked in some way with a conceptual meta-structure. In order for the system to have the versatility that the teaching-learning process requires, the educational knowledge representation should have some of the following characteristics: categorized, structured, coherent, continuous, adaptive, regulated, reusable and interoperable.

The teaching process is limited to the presentation of adapted sensory stimuli to the student. These stimuli are dynamically generated or selected from a set of Educational Resources (eRs). An eR is composed of a sequence of instructional actions with implicit learning processes involved. These vary from the presentation of text, image and sound stimuli to simulators, chats and shared applications. The selection procedure of eRs is based on metadata parameters, especially on pedagogical features that are specified in the resource type (channel, audience, strategy…).
Following the above recommendations and the educational models analyzed, in the COES we suggest a traditional knowledge representation based on a network of *Educational Knowledge Nodes* (EKNs). They are structured in a network of nested elements using *Educational Knowledge Relations* (EKRs) that may point to other nodes (EKNs) or resources (ERs). The network generates a meta-structure of ERs that systems display in the user interface to act on the learner’s cognitive state. The structure’s granularity and complexity level depend on the degree of inclusion of some nodes into others.

The proposed COES educational knowledge spans from simple resources associations to more complex representations in a semantic network. It is more generic than common specifications like ADL-SCORM and IMS-CC but is compatible with them. The main difference is that an EKN makes it possible to establish relationships between all levels: didactic, instructional, conceptual, competence, and so on (see next section). This way, designers can codify educational knowledge as symbolic as they consider making knowledge structure more stable and letting it remain unchanged in each instructional session. We could say that traditional models allow the representation of domain contents, while the COES model facilitates the encoding of domain knowledge.

In order to update and keep track of the student’s knowledge you need to establish a link between the educational and cognitive domains. In the COES model, this relationship is made by *Cognitive Sentences* (CSs). These are descriptions of the cognitive state that are processed when the student plays an educational knowledge node (EKN). In other cases, these sentences work as prerequisites for the activation of an educational node. Cognitive sentences are an implementation form of *Insights* (Ausubel, Novak, & Hanesian, 1983), *Chunks* (Anderson & Lebiere, 1998) or *Propositions* (Pozo, 2003). They make cognitive changes and, in doing so, should manage certainty measures.

Teachers use the educational knowledge of a particular domain together with a meta-knowledge that encodes pedagogical skills for process controlling. This pedagogical knowledge represents instructional principles such as positive reinforcement, variability, action, etc., that facilitate the proper selection and sequencing of contents. It is a type of procedural knowledge based on *Pedagogical Regulators* (PRs) that controls the process, reading information from the emotional, characteristic and instructional domains. Common IESs implement an explicit pedagogical knowledge just as expert systems do using PRs called logical rules. However, there are other valid implicit representations such as neural networks, in which the PRs are called nodes, artificial neurons, and so on.

The control of the educational domain is performed by the *Educational Processor* (EP), which receive actions from the interaction domain and generate a response by consulting the emotional, characteristic and cognitive states. The educational domain communicates with the interaction domain through a language based on elements called *Educational Actions* (EAs): show content, reply, consult, advise, motivate, evaluate, and so on.

The operation of the educational processor requires the maintenance of a working memory that records the educational strategies and techniques being used and the states of active educational resources (ERs) and nodes (EKNs). The processor consists of three memory subsystems: *Educational Domain Stable Memory* (ESDM) a long-term declarative type that records the domain knowledge; *Educational Pedagogical Stable Memory* (EPSM) a long-
term procedural type that works with process regulators; and *Educational Temporary Memory* (ETM) a short-term declarative type that keeps process states. An *Educational State* (ES) collects all information about the activation of a node (KN) for a student during an instructional session. The state is the sum of *Educational Features* (EFs) such as: repeated, read, viewed, known, evaluated, learned, strategy used, etc.

**Generic Educational Knowledge**

The educational domain handles transmitter-knowledge used by a teacher in his activity, whereas the cognitive domain tries to represent transferred-knowledge in the learner model. Usually, many ways exist to explain the same concept; therefore educational knowledge is an explicit temporal representation of the content created by a teacher to deliver a piece of knowledge at the cognitive level. It could be said that the cognitive domain deals with Thinking-oriented Knowledge (ToK) while the educational domain works with Learning-oriented Knowledge (LoK). Knowledge representation uses conscious/explicit/symbolic elements that facilitate logical reasoning and unconscious/implicit/subsymbolic elements related to automated processing. This division should also be implemented in the educational and cognitive domains through several levels as Figure 3 shows. Educational knowledge is codified in didactic elements that contain instructional resources and activities. It is explicit and works sequentially. Knowledge in the cognitive domain depends on the features of the internal processors in the human mind and it works in parallel. It is associative-implicit and codified in conceptual elements based on perceptive parameters.

![Figure 3: Knowledge comparison: ToK - LoK](image)

In this work, we put forward a flexible educational knowledge representation, directly linked to the cognitive domain, which facilitates student tutoring and monitoring. It is stored in a knowledge base, and it is encoded at different levels that determine the control possibilities of the teaching and learning. The level of representation establishes the features of the control variable and affects the pedagogical/adaptive capacity of the system. Figure 4 summarizes the different views of the educational knowledge representation from the physical level to the logical one (Chi, 2009; Benyon, 1993), and their connections with learner monitoring.

The resource layer is the basic representation needed for educational system operation. The granularity scale and the encoding format of resources are the main factors that determine the adaptation possibilities of the presentation. Many systems incorporate a level of specification called didactic/instructional to extend the adaptability to the sequence. This layer defines the methodology of the instructional process through a hierarchy of contents and activities with structural relationships, as in RLATES/IGNATES (Iglesias, Martínez, Aler, & Fernández, 2008) or ZOSMAT (Keles, Oacak, Keles, & Gürçü, 2009). This level of specification usually incorporates prerequisites rules that determine the instructional flow (Gagné, Briggs, & Wagner, 1988) as in SmartTutor (Cheung, Hui, Zhang, & Yiu, 2003). Furthermore, the resource adaptability is achieved through flexible links between instructional elements and the assets that map them.
Because there are many instructional ways of presenting, structuring and teaching the same concept, systems establish a higher level of representation to unify student tracking, which we call the competence layer, where learner knowledge and the skills to achieve are specified. At this level of representation, instructional elements known as LO (Learning Objects) exist, such as IEEE-LTSC, ADL-SCORM (ADL, 2004), IMS-LD (2003), IMS-CC (2008), RLO (CISCO Systems, 2003), ePack-Blackboard and specifications as LMML (Süss, 2001), LAMS (LAMS Foundation, 2002) adopted by Moodle, PALO (Rodriguez-Artacho & Verdejo, 2004) and the ALOCoM model (Verbert, Duval, Meire, Jovanovic, & Gasevic, 2006). This object package is a set of structured resources, metadata described, with an implicit methodology and learning objectives. Such objects improve the learning process by distributing and sharing instructional resources. However, they are not being used as expected, probably because of the lack of consensus on a common core ontology (Balatsoukas, Morris, & O’Brien, 2008) and the viability of many proposals. The LAOS model (Cristea & De Mooij, 2003) is an example of this level of representation.

Competencies and objectives are artificial taxonomies related but not equivalent to the real knowledge. To improve monitoring of the student’s cognitive skills, authors establish a new layer where knowledge is represented at the conceptual level. Samples of this layer can be found in the AIMS system (Aroyo, Mizoguchi, & Tzolov, 2003; Aroyo, Denaux, Dimitrova, & Pye, 2006) and the TEx-Sys system (Stankov, Rosic, Zitko, & Grubisic, 2008).

Ontologies and concept maps, disciplines that facilitate knowledge representation at the semantic level, have become ones of the development lines of educational knowledge encoding in recent years (Chi, 2009; Martin, Mitrovic, & Suraweera, 2008; Boyce & Pahl, 2007; Coffey, 2007; Devedzic, 2006), especially in application to the Semantic Web (Berners-Lee, Hendler, & Lassila, 2001). This conceptual-semantic way of representing the domain model are used in the proposal of (Papasalouros, Retalis, & Papaspyrou, 2004), the Inca architecture (Nabeth, Razmerita, Angehrn, & Roda, 2005), the CAM (Hendrix, De Bra, Pechenizkiy, Smits, & Cristea, 2008) and Hera (Houben, et al., 2008) models, and the IWT (Gaeta, Orciuoli, & Ritrovato, 2009) and ICDS (Lee, Lee, & Leu, 2009) systems.

The representation of educational knowledge directly determines the capacity of IESs. Basic systems represent knowledge in a single asset that implicitly encodes the didactic, methodological and cognitive structure. Monitoring, if it exists, is limited to logging the inputs and resource access times. Advanced systems use cognitive recording (what has been learned) and instructional tracking (what has been done). In those systems, knowledge is encoded in a highly fragmented way, interlinked and metadata described. Knowledge components are organized into complex didactic, competence and conceptual structures so as to improve the monitoring and allow the adaptive process of dynamic content generation; they clearly distinguish resources from their organization and use.
The more representative educational systems share a common domain model structure with a number of specification levels. Depending on the needs of the system (Chi, 2009; Sosnovsky, 2006; Aroyo, Mizoguchi, & Tzolov, 2003) we find the following: the physical/perceptual layer of resources, the instructional/didactic layer, the methodological layer and the semantic layer. Sometimes, several optional intermediate levels of representation are inserted to facilitate system processing, as shown in Figure 5.

Following the suggested COES and the structural scheme (Figure 5), we propose a Generic Educational Knowledge (GEK) mapped into an eKN/eKR network as show in Figure 6. It is organized from the top abstract elements called the nucleus to the bottom specific resources. Every relation can point to a specific node or can include a selector script that allows searching for the appropriate node from databases or remote repositories. In addition, relations may incorporate a filter to select parts of the referenced node.

![Figure 5: Levels of educational knowledge representation](image)

Learning content specifications like ADL-SCORM (ADL, 2004) or IMS-CC (2008) are based on independent and interchangeable objects or packages that encode one or more ways to teach-learn something. However, we have opted for a closer representation to the cognitive domain, so that when the system detects a deficiency in the student cognitive state, it may resort to the educational domain. Furthermore, each educational node (eKN) is not a complete and independent object that can be packaged and shared with all its functionality. Frequently, following the open corpus trend, educational nodes include flexible relationships that refer to items with certain parameters that must be sought outside the node coding itself. This ensures that knowledge is organized with a higher semantic charge, adaptive capacity and component reusability.

At the highest semantic level of the educational knowledge structure is a collection of nodes called the SEN (Semantics and Epistemological Nucleus). These elements can be conceptual nodes or didactic-structural elements that teachers create to facilitate the learning process. They are identified by a globally unique identifier and metadata, which are used to construct flexible links. The metadata includes information about type (conceptual/didactic), title, abstraction level and keywords. A SEN is equivalent to the class/entity of different modeling forms of didactics and semantics. SEN content is defined by **Semantic Relations** with other SENs. They are used to establish subordination, generalization and combination with other SENs to express WhatIs, WhatHas, WhatHappens, HowWorks, HowIsMade, and so on. SENs are complemented with both teaching (how to explain) and perceptual (how to show) information. This information is linked through **Instructional Relations** that establish the function (Guidance/Introduction/Content/Documentation/Assessment) of a node in the lower levels.
The methodological layer is composed of methods and activities packed in PROCESS nodes. Each of the nodes encodes a specific way of teaching/learning the meaning of its parent SEN, and so they resolve the need for different ways to teach/learn the same concept to extend the acting capabilities in the scope of multiple intelligences (Gardner, 1993) and to enable the SEN adaptive processes to the learner. For example, authors could plan a learning process that follows Bloom’s levels progressively through the selection of the corresponding PROCESS (Hwang, Wang, Hwang, Huang, & Huang, 2008). The definition of PROCESS nodes could include prerequisites and metadata that allow database searching through type, instructional method, student characteristics, teaching strategies and keywords. They are encoded as a flow of ACTIVITY nodes that controls the presentation sequence of the environments that interact with the student. PROCESS activation runs in a hierarchical space through Action Relations coded in terms of predecessor-successor. Depending on the activity type, the interaction can occur from the resources to the student (presentations), between the student and the resources (documents), between the student and his classmates (discussion) and between the student and the system (tutoring). When an ACTIVITY node requires the use of assets, it includes Content Relations with nodes in the lower layers.

The content layer consists of didactic structures (Documents/Presentations/Questionnaires...) defined by ORGANIZATION nodes, which are equivalent to Organization elements in ADL-SCORM or Environment nodes in IMS-LD. Each ORGANIZATION contains instructional elements called STIMULI that interact with the student to achieve an educational objective. Sequence Relations define the clusters, the order of presentation, the activation conditions and the estimated duration of the referred stimuli. A stimulus is a set of physical resources (text, image and sound) that follow educational goals to change the student’s cognitive state. They are equivalent to the Item elements of ADL-SCORM and can incorporate tracking options such as SCOs (Sharable Content Objects) or simply be presented as an asset. Cognitive and aptitude monitoring is implemented through Cognitive Sentences (CSs) that trigger when a student successfully completes an ACTIVITY or a STIMULUS. They can record new knowledge to the student’s cognitive domain or change the certainty of existing knowledge.

Distance learning has usually made available to the student a set of continuous learning resources (documents, presentations, videos, animations and simulations) and discrete resources (texts, graphics, links and images) (Verbert & Duval, 2004). Resources are located at the lower material level of the educational knowledge structure to interact with the student to transfer knowledge. Educational resources are increasingly specified by soft links (Brusilovsky & Henze, 2007) that allow them to be searched, filtered and selected from large and dynamic repositories using metadata such as type (exercise, questionnaire, diagram, graph, table, text...), format, language, difficulty, etc. (see IEEE-LOM).

Educational knowledge elements (except resources) encode data, but not its interface instantiation. Any node that can be shown on the user interface may include Presentation Relations with resources, such as backgrounds, icons, titles, covers, etc., to make it more intuitive and adapted to the learner’s style.
The creation of a GEK base usually begins with a source document located in the bottom psychical/material layer. This is broken into subdocuments that are structured by creating nodes in the upper levels. In some cases the process is reversed; for example, authors can begin with an ontology that is supplemented with new relations to the nodes in the lower layers.

Educational knowledge codification is achieved by any method that makes it possible to incorporate some elements into others. Implementation through a relational database improves query and update performance, compared to XML-based languages like RDF/OWL. We opted for a database for local educational nodes and an XML coding for the nodes in remote repositories (Figure 7). In any case, we can move from one encoding to another depending on the system needs.

![XML-encoded sample of a GEK node](image)

**Figure 7:** XML-encoded sample of a GEK node

### Evaluation

The GEK model was evaluated by an e-learning course in 2008 and 2009 about Web Design in the Teacher Training area. The course was worth one European Credit (ECTS) and held at the Institute of Educational Sciences in the
Technical University of Madrid. To check the interoperability and effectiveness of the GEK model (Figure 8), we used two educational systems: an adaptive educational hypermedia system named TIX (eXtensible Intelligent Tutor) (Bravo & Caravantes, 2004) and a cognitive educational system called MAP (Adaptive Pedagogical Module). Both systems consult learning elements stored in a GEK repository about Web Design. As a reference model we used the same curriculum on Web Design encoded in SCORM1.2 LO hosted on Moodle. A total of 102 students applied for and attended the course in successive phases with different systems. However, only data from 87 students were used for the evaluation process because 15 students did not develop the commitment and continuity required. Of the 87 students in the evaluation, 17 students attended the course in Moodle, 25 in MAP, 29 in TIX and 16 in both MAP and TIX.

TIX is a web-based system that controls the teaching-learning process through the activation of links in the user interface. It consists of an http-server application that uses the GEK base to generate HTML pages with links adapted to the student (Figure 9). It combines the specific control instructions introduced by a human tutor during the learning process with the automatic control programmed into implicit pedagogical rules.

MAP is a Cognitive Tutor (Anderson, Corbett, & Koedinger, 1995) that aims to simulate the internal working of the student learning process, and thus increase the regulation scope that traditional AHS monitoring allows (Rodríguez & Nabeth, 2007). The system consists of two components, as shown in Figure 9: a web client that performs the slave interface function as an RIA (Rich Internet Application) and a master server in charge of the processing of the student interaction and tracking. Essential control and processing are performed in the server, whose architecture is based on simulator elements called mental processors. Each of them plays a functional simulation of a learner mental...
system in which, as illustrated by cognitive neuroscience studies, there are many highly interconnected and distributed subsystems. When a MAP server starts, usually triggered by an external signal, the main mental processor is instantiated and becomes the MAPTutor. Each time the MAPTutor identifies a new person during the interaction process, it creates another linked mental processor. When a learner disconnects, the MAPTutor removes the associated mental processor and stores its status in long-term memories.

The GEK base about Web Design (Figure 10) consists of 316 SEN nodes. Of them, 38 are conceptual nodes used as prerequisites and structured into 28 clusters, and 241 are conceptual nodes of 66 clusters that encompass the course concepts. The remaining 37 are didactic nodes that shape the course. Overall, the course handles 242 cognitive sentences, among which 166 are assessed. From the home didactic node of the course, systems analyze semantic information (Jovanovic, et al., 2007) and build two semantic knowledge bases of both the didactic and the conceptual type (Figure 10), which make up the educational domain of systems. The GEK base, SCORM objects and item bank were made by a teacher-author engaged full time for 3 months.

Following the GEK structure (Figure 6), the 278 SEN nodes that shape course knowledge are described by relationships with nodes at lower levels. The load of levels, summarized in Figure 11, shows a knowledge base that is balanced in content and material layers and shortly methodology described. The 0.22 methodology index is equivalent to having two methodology choices in one of nine SEN nodes.

Figure 10: Sample of a GEK representation about Web Design

Figure 11: The analysis index of the GEK representation about Web Design. The indices are calculated by normalizing relations with respect to the number of SEN nodes (278)
When a course begins, systems use assessment type relations of the GEK base to generate an initial questionnaire. The student's knowledge base is initialized with cognitive sentences associated with correct answers on the questionnaire. The TIX and MAP systems compare the course and student knowledge bases to personalize instruction. They make an open learner model interface (Bull, Ahmad, Johnson, Johan, Mabbott, & Kerly, 2008) with didactic and conceptual nodes that include the students’ learning scores so as to enable the students to adapt their learning process. Each node offers content, information and assessment links. The achievement of learning activities triggers cognitive sentences that fill the students' knowledge base and update the certainty degrees of learning. We created two complementary mathematical parameters for managing certainty: perception certainty (C_P) and knowledge certainty (C_K). The C_P of a STIMULUS node is updated according to the time spent (t_s) by the student and the estimated time (T_S) associated with the stimulus. According to the tests carried out there is a wide variability in the time spent by students on the same stimulus, estimated as ±2/3. The time conversion graph to C_P parameter is shown in Figure 12. It shows that when a student spends 1/3T_S, a C_P=50% is established, while a t_s greater than 5/3T_S generates a C_P=100%. Moreover, the C_K parameter combines C_P and the results of assessment activities. The C_P parameter is transferred to C_K in the range of 0–75% as Figure 12 shows. In addition, each positive assessment does increase C_P in 2/3 of the remainder to 100%. Thus C_K=75% represents the limit between the perceived state and the known state.

Students developed learning activities over 10–20 days. When all nodes of the student's knowledge base surpass C_K=75%, the system reports "course completed" and generates a final questionnaire. The results of the final questionnaire as a measure of academic performance (Figure 13) show significant differences between students that used a cognitive system (MAP) and those who attended the course through the Moodle platform. The results registered by students in the adaptive hypermedia system (TIX) fall among the others.

As an additional comparative variable we calculated the Instructional Effort as the average of the perception certainty (C_P) of the content nodes (no assessment, no practice, no information ...) viewed on screen (C_P ≥ 50%) and weighted with respect to their T_S. The results show significant differences indicating that students using the cognitive system (MAP) spent more time attending resources on the user interface than students in the adaptive hypermedia system (TIX).
Conclusions

In working with computers, system behavior depends on two main factors: architecture and content. In this article, we combined both factors and proposed two frameworks that shape the educational domain from the functional and knowledge representation views.

We described the educational domain of a reference ontology for educational systems that we call the COES. In addition we propose a reference model for generic educational knowledge called GEK that implements the COES and is compatible with the main specifications for e-learning like ADL-SCORM and IMS-CC. It supports a highly flexible representation by means of relationships between the elements in different layers, in an attempt to reduce the gap between existing LMSs, AHSs and the Educational Semantic Web.

The GEK model is based on two main layers that are pedagogically autonomous: a top semantic layer and a bottom material layer. The model is supplemented with two intermediate layers that explicate the educational information implicitly encoded in resources. These intermediate layers extend the possibilities of adaptive educational systems in the same way that digital systems increase the capabilities of analog systems.

The top semantic layer enables us to have an educational knowledge representation closer to the knowledge used by a human teacher that dynamically argues and generates the appropriate instructional interaction and selects the resources that best fit the educative strategy. Furthermore, the model is flexible and updatable; authors can dynamically include new information in the nodes at the corresponding level.

How the GEK model is used by educational systems depends on their capabilities, from the simple adaptation of presentation to the complex tutoring teaching at a cognitive level. We implemented the GEK model in two educational systems: a web-based adaptive hypermedia system (TIX) that controls link activation and a cognitive tutoring system with dialog interaction (MAP). The comparative analysis of the results (Figure 13) showed a higher instructional effort in MAP learners that led to a 12.8% higher academic performance than that found among users of the Moodle benchmark system.

The results obtained in the test course confirm the feasibility of the model. Educational knowledge in the GEK format allows a wide range of adaptive possibilities, depending on the coding effort made by the authors. It can be used indistinctly by different systems like adaptive hypermedia or cognitive systems. On the other hand, it supports encoding flexible links to distributed nodes and resources, following the open-corpus trend. It can also be interchangeably used in a wide range of educational systems that encourage the interoperability of systems and students.

We are now augmenting the descriptive burden on the semantic and methodology layers in order to extend the adaptive capabilities and enable direct semantic instruction without the use of physical resources.

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