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**Reference Model for Adaptive and
Intelligent Educational Systems supported
by Learning Objects**

Dissertation thesis

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CONTENTS

ACRONYMS

3PL	Three Parameters Logistic
AEHS	Adaptive Educational Hypermedia Systems
AHS	Adaptive Hypermedia Systems
AI	Artificial Intelligence
AIES	Adaptive and Intelligent Educational Systems
AIWBES	Adaptive and Intelligent Web-Based Educational Systems
ALS	Adaptive Learning Systems
AWBEHS	Adaptive Web-Based Educational Hypermedia Systems
CAD	Computer Aided Design
CAL	Computer Aided Learning
CAT	Computerized Adaptive Testing
DM	Domain Model
HS	Hypermedia Systems
HTML	HyperText Markup Language
ICT	Information and Communication Technologies
ICAI	Intelligent Computer Aided Instruction
ICC	Item Characteristic Curve
IRT	Item Response Theory
ITS	Intelligent Tutoring Systems
JSP	Java Server Page
LMS	Learning Management Systems
LG	Learning Goal
LO	Learning Object
LOM	Learning Object Metadata
SDG	Simple Directed Graphs
SM	Student Model
TM	Tutor Model
UML	Unified Modeling Language
XML	eXtensible Markup Language

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Reference model for intelligent and adaptive educational systems supported by learning objects

ABSTRACT

Computer Aided Learning, known more widely with the generic name of e-learning, has become a powerful tool with lots of potentialities within educational field. Even though, one of the main critics that it receives is that in most cases the implemented courses follows a *"one size fits all"* approach, which means that all students receive the same content in the same way being unaware of their particular needs. This problem is not due only to the absence of direct interaction between student and tutor, but also because of the lack of an appropriate instructional design.

There are several approaches which deal with this issue and look for adapt the teaching process to students. One could say that in the top of those approaches the Adaptive and Intelligent Educational Systems are situated, which merges the functionalities of two approaches: the Adaptive Educational Hypermedia Systems and the Intelligent Tutoring Systems. Nevertheless, after an extensive literature review, a major inconvenience is still found for this kind of systems and particularly for their reference models: or they are too simple, including just a few functionalities; or they are too complex, which difficult their design and implementation. Considering this panorama, the main objective of this dissertation thesis was the definition of a reference model trying to reach such an elusive equilibrium, in such a way that allows the design of courses which adapt themselves in an intelligent and effective way to the progress and characteristics of each student but without being too complex. Another important feature is that this model integrates Learning Objects, promoting this way flexibility and reusability.

In order to achieve this general objective, three sub-models were considered: a domain model, a student model and a tutor model. The first one serves to structure the knowledge domain and was defined using the notion of learning goal and a flexible multilevel schema with optional prerequisite operations. The second one aids to characterize students and considered personal, knowledge and psycho-cognitive information. The third one may be considered as the hearth of the system and defines the adopted adaptive functionalities: sequencing and navigation, content presentation, assessment, and collaborative support.

With the aim of clarify the three sub-models, as well as all their components and relationships, an instantiation example was also presented. Such an instantiation was called Doctus, an authoring tool for adaptive courses. Doctus was not only helpful to exemplify the setup of the referece model as a whole, but also to refine sub-models and several procedures envolved. As final part of the dissertation, the implementation and preliminary validation of Doctus was performed. This was done with 51 subjects, teachers from different formation levels. The obtained results in this stage were outstanding, all the adaptive functionalities were well evaluated and all of those polled

felt enthusiastic about counting with a tool for helping them in their teaching practices considering students as particular individuals.

Modelo de referencia para sistemas educacionales adaptativos inteligentes soportados por objetos de aprendizaje

RESUMEN

El aprendizaje asistido por computador, conocido más ampliamente con el nombre genérico de *e-learning*, se ha convertido en una poderosa herramienta con amplias potencialidades dentro del campo educativo. Aun así, una de las mayores críticas que este recibe es que en la mayoría de los casos los cursos que son implementados siguen un enfoque "*one size fits all*", es decir, que todos los alumnos reciben exactamente el mismo contenido y de la misma manera desconociendo sus necesidades particulares. Esta falla radica no sólo en la falta de interacción directa entre alumno y tutor, sino también en la falta de un diseño instruccional apropiado que considere diversos de los enfoques disponibles hoy en día.

Existen diversos enfoques que buscan solucionar este problema y adaptar el proceso de enseñanza a los estudiantes. Se podría decir que a la vanguardia de estos enfoques se encuentran los Sistemas Educacionales Inteligentes Adaptativos, los cuales combinan las funcionalidades de dos enfoques: los Sistemas Hipermedia Educacionales Adaptativos y los Sistemas Tutoriales Inteligentes. Sin embargo, luego de una extensa revisión bibliográfica, se encontró que existe aún un inconveniente importante con este tipo de sistemas y en particular con sus modelos de referencia: o son demasiado simples, incluyendo solamente unas pocas funcionalidades; o son demasiado complejos, lo cual dificulta su diseño e implementación. Considerando este panorama, el objetivo principal de esta tesis fue la definición de un modelo de referencia intentando alcanzar tal equilibrio esquivo, de tal manera que permita el diseño de cursos que se adapten de una manera efectiva e inteligente al progreso y características de cada estudiante pero sin ser demasiado complejo. Otra propiedad importante de dicho modelo es que integra el uso de Objetos de Aprendizaje, promoviendo así la flexibilidad y la reusabilidad.

Con el fin de alcanzar este objetivo general, tres sub modelos fueron considerados: un modelo del dominio, un modelo del estudiante y un modelo del tutor. El primero sirve para estructurar el dominio de conocimiento y fue definido empleando la noción de objetivo de aprendizaje junto con un esquema flexible multinivel con operaciones opcionales de prerrequisitos. El segundo busca caracterizar los estudiantes y considera información personal, de conocimiento y psico-cognitiva. El tercero puede ser considerado como el corazón del sistema y define las funcionalidades adaptativas consideradas: secuenciamiento y navegación, presentación de contenido, evaluación, y soporte colaborativo.

Con el fin de clarificar los tres sub modelos, así como todos sus componentes y relaciones, se presentó además un ejemplo de instanciación. Tal instanciación se denominó Doctus, el cual consiste en una herramienta de autor para cursos adaptativos. Doctus no solamente sirvió para ejemplificar el uso del modelo de referencia en su totalidad, sino también para refinar los sub modelos y algunos procedimientos

involucrados. Como parte final de esta tesis, se realizó también la implementación y validación preliminar de Doctus. Esto se hizo con 51 sujetos, todos profesores en diversos niveles de formación. Los resultados obtenidos en esta etapa fueron sobresalientes en el sentido que todas las funcionalidades adaptativas fueron bien evaluadas y todos los encuestados manifestaron su entusiasmo por contar con una herramienta que les ayudara en sus prácticas docentes considerando a sus estudiantes como individuos particulares.

Palabras clave: Modelo de referencia, Adaptación, Objetos de Aprendizaje.

Modelo de referencia para sistemas educacionais adaptativos inteligentes suportados por objetos de aprendizagem

RESUMO

A aprendizagem assistida por computador, conhecida mais amplamente com o nome genérico de e-learning, converteu-se numa poderosa ferramenta com amplas potencialidades dentro do campo educativo. Mesmo assim, uma das maiores críticas que esta recebe é que na maioria dos casos os cursos que são implementados seguem um enfoque *"one size fits all"*, isto é, que todos os alunos recebem exatamente o mesmo conteúdo e da mesma maneira desconhecendo suas necessidades particulares. Esta falha radica não só na falta de interação direita entre aluno e tutor, senão também na falta de um desenho instrucional apropriado que considere alguns dos diversos enfoques disponíveis hoje em dia.

Existem diversos enfoques que procuram solucionar este problema e adaptar o processo de ensino os estudantes. Pode-se dizer que na vanguarda de estes enfoques encontram-se os Sistemas Educacionais Inteligentes Adaptativos, os quais combinam as funcionalidades de dois enfoques: os Sistemas Hipermídia Educacionais Adaptativos y os Sistemas Tutoriais Inteligentes. Embora, logo de uma extensa revisão bibliográfica, se encontrou que existe ainda um inconveniente importante com este tipo de sistemas e em particular com seus modelos de referência: ou são demasiado simples, incluindo somente umas poucas funcionalidades; ou são demasiado complexos, o que dificulta seu desenho e implementação. Considerando este panorama, o objetivo principal de esta tese foi a definição de um modelo de referência intentando alcançar esse equilíbrio esquivo, de tal maneira que permita o desenho de cursos que se adaptem de una maneira efetiva e inteligente ao progresso e características de cada estudante, mas sem ser demasiado complexo. Outra propriedade importante desse modelo és que integra o uso de Objetos de Aprendizagem, promovendo assim a flexibilidade e a usabilidade.

Para alcançar este objetivo geral, três sub modelos foram considerados: um modelo do domínio, um modelo do estudante e um modelo do tutor. O primeiro serve para estruturar o domínio de conhecimento e foi definido usando a noção de objetivo de aprendizagem junto com um esquema flexível multi-nível com operações opcionais de pré-requisitos. O segundo visa caracterizar aos estudantes e considera informação pessoal, de conhecimento e psico-cognitiva. O terceiro pode ser considerado como o coração do sistema e define as funcionalidades adaptativas consideradas: sequenciamento y navegação, apresentação de conteúdo, evacuação, y suporte colaborativo.

Com o fim de clarificar os três sub modelos, assim como todos seus componentes e relações, se presentou um exemplo de instanciação que se denominou Doctus, o qual consiste em una ferramenta de autor para cursos adaptativos. Doctus não somente serviu para exemplificar o uso do modelo de referência em sua totalidade, mas também para refinar os sub modelos e alguns procedimentos involucrados. Como parte final de esta tese, se realizou também a implementação e validação preliminar de Doctus. Isto foi

feito com 51 sujeitos, professores em diversos níveis de formação. Os resultados obtidos em esta etapa foram sobressalientes no sentido que todas as funcionalidades adaptativas foram bem avaliadas e todos os pesquisados manifestaram seu entusiasmo por contar com uma ferramenta que lhes ajudara em seus práticas docentes considerando a seus estudantes como indivíduos particulares.

Palavras-chave: Modelo de referência, Adaptação, Objetos de Aprendizagem.

1 INTRODUCTION

This chapter, as its name implies, introduces this thesis presenting the motivation, conceptual framework, problem description, and state of the art. Later it defines thesis scope, this is, the research hypothesis, objectives and contributions.

1.1 Contextualization

It is not a secret that XXI century is the era of the knowledge and information-based economy, and that society progress is more dependent of science and technology development than in any other moment in history, being the intellectual resources the major source to promote innovation. This insatiable need for knowledge represents important challenges in the process of education, training, updating an improvement of skills, not just for the academic field, but also for industry and society in general. As it is mentioned in (LEARNFRAME, 2000 pp.17-18):

> Where the resources of the physically-based economy were coal, oil, and steel, the resources of the new, knowledge-based economy are brainpower and the ability to effectively acquire, deliver and process information. Those who are effectively educated and trained will be the ones who will be able to economically survive and thrive in our global, knowledge-based economy. Those who don't will be rendered economically obsolete.

An alternative to solve this increasing need of knowledge acquisition is the Computer Aided Learning (CAL) which has become very popular in the last years thanks to its principle of flexible access anytime and anywhere. Among CAL's main strengths one could mention: a) it increases availability of learning experiences for those students who cannot or chose not to assist to traditional face-to-face classrooms; b) it allows for the development and divulgation of instructional content in an efficient way in terms of cost and; c) it allows for increasing the coverage of students without a deterioration in the education quality.

To strength those statements it is important to mention that in United States, approximately 3.9 millions of people studied in 2007 university on-line courses, 12% more than previous year, whereas the whole university population grew 1.2% according to data from Sloan Consortium[1]. In this country, the National Center for Education

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[1] www.sloan-c.org

Statistics estimated that number of public school students who enlisted in technology-based distance courses grew around 65% between 2002-03 and 2004-05. In a more recent study presented in (PICCIANO & SEAMAN, 2009) it was estimated that more than a million of K-12 students took online courses during 2008 and 2009.

The main question that these data lead to, is if this approach is more effective than traditional, face-to-face education, and if it is not, why this tendency has appeared. According to a study that the SRI International[2] consultant made for the United States Department of Education, technology-based education is in fact more effective, with a small difference in favor when it is completely virtual, but quite bigger when it refers to projects that combine traditional classes with virtual formation using new technologies. It is not, as conclusions of such study say, that computers have some sort of magical effect, or that model itself is more effective. Instead it states that the use of such tools in education usually implies that student spends more time studying, looking for additional information for his/her own, sharing it, and collaborating with classmates. In summary, being more prone to take the lead of his/her own learning instead of being a passive individual most of the time anonymous in a crowded classroom (EL PAÍS, 2009).

In tune with this affirmations, in the survey presented in (U.S. DEPARTMENT OF EDUCATION, 2009) a systematic analysis was made about the researches in this topic between 1996 and 2008. Such a survey selected 99 studies which made a reliable quantitative comparison among the two kinds of teaching, choosing finally 49, most of them very recent. Assigning them values to the learning difference, measured throughout reliable test, the central outcome was that entirely CAL produced a slightly better effect than traditional teaching.

1.2 Conceptual framework

CAL refers to the use of computers as a key element within educational environment. Although this definition may cover the general use of computers within a traditional classroom, it is more accepted that it refers specifically to a structured environment where computers are used explicitly for the teaching process, being the students an active part on it. Another very popular term associated to CAL is e-learning, which, even if does not have a universally accepted definition, is usually related with distance education supported by Information and Communication Technologies (ICT).

Going back in history, it is important to mention that first CAL systems dated from early 50's, more known as Computer Aided Instruction or Computer Based Training, were characterized for being more focused into just instruction than in actual teaching. The functionality of these early systems was very restricted to the software and hardware of that time: interaction with user was made through terminals and there was very poor processing and storage capacity. One of the more known examples is PLATO: Programmed Logic for Automated Teaching Operations, which was developed in the Illinois University with the aim of teaching courses in a massive and automatic way.

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[2] www.sri.com

Until 80´s, most of these systems characterized for teaching in a very procedural way, with no personalization features, and in an unfriendly manner. From then, CAL has evolved a lot, promoted by ICT reception not only to complement traditional classrooms but, as mentioned before, to reach more students (probably located geographically far away) and in a better way. Such evolution allowed for the emergence of several approaches with their own particularities, being their differences unknown in many cases for teachers and instructional designers.

Being aware of those differences, a taxonomy of several of these approaches is presented in this section, describing each one in a brief but concise way. For the sake of a better understanding it was divided in four major trends as it is presented in figure 1.1, presenting their most standing features and, where it has been possible, listing some studies and implemented systems.
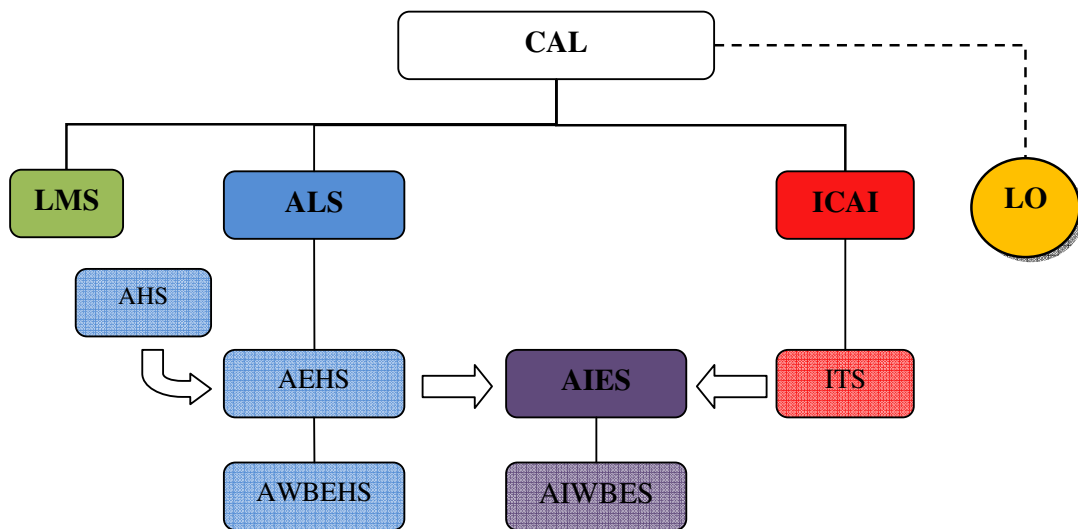
Figure 1.1: Taxonomy of CAL approaches

1.2.1   Learning Management Systems

The Learning Management Systems (LMS), also known as Course Management Systems, are web based platforms whose main features are to manage, monitor and report interaction of students with the learning material, with teacher and with other students. In order to do that, most LMS generally use a client-server architecture where teachers configures applicative interface using web forms to make course contents available. This architecture and mode of use has allowed the overcrowding of LMS, promoting the rising of many robust commercial implementations.

The LMS also characterize for providing a large set of tools to assist the development of courses. Among these tools one could mention files manager, forums, chat, calendar, automatic assessment questionnaires, and statistics of use, among others. All of them are precisely what make that LMS, although they were originally designed to develop on-line courses, are being used for many institutions to complement face-to-face classrooms, facilitating the teachers' labor, centralizing resources and serving as meeting point for students.

Table 1.1 shows a list of some of the most popular LMS. A detailed comparison of some of them, including functionalities and technical specifications may be found in (WEBCT, 2008).

Table 1.1: LMS list

Name	URL	License type
Amadeus	amadeus.cin.ufpe.br	Free
Angel learning	www.angellearning.com	Integrated to Blackboard
BlackBoard	www.blackboard.com	Proprietary
Claroline	www.claroline.net	Free
Dokeos	www.dokeos.com	Free
ILIAS	www.ilias.de	Free
Joomla	www.joomlalms.com	Proprietary
Moodle	www.moodle.org	Free
OLAT	www.olat.org	Free
Sakai	www.sakaiproject.org	Free
Schoolar360	www.scholar360.com	Proprietary
Sharepoint	www.sharepointlms.com	Proprietary
WebCT	www.webct.com	Integrated to Blackboard

1.2.2 Adaptive Learning Systems

The Adaptive Learning Systems (ALS), also known as Adaptive Learning Environments or Adaptive Courseware Environments, refer in general to those systems that presents a knowledge domain to students in an adapted way, under the principle that it increases significantly learning speed (DAVIDOVIC et al., 2003). In these systems the adaptation scope is manly related to preferences and characteristics of students. Preferences are related to student's likes in his/her role of a computer system user: colors, sizes, fonts, etc; whereas characteristics are related to educational processes: knowledge level, learning goals, etc. To contrast all this information with the knowledge domain, two adaptation levels are usually considered: content and links. The first one is known as adaptive presentation and the second one as adaptive navigation support.

Within the ALS, the Adaptive Educational Hypermedia Systems (AEHS) as its name implies, are a particular approach whose presentation structure is based on hypermedia content (hypertext + multimedia). As it is shown in figure 1.1, they are directly related to the Adaptive Hypermedia Systems (AHS) which have been widely used as presentation tools for personalized content. The general schema for these systems, presented in figure 1.2, is the same as the AHS because AEHS may be considered as a specific application with the difference that students are the users of the system so models are related to their learning process.

In this point, it is important to clarify the difference between two terms: *adaptable* and *adaptive*. In one hand, systems that allow the user to change certain parameters and adapt their behavior accordingly are called *adaptable*. In the other hand, systems that adapt themselves to the user automatically, based on the assumptions they make about user needs are called *adaptive* (OPPERMAN et al., 1997). Considering this difference,

when using the term *adaptation* in the rest of this document, it will refer to the second term.
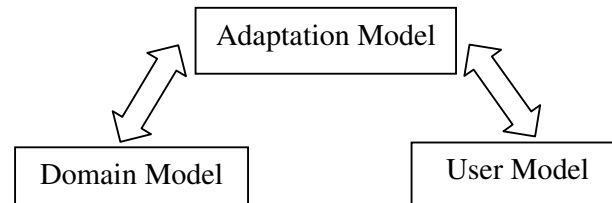
Figure 1.2: AHS general schema

Knutov et al. (2009) propose six questions to explain general purpose of adaptation in AHS, from which, the next ones were formulated:

- From what adaptation could be made? (from what?)
- To what adaptation could be made? (to what?)
- Why adaptation is required? (why?)
- What could be adapted? (what?)
- When adaptation could be used? (when?)
- How adaptation could be made? (how?)
- Where adaptation could be used? (where?)

Whose answers are related to models presented in figure 1.2. The final application is based on the Domain Model (DM) that describes how conceptual representation of the domain is structured. In other words, DM usually answers question "from what?", indicating the elements that composes such domain as well as their relationships.

The User Model usually answer question "to what?" giving information about user preferences and characteristics. This model may also help to answer question "why?" providing information about user goals.

Final application must adapt instruction, content, presentation and navigation to user and, in order to do that, the Adaptation Model must communicate with the other two to answer questions "what?" along with "when?" and "how?".

Finally, "where?" may be understood as a more general question that refers to the AHS application area, this because it does not have to be necessarily educational. Other potential applications are information systems, personalized views, help systems, etc.

AEHS has as advantage that it allows developing non-linear interactive applications and admits a direct link between adaptation techniques and user interface. A classification of these techniques for the two previously mentioned adaptation levels may be found in (BRUSILOVSKY, 2001):

Adaptive presentation
  o Text presentation: extension, detail level, contextual information, etc.

- o Multimedia objects presentation: format, size, quality, etc.
- o Mode: selection of one or more objects according to user features

Adaptive navigation support

- o Direct guidance: insertion of "next" type links
- o Ordering: links localization according to some criterion (relevance for instance)
- o Hiding: restricted access to certain contents
- o Formatting: changing in links appearance to denote some special feature like visited, non-visited, recommended, optional, etc.
- o Generation: insertion of extra links
- o Navigation map: graphical representation of hyperspace

Some widely documented AEHS are: ESCA (GRANDBASTIEN & GAVIGNET, 1994), SYPROS (GONSCHOREK & HERZOG, 1995), ELM-ART (BRUSILOVSKY et al., 1996), Hypadapter (HOHL et al., 1996), Hypercase (MICARELLI & SCIARRONE, 1996), InterBook (BRUSILOVSKY et al., 1998) and KBS-Hyperbook (HENZE & NEJDL, 2001).

As it may be seen in figure 1.1, AEHS have a subdivision known as Adaptive Web-Based Educational Hypermedia Systems (AWBEHS) which are focused specifically on the web so users (students) access them throughout a web navigator. This approach is in fact quite natural for this kind of applications considering that web is based in languages like HTML and XML that facilitates some fundamental tasks from AEHS about links schema. Another advantage is that it allows accessing in real time to applications from any equipment in a local network or over Internet.

One disadvantage of this approach however, compared to non-web AEHS, is that these last ones may have a more strengthen relationship between interface and underlying functionality, this is, every user action may be recorded: every mouse movement, scrolling, window size change, etc., and such information may be used for adaptation purposes (DE BRA et al., 2004).

Some well-known implemented AWBEHS are: AHA (DE BRA & CALVI, 1998), AHM (DA SILVA et al., 1998), TANGOW (CARRO et al., 1999), ECSAIWeb (SANRACH & GRANDBASTIEN, 2000), SmexWeb (ALBRECHT et al., 2000), AIMS (AROYO & DICHEVA, 2001), NetCoach/ART-WEB (WEBER et al., 2001), AHA! 2.0 (DE BRA, et al., 2002), MetaLinks (MURRAY, 2003), CoMoLe (MARTÍN et al., 2006) and GOMAWE (BALIK & JELINEK, 2007).

1.2.3 Intelligent Computer Aided Instruction

The Intelligent Computer Aided Instruction (ICAI), also known as Intelligent Computer Aided Learning or Intelligent Learning Environments emerges as a natural evolution of first CAL systems providing an individualized learning experience for student simulating interactions with a real teacher. Within this context, when talking about individualized or personalized instruction it is understood that the system does not treat all students equally, so they do not receive the same content in the same time nor

in the same way. To achieve such a task, these systems represent in a separate way the content, the teaching strategies and the student characteristics.

Within ICAI, one of the most known approaches are the Intelligent Tutoring Systems (ITS). Even if their more general definition is that they are tutoring systems that have incorporated intelligent components, commonly associated to Artificial Intelligence (AI) techniques, some authors extends such definition adding that they may count with procedures and representations of knowledge from the computational linguistics and cognitive sciences fields (SAMUELIS, 2007). ITS are a well-known approach from ICAI and may be described as computer systems that try to imitate a human tutor generating interactions when they are required by students, as well as detecting individual learning problems and providing means to solve them. In this sense this kind of systems are quite different from early CAL systems (VICARI & GIRAFFA, 2003). Some of these differences are presented in table 1.2.

Table 1.2: Traditional CAL versus STI

	Traditional CAL	ITS
Theorical basis	Skinner theory (behaviourism)	Cognitive psychology
System schema	One only structure defined in an algorithmic way	Structure subdivided in models
Content sequencing	Fixed	Heuristic
Student modeling	Validation of final answers	Validation of the whole student – system interaction
Instruction features	Tutorial, exercises	Socratic, interactive environment, guidance

Although there is not an explicit consensus about ITS components, most authors agree that they have a general schema like the one presented in figure 1.3, which is consistent with the previously mentioned CAL separation principle.
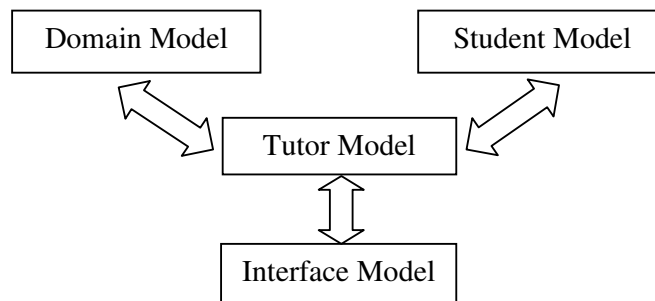
Figure 1.3: ITS general schema

Knowledge is structured in the Domain Model (DM) and its representation would depend manly of the general kind of such knowledge, this is, if it is factual, relational, procedural, analytic, etc. Some common representation forms are directed graphs, hierarchical trees, semantic networks, production rules, expert systems, etc.

In the Student Model (SM) is where all individual student characteristics are stored. As it is mentioned in (EYHARABIDE et al., 2009) information in this model may be divided in several categories like personal (name, age, gender, etc.), cultural (race, residence region, etc.), technological (access device, bandwidth speed, etc.) and system interaction (accessed content, number of sessions, etc.). Several works add to this information some other categories like environmental conditions, emotional, personality-related, among others.

The Tutor Model (TM), also known as Pedagogical Model, is the one in charge of guiding the teaching process, deciding which pedagogical actions must be performed, as well as how and when that must be done. In other words this model deals with delivering the didactical strategies that are specified in the system in an adapted way to the student needs (based on SM), considering the knowledge domain (from DM).

Finally, the Interface Model determines how activities and contents are presented in the screen to each student. This model deals with the lower level interaction details like files formats, links, buttons, forms, etc.

A very extensive list of implemented ITS and tools to develop them, as well as the corresponding references, is found in (MURRAY, 1999).

1.2.4   Adaptive and Intelligent Educational Systems

Figure 1.1 shows that Adaptive and Intelligent Educational Systems (AIES) may be considered as an intersection between AEHS and ITS. More specifically, as it is show in figure 1.4, it may be said that from AEHS they inherit adaptive presentation and adaptive navigation support, described in section 1.2.5, whereas from ITS they usually incorporates some of the next functionalities (BRUSILOVSKY & PEYLO, 2003; PEÑA, 2004):

- Curriculum sequencing: suggesting to student the "optimal" learning path, understood as the planed sequence of activities and contents that he/she must accomplish within the knowledge domain.
- Adaptive assessment: in the same way that instruction should be provided in an individual basis, assessment should be too. The most common way to do that is presenting assessment items in a sequence that is dependent on the correctness of the examinee's responses, looking for an accurate measure of his/her achievement level.
- Intelligent analysis of solutions: more than assessment, its goal is to discover the mistakes committed by student, e.g. misconception, miscalculation, etc., looking for plausible causes with the aim of helping him/her to correct them.
- Problems solving support: to provide intelligent help, e.g. giving advices, reminders, etc., to student when he/she faces a specific activity. This functionality differs from the previous one because it is not remedial, so is not performed just when a mistake in the student reasoning is detected, but as some sort of continuous guidance.
- Adaptive collaboration support: to use the system's knowledge about students to facilitate collaborative learning activities. Examples include forming a group for collaborative problem solving at a proper time, or finding the most adequate peer to answer a doubt about a specific topic.
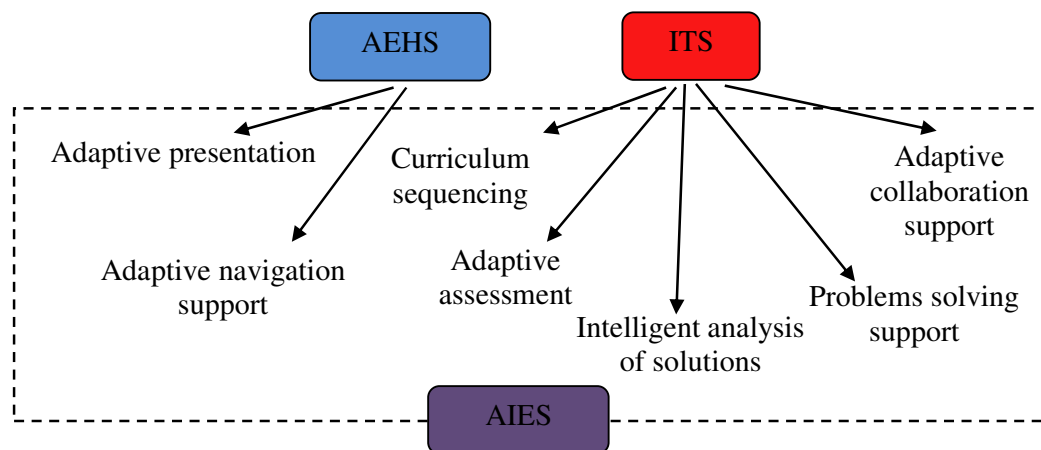
Figure 1.4: AIES typical functionalities

In the same way that in AEHS, the AIES have a subdivision called Adaptive and Intelligent Web-Based Educational Systems (AIWBES) whose functionalities and technical issues, as its name implies, are related specifically with web format. As mentioned in (KELEŞ et al., 2009), this is the more common trend, and there are several successful efforts to translate existent systems to the web world (RITTER, 1997; ALPERT et al., 1999), whereas there are many other whose since their conception were designed to run in this environment (CHEN, 2008; LIN et al., 2008).

Some well-documented AIWBES are: AdaptWeb (OLIVEIRA et al., 2003), MAS-PLANG (PEÑA, 2004) and ZOSMAT (KELEŞ et al., 2009). In the regional scope one could mention: SICAD (DUQUE, 2005), ALLEGRO (JIMÉMEZ, 2006), AMPLIA (VICARI et al., 2008) and CIA (MORENO et al., 2009), which have some of the functionalities described previously.

1.2.5 Learning Objects

Learning Objects (LOs) are presented in figure 1.1 as a separated "bubble" in the CAL context for a simple reason: More than being an approach to create learning systems, they may be considered as an alternative to represent, and finally to store educational content.

Although there are a lot of definitions of what a LO may be, in a very concise way it can be said that is any digital resource that is used in a simple or composite way to support teaching/learning process and that may be re used. A very common metaphor that is used to explain LOs and to extend previous definition is the LEGOs blocks: little instructional pieces (LEGOs) that may be assembled between them in a bigger instructional structure (a castle for example) and that may be reused later in other structures (a spaceship for example).

This analogy, although is very illustrative, has the next conceptual problems related to LOs properties (WILEY, 2001): a) any LEGO block may be combined with any other; b) LEGO blocks may be assembled in any way; c) LEGO blocks are very simple so even a child may combine them. Considering these issues, the same author proposes the atom as a new metaphor for LOs: an atom is something little that may be combined and recombined with others to form bigger structures (molecules). This metaphor is

more harmonious with LOs properties: a) not any atom may be combined with any other; b) atoms only may be assembled among them depending of their own internal structure; c) some training is required to combine atoms. Summarizing, these properties mean that structuring of educational content from LOs is possible as long as there is an appropriate instructional design in the middle.

One important feature of LOs is that they may be described through metadata that facilitate their administration. Such metadata may be defined by standards, being the more known Learning Object Metadata (LOM) from IEEE, although there are also several initiatives known as specifications, which procure to capture a consensus between researchers summarizing or extending certain aspects of an existent standard. A list of some of those initiatives for specific regions, countries or research centers and universities is presented in table 1.3.

Table 1.3: LO metadata initiatives

Name	Comunity	URL
Dublin Core	Internacional	http://dublincore.org/
UK LOM Core	United Kingdom	http://metadata.cetis.ac.uk
CanCore	Canada	http://cancore.athabascau.ca
ANZ-LOM	Australia and New Zealand	http://www.thelearningfederation.edu.au
OBAA	Brazil	http://www.portalobaa.org
NORLOM	Norway	http://www.itu.no/no/NSSL
ISRACORE	Israel	http://www.iucc.ac.il

Considering their features, and particularly their reusability philosophy, lots research groups and institutions have adopted LOs as an importer part of their CAL processes and, as a consequence of that, several sources have emerged and became of huge help for the educational community. Some of those sources, known as repositories and federations are listed in table 1.4.

Table 1.4: LO repositories

Repository	URL
ARIADNE	http://www.ariadne-eu.org
ALI: Apple Learning Interchange	http://ali.apple.com
CAREO: Campus Alberta Repository of Educational Objects	http://www.ucalgary.ca/commons/careo
FEB: Federação de Repositórios Educa Brasil	http://feb.ufrgs.br
LA FLOR: Latin American Federation of Learning Object Repositories	http://laflor.laclo.org
LORN: Learning Object Repositories Network	http://lorn.flexiblelearning.net.au
MELOR: Medical Learning Object Repository	http://gilt.isep.ipp.pt:8080/melor
MERLOT: Multimedia Educational Resource for Learning and Online Teaching	http://www.merlot.org

| MIT Open Courseware | http://ocw.mit.edu |
| Wisc-online | http://www.wisc-online.com |

1.3 Research problem

After the conceptual framework analysis presented in section 1.2, the next reflections were extracted:

1. Even if the LMS are the kind of applications more used by educational institutions of different formation levels around the world thanks to their robustness and ease of use, they are support platforms which do not provide an actual individualized teaching, or at least not in their original commercial versions.

2. Differently to LMS, ALS and ICAI are approaches that have as main goal to provide an individualized learning experience, being in this way a lot more appealing. Both approaches however have as disadvantage that they usually do not count with generic authoring tools of ease use, due to their conceptual and functional complexity. According to Moundridou & Virvou:

> The main flaw of ITSs and possibly the reason for their limited use in workplaces and classrooms is the complex and time-consuming task of their construction (2003, p. 158).

Consequently with this affirmation Woolf & Cunningham (1987) estimate that an hour of educational material for an ITS for example requires more than 200 hours of development time. Although such estimation may have been reduced due to the technology advances, the truth is that proportion is still high.

3. Although it could be said that ICAI systems are more advanced than ALS from the pedagogic point of view, it is clear that there are some conceptual similarities among them. As it can be seen in figures 1.2 and 1.3 both approaches are based in an architecture that distinguishes two models: a Domain Model – DM and a Student Model – SM. Both also have a third model. In the case of ICAI, and particularly in ITS, it refers to the Tutor Model – TM, whereas in ALS to the Adaptation Model. Even if they are not the same because in the case ITS it covers a larger spectrum of processes, in some AEHS the authors particularized this model giving it similar titles as Teaching Model (DE BRA et al., 1999), Pedagogic Model (HENZE, 2000), or Narrative Model (CONLAN et al., 2002).

4. Precisely, due to the similarities described in previous reflection, and as a natural evolution of both approaches, it may be said that AIES are found in the vanguard because it combines some of their best functionalities. Even if this sounds very promising, it also implies that the complexity in its design and implementation is higher. In fact, if one wants to see a graphical representation

of the relationship between these two dependent issues, it would be something like the one presented on figure 1.5.
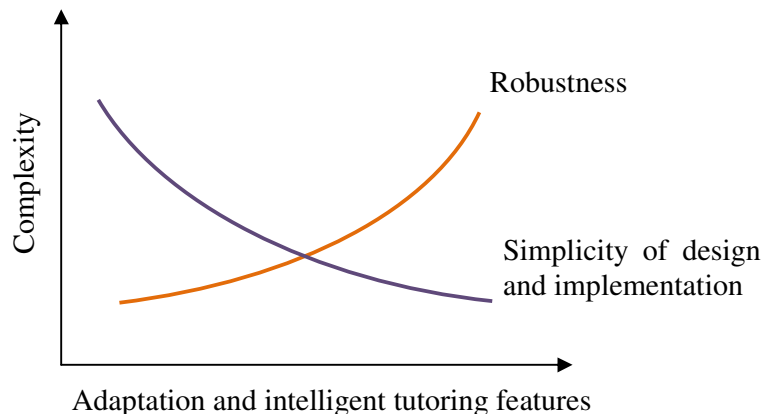
Figure 1.5: AIES dilemma

5. Independently of the approach, LOs seem to be a very useful alternative in CAL, particularly because their granularity, as well as the way they are developed and specified, promotes reusability. In Wiley's words:

> If learning objects ever live up to their press and provide the foundation for an adaptive, generative, scalable learning architecture, teaching and learning as we know them are certain to be revolutionized. (2002, p. 15)

From these reflections, it could be said that complexity in the design and implementation of the educational systems in the analyzed approaches increases as they have more adaptation and intelligent teaching features with the aim of providing a more individualized learning experience. Being so, the research problem may be defined as providing mechanisms that allow the development of this kind of systems but achieving equilibrium between the two issues mentioned. In other words, the problem is how to define a reference model for AIES, without having too much complexity, but detailed enough to facilitate subsequent implementations which would represent powerful tools in educational context.

It would be even more helpful if such model contemplates LOs as part of its foundations. Besides the advantages described in section 1.2.11, there are lots of reasons for choosing LOs to encapsulate educational content, being three of them particularly interesting. The first one is that they allow separating the knowledge domain structure from actual content, providing flexibility and, as mentioned before, reusability. The second one is that metadata that describe them may be used not only for characterizing purposes but also for adaptation. And third is that there are nowadays a considerable number of LOs repositories, many of them with open use licenses, where teachers and designers may access thousands of them.

1.4 State of the art

Considering that in research literature around AIES there is a very significant number of studies and publications, the next selection criteria were chosen for the state of the art: a) they may come from any of the approaches described in section 1.2, always as they cover explicitly the user, i.e. student, adaptation; b) they should present a clear separation of the systems components that are considered to achieve such adaptation; and c) they should include an adequate description with a considerable detail level about those components and their relationships. This criterion excludes platforms, systems and specific tools from which their design is unknown or non-properly described.

Within these criteria it does not appear the explicit use of LOs even if they are a fundamental part of this research. Such situation is due to LOs are a relatively new concept and very few studies use them considering the previous criteria. This however is not necessarily an obstacle because, as it will be seen later, many issues about adaptation may be extrapolated to consider them.

The studies that accomplish the mentioned three criteria are described here in chronological order.

AHAM (Adaptive Hypermedia Application Model) (WU, 2002) is a reference model for the design of AHS which, even if are not focused specifically in the educational context, servers as an important reference point because it aims to provide personalized views to the user based on his profile. In other words this model may be useful for the AEHS design but from a higher abstraction level considering that its main goal is not learning but just information transmission. This study is an extension of the Dexter model (HALASZ & SCHWARTZ, 1990) which is in turn a well formalized reference model but for conventional Hypermedia Systems (HS). It adopts the AHS definition provided by (BRUSILOVSKY, 1996) which states that it is any HS that captures some user characteristics and use them to adapt several system visible features.

AHAM defines three sub models that coincides with the ones presented in figure 1.2, which together conform what in Dexter model is called the storage level. The final goal of these models, as author expresses, is to describe the structure and functionality of the designed AHS as well as to make the communication, or more precisely the translation, between them possible. As it is shown in figure 1.5, in the lower part of the complete scheme, the content is found (in the within-component layer), whereas its relationship with the storage layer is made throughout connection points defined in the anchoring layer. The 'T' structure in the storage level is due to the boundaries and interaction among the three sub-models. Finally, in the upper part of the scheme, the run-time layer is found where the final user presentation is located.
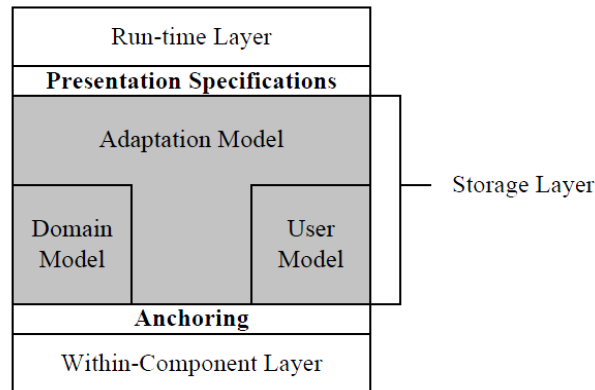
Figure 1.6: AHAM general scheme (WU, 2002)

Similar to AHAM, Munich (KOCH & WIRSING, 2002) is a reference model for AHS and is also considered an extension of the Dexter model to which incorporates some user modeling issues and rules-based adaptation mechanisms. The main feature of this study is that proposes an object oriented specification described in UML which integrates an intuitive visual representation with a formal OCL (Object Constraint Language) description.

The Goldsmith model (OHENE-DJAN & FERNANDES, 2002) is similar to the previous two although is not based in the Dexter model and even presents a comparison between them arguing that its scope is wider. It consists in the description of an abstract model which defines the functionality of a core for HS as well as the specification that allows its personalization. Such a model is composed of functions which are divided in three types or regions: the ones from the H-region that models the non-customizable user-application interaction where a formal specification of the hyper-pages that stores information is required; the ones of the P-region that models content personalization performed in an explicit way for the user through an annotation and rewriting processes which are later translated to an also formal language; at last, the ones of the A-region that models the content adaptation which is performed in an autonomous way by the system.

In (CRISTEA & AROYO, 2002) a model to design authoring tools for AWBEHS is presented. Such a model is composed of three layers, the first one is the conceptual layer that expresses the DM and is divided in two sub layers, one for atomic concepts, understood as a part of the knowledge domain, an another one for composed concepts. Second layer contains lessons that are analogous to a chapters and sub-chapters structure, and represent the order and manner in which concepts are presented. Third layer is also divided in two sub-layers, one for student adaptation that specifies which material must be presented under what set of conditions, and another for presentation that specifies the format in which information as such is showed in the web pages.

LAOS (CRISTEA & MOOIJ, 2003) is a generalization of the previous work because is not focused specifically in educational systems but has AHS in general. Besides the AHS general models, this research proposed two new ones: the Restriction and Goals Model and the Presentation Model. The first one tries to provide a presentation that is more focused in the instructional goals and at the same time limits the search space in the knowledge domain, whereas the second one takes in consideration the interface proprieties and provides a connection with the code generation for different platforms (HTML for instance). The general structure considering the five models is presented in figure 1.7. Besides this division, this research also proposes the use of operators to manipulate the elements in each model.
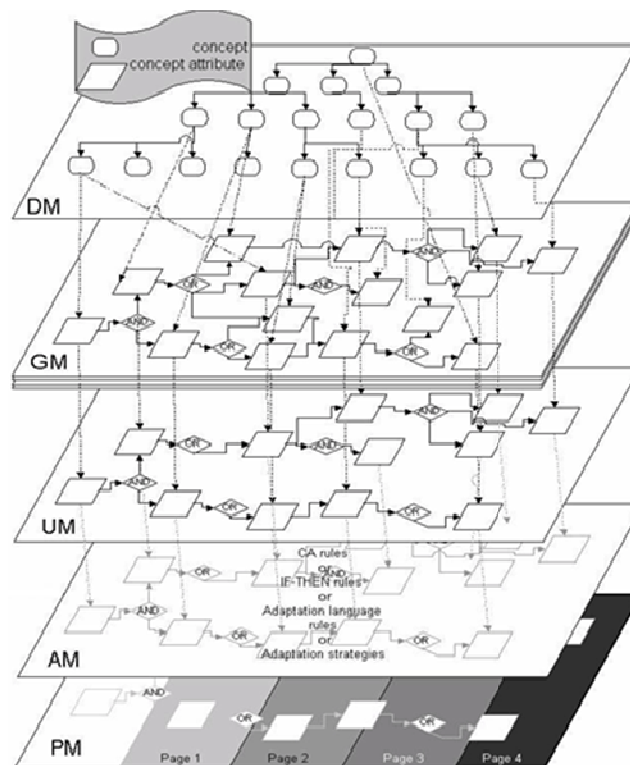
Figure 1.7: LAOS layers (CRISTEA & MOOIJ, 2003)

In (CRISTEA & CALVI, 2003) a study that somehow complements the previous one is presented. Although it does not consider de GM it does specify in detail the AM which divides in three levels. In the lower level the techniques for content presentation and navigation support are presented. In the middle level such techniques are grouped in typical adaptation mechanisms and for them, a set of rules and operators are build which defines a programming language for the adaptation strategies. Finally, in the higher level the user's cognitive styles are considered to determine the more appropriate didactical strategies.

GAM (Generic Adaptivity Model) (DE VRIEZE et al., 2004) starts from AHAM model but is more generic because it may be used also for non-hypermedia applications.

Another two fundamental differences are that GAM has a lower abstraction level and proposes an additional model to describe application interface considering its connection with the AM. To specify the relationships among the four models, GAM is based on a states machine approach in which all user interaction with the application generates an event that may produce a change. Such a change in turn may be translated into the modification of a state.

In (KARAMPIPERIS & SAMPSON, 2005) a general AHS structure similar to AHAM is considered but focusing in the AM which subdivide in two processes: one for concept selection and another for content selection. The first one refers to the mapping of the learning goals with the concepts from the knowledge domain as the student advances trough course, whereas the second one refers to the resources that are selected to cover each concept based on the relationship between their educational features and the student's cognitive characteristics and preferences.

To perform these processes, this study differentiates from others that consider predefined adaptation rules proposing a decision model which, based on the generation of all possible learning paths that maps certain learning goal, selects the more appropriate resources for each student.

In (CHEN et al., 2006) a model for the curriculum sequencing in AIWBES is proposed using an Item Response Theory (IRT) approach. It considers several aspects as the difficulty level of the course, the student knowledge measured trough initial tests and the relationships between de domain concepts.

Although authors do not call it that way, in (BOUZEGHOUB et al., 2006) an ALS model supported in LO is proposed using a general schema with three models: the DM which in this case represents the concepts that are covered with the LOs; the SM where basically his/her preferences and progress are stored; and a Pedagogical Model which is in charge of presenting LOs to student. Another distinctive feature of this work is that it uses metadata for LOs and a RDF (Resource Description Framework) algebra for the operations that may be applied.

In (CURILEM et al., 2007) a mathematical model, specifically under the finite automata approach, is described for the architecture and functionalities of ITS with the aim of facilitating the integration of its design between computing and pedagogy fields. This study considers two pedagogical strategies joint to three theories to build the tactics. Here, a strategy is understood as the set of conditions and stages that are needed for the teaching/learning process, whereas the tactics indicate how a strategy may be implemented.

TEx-Sys (STANKOV et al., 2008) is a model for the construction of ITS based on pedagogical activities considering the next four phases cycle: didactic, perception, diagnosis and evaluation, and finally help and remediation. The didactic phase involves the specification of the knowledge domain, the student characterization and the adaptation methods for instruction according to the student needs. The perception phase

deals with the student's previous knowledge, whereas the diagnosis and evaluation phase deals with its evolution. In case of existing, the student's conceptual errors activate the help and remediation mechanism with the aim of minimizing the difference between his/her knowledge and the taught domain.

Some interesting features of this study are that it uses semantic networks to formalize knowledge domain and has a simple procedural mechanism for adaptive assessment.

In (CHEN, 2008) a model that is similar to (CHEN et al., 2006), previously described, is presented, with the main difference that it does not use IRT for curriculum sequencing but proposes a genetic algorithm approach instead.

CIA (MORENO et al., 2009) may be considered within AIES approach because it considers content adaptation and adaptive assessment issues jointly with AI techniques. In this work the DM is modeled as a hierarchical tree with a specific structure where LOs are located in its leaves. Such LOs are described through a metadata standard and the adaptation process is based in one student's cognitive characteristic, the learning styles, according to a specific model. For the implementation of the whole system, a software agents architecture is proposed where each one of them has a particular role: to represent systems actors (students and teachers), to manage the four main ITS models (domain, user, tutor, and interface), or to perform a specific sub process like adaptive assessment.

Similar to the previous study, SICAD+ (DUQUE, 2009) may be considered as an AIES focused mainly in the adaptation task and is supported by software agents. It differentiates however for being a lot more generic about domain structure, the pedagogical strategies that may be implemented and the student's characteristics that are used to adapt content. The core of this study is a planner module that incorporates the adaptation strategy and translates the curriculum sequencing problem in a AI planning problem, which is solved using an algorithm called HTN (Hierarchical Task Network). Although in this study author does not talk about LO but educational content in general, it is clear that in this case they are analogous ideas and even author proposes the use of metadata standards that are used precisely in the LO world.

As a summary of this section, the next reflections may be highlighted:

The reference models for AHS and AEHS (WU, 2002; KOCH & WIRSING, 2002; OHENE-DJAN & FERNANDES, 2002; CRISTEA & AROYO, 2002; CRISTEA & MOOIJ, 2003; CRISTEA & CALVI, 2003; VRIEZE et al., 2004; KARAMPIPERIS & SAMPSON, 2005) have as advantage being very robust and formal about the components definition, functionalities and their relationships. Besides that, even when they are delimited to hypermedia applications, many of their techniques may be applied, or even more extrapolated, to other kinds of adaptive educational systems.

About the analyzed models for ITS (CURILEM et al., 2007; STANKOV et al., 2008) it may be said that, precisely for being focused in very complex systems, they are too general models which do not describe in a formal way all their functionalities. In contrast to this situation, works like (CHEN et al, 2006; CHEN, 2008) of the AIES approach, although they are quite detailed, are focused only in certain features of those systems, without specifying the relationship with the other components.

Other researches such of Bouzeghoub et al. (2006) that incorporate adaptation and LOs within the ALS approach are too simple, because consider only some adaptation issues, leaving apart some others that are equally important for all CAL systems like assessment for example.

More recent researches like the one presented in (MORENO et al., 2009) have the advantage of joining interesting issues as the consideration of student's cognitive characteristics for educational content adaptation based on LOs. It has however as disadvantage that is not generic enough to help in the design of other applications and in which, neither the DM, nor the TM are flexible.

From all analyzed works, the one presented in (DUQUE, 2009) is perhaps the closer to what this thesis pretends, because it is a generic model for the creation of adaptive educational systems that uses LOs. There are however several fundamental differences that may be identified. The first one is that, even if it is a generic model, the detail level in which is described is closer to the analysis stage than to the design (from the software engineering point of view) and does not present a formalization of all involved tasks. The second one is that it uses a specific mechanism based on HTN for curriculum sequencing and content presentation, which may turn complex in the later implementation stage. The last one is that it is supported in a software agents architecture which, although it could be helpful, also increases the implementation complexity.

1.5 Research hypothesis

Enclosed within the research problem described in section 1.3 and considering the state of the art presented in section 1.4, the next research hypothesis is formulated:

It is possible to achieve a comprehensive design of personalized educational systems, which adapts to the student's needs and characteristics, using AIES techniques as well as LOs to support the teaching/learning process.

1.6 Thesis objectives

In order to answer the research hypothesis, the next thesis' general objective is formulated:

General objective

To define a robust reference model for the design of computer aided learning systems which adapt themselves to students and are supported by learning objects.

Specific objectives

The previously described general objective is decomposed in the next specific objectives:

1. To specify a flexible Domain Model in order to structure the knowledge to be learned.
2. To define a rich Student Model, considering diverse kinds of information.
3. To describe a Tutor Model which, in concordance with the previous two and considering Learning Objects as fundamental components, allows the instruction, monitoring and assessment of students in an adaptive way.
4. To instantiate the proposed model with the design of a particular educational software for the creation of on-line courses with all the considered features.
5. To validate the design performed in the previous objective, throughout the implementation and preliminary evaluation of a computational prototype.

1.7 Scope

As in all research projects, it is important to define a scope regarding what is considered and what is not. As it was stated in the research hypothesis from section 1.5 the idea is to cover AIES considering the main three models DM, SM and TM (the name of the last one was chosen from ICAI rather than from ALS approach for being more widely used) from a very systematic point of view. It includes using some of their techniques, but it does not specify which ones exactly. In the figure 1.4 seven of those techniques are presented and, before saying which were considered, it is important to say that such a decision was taken keeping in mind the thesis aim. More specifically, for being a "reference model" it has to be general enough in the sense of not being attached to a particular domain. This criterion excludes the intelligent analysis of solutions and problem solving support techniques because they are particular by nature. For instance, a model that considers one of both techniques for teaching basic algebra cannot be extrapolated to other scenarios because all its reasoning would be confined to that field.

The remaining five techniques are not incompatible with this criterion and therefore are considered in this thesis. However three further explanations should be made. The first one is that adaptive navigation support from AEHS and curriculum sequencing from ITS has analogous aims so they will be merged. The second one is that adaptive assessment usually considers only the scoring of the student's knowledge level, but not what should be done after. In this proposal the feedback process including some remediation actions is incorporated explicitly as the assessment final step. The third one is that although the adaptive collaboration support was not originally considered in the proposal of this thesis, it was finally added to the model for considering that

collaborative activities may provide enormous help in the learning process being a complement to the individual activities.

Now, with regard to the particular student's characteristics that are used in this proposal, it is important to mention that additional considerations which were found during literature revision and may be useful for adaptation purposes are excluded of the thesis scope for the sake of simplicity. However, given the formalism of this research, the systems that could be designed are not exempted of including them.

Going back to the thesis aim, being a "reference model" also means that it is not attached to particular pedagogical strategies. Even if such strategies joint with the corresponding tactics are extremely important for CAL in general, in this model it is supposed that they should be defined in the instantiation process as well as in the used educational resources which in this case includes the LOs. In order to clarify terms "strategy" and "tactic", and similarly to what is stated in (CURILEM et al., 2007), it could be said that pedagogical strategies propose the conditions and phases that are indispensable to the teaching–learning process, whereas the pedagogical tactics indicate how the strategies will be implemented in particular situations. In other words, strategies are contained in the pedagogical activities offered to the student and tactics are implemented by the resources that are used in them.

Finally, it is relevant to highlight that besides DM, SM and TM, what in some ALS is known as run-time layer and in some ICAI as interface model (see figures 1.6 and 1.3) is also considered in this proposal as part of the systems that may be designed, but it is not detailed in the formal way that the other three are, because it is an implementation issue that is beyond the scope. However, and with the aim of explaining its use, an example case is presented which corresponds mainly to objective 5.

1.8 Stages

In order to accomplish the thesis objectives, the next set of stages and tasks was defined.

Stage 1: Domain Model

1.1. DM scheme: to define a conceptual and functional structure for the domain, detailing all its components and relationships.
1.2. Pre-requisites structure: to define a structure that allows the design of courses with some instructional guideline e.g. hierarchy, sequencing, parallelism, etc.

Stage 2: Student Model

2.1. Personal information: to define the kind information that may be used not only to identify student as a system user, but also for adaptation purposes.
2.2. Knowledge-related information: to analyze the different kinds of models that may be used to map student knowledge with the knowledge domain.
2.3. Psycho-Cognitive information: to define the kind of information that may help in the learning process and particularly with regard to adaptation.

Stage 3: Tutor Model

3.1. Adaptive sequencing and navigation support: to define how curriculum would be deployed to student as he/she advances in the learning process.

3.2. Adaptive presentation: to define a mechanism for the selection of the more appropriate LO or LOs that would be presented to a student during a particular learning activity. This task considers also the LOs' specification and their relation with DM, SM and TM.

3.3. Adaptive assessment and remediation: to define a progressive assessment mechanism according to student aptitudes and how to provide helping when he/she fails.

3.4. Adaptive collaboration support: to define how students may be paired or grouped with the aim of engaging collaboration trough learning assistance and other activities.

Stage 4: Model instantiation

4.1. Each one of the three previous stages must be accompanied with the instantiation of the corresponding models for the design of a specific application. This is done in order to present an example to clarify even more the aim and functions of each model as well as their relationships.

Stage 5: Prototype implementation

5.1. Application architecture: to define the hardware and software architecture to implement the prototype.

5.2. Features: to define the main interfaces of the prototype and those features that are not described in previous stage for being specific of the application.

5.3. Implementation: to codify the whole application and perform basic functionality tests.

Stage 6: Prototype validation

6.1. Experiments: to define the set of usability tests and measuring mechanisms with pilot user groups for teachers as well as for students.

6.2. Results: to perform the previously defined tests and analyze the obtained results.

1.9 Contributions

The main contributions of this thesis in the CAL field may be summarized in the next points:

- It proposes a reference model which has several important connotations. The first one is that it is not bounded neither to a particular knowledge domain nor a specific pedagogical strategy, i.e. it is generic. This does not necessarily means that it may be used in absolutely any domain and under any strategy, but that it could be useful

in a wide spectrum of them as always that final users in their role of courses creators (teachers, domain experts and instructional designers) follow some appropriate guidelines. The second one is that adaptation, the final aim of this thesis, may be performed considering one or several criteria that are not particular as well, which makes possible the use and experimentation of diverse theories and approaches.

- As mentioned in section 1.3, one of the principles of this work is to achieve equilibrium between the AIES functionalities and the ease in their design and implementation. For doing that, a set of essential functionalities and considerations were covered, having in mind the previously mentioned generalization criterion as well as an extensive state of the art revision, part of which is presented in section 1.4. Even if other functionalities and characteristics are not considered here, as it was said in section 1.7, there won't be significant difficulties to incorporate them in further works thanks to the used formalism level; by the contrary such formalism would facilitate these efforts.

- In terms of software development, its purpose is focused in the design stage, which implies a formal description of all the system components as well as its functionalities and relationships. This issue differentiates this research of others where just a superficial description of an implemented AIES, with one or more of the analyzed functionalities, is presented and makes achieving a successful implementation very difficult for who could be interested. This issue also allows reaching a better dialog between cognitive and technical fields, allowing handling a common language between experts from both sides.

- It defines how to incorporate LOs into the AIES world, not only conceptual but functionally exploiting several advantages that it implies: a) they may have a fine granularity, providing flexibility and re-usability; b) they are described through well-defined metadata which facilitates their management; c) they may be accessed from lots of repositories which allows final users having tons of available resources; and finally d) it allows joining a worldwide community that promotes them as powerful pedagogical tools.

- Besides the detailed description of all models, this thesis presents a validation case in the form of an instantiation that consists in the design of a particular application. This not only clarifies even more the model proposed, but also demonstrates its viability, inviting this way to other researches to develop their own instances. It is important to mention however that such instantiation is only a particularization so the corresponding design decisions do not try to impose any pedagogical nor technical considerations but to exemplify how they could be incorporated.

- The AIES standard structure (also shared by ICAI and ALS) that considers three main models DM, SM and TM is adopted. This allows that the designed systems may be comparable functional and conceptually with others from those approaches, allowing a translation among them.

1.10 Document's outline

Based on the development of the six stages defined in section 1.8, a graphical representation of the proposed model's general schema is presented in figure 1.8.
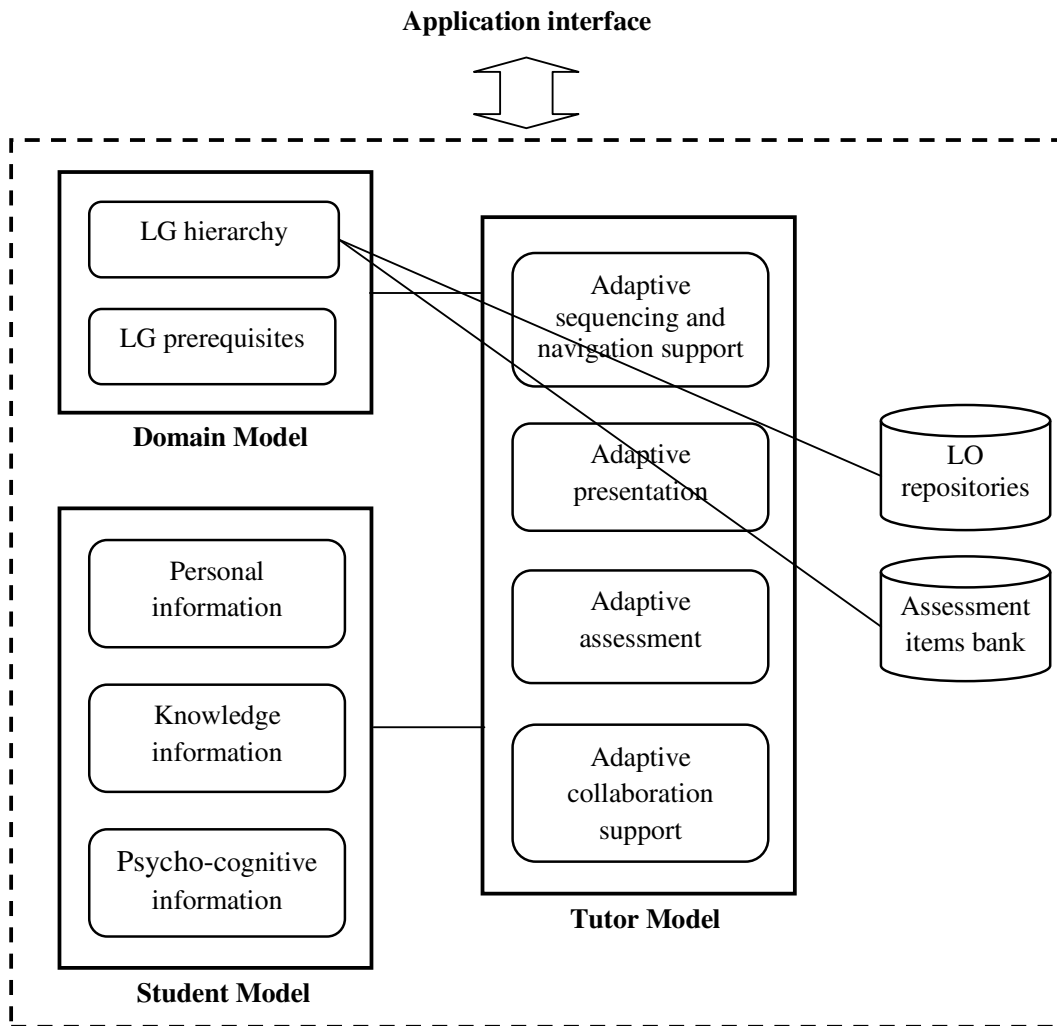
Figure 1.8: General schema of the proposed model

In order to facilitate the thesis reading, the structure of the next four chapters aims to describe in detail all these components. Chapter 2 describes the DM that corresponds to the development of Objective 1, Chapter 3 describes the SM that corresponds to the Objective 2 and Chapter 4 describes the TM that corresponds to the Objective 3. Breaking this protocol, Objective 4, which refers to the instantiation of the reference model in a particular application called "Doctus", is not presented in a separated chapter but at the end of chapters 2 to 4, just before the chapter reflections, being useful as a clarifying example. The implementation and validation of such instantiation is described

on Chapter 5 which corresponds to the development of Objective 5. To finalize, Chapter 6 presents the thesis conclusions and future work.

2 DOMAIN MODEL

As mentioned in the previous chapter, the DM provides a structured conceptualization of the domain knowledge to be taught and, in this way, helps to answer the question "from what adaptation is made?" In this chapter a proposal for such a conceptualization is presented, giving a detailed explanation of all its components and relationships. This will be useful in next chapters to understand some issues of SM and TM.

2.1 Domain Model schema

According to (BRUSILOVSKY, 2003), the starting point of any adaptive systems is a structured DM that is composed of a set of small domain knowledge elements. Such elements are named differently in different systems: concepts, knowledge items, topics, knowledge elements, learning objectives, learning outcomes, but in all the cases they denote elementary fragments of the domain. Here, with the aim of working with a DM not just from a well-structured point of view but also from the pedagogical one, the notion of Learning Goal (LG) will be used. Also known as educational objectives, pedagogical goals and other denominations in different works, the LGs may be defined as statements that describe, in terms of observable behavior, the results that are expected from the teaching/learning process. Further information about this notion may be obtained in (DUQUE, 2009).

In order to structure the LGs, and therefore the DM, a collection of one or more Simple Directed Graphs (SDG) will be used. This approach was used instead of others more robust, ontologies for example, because it simplifies DM instantiation and its connection with the SM and TM as explained later.

A SDG is defined as a pair $G = (V, A)$ with a set V, whose elements are called vertices or nodes, and a set A of ordered pairs of vertices, called arcs (also known as directed edges or arrows). In this case the vertices are the LGs, whereas the arcs represent decomposition operations, it means that there could be atomic LGs (a leaf) or composite (a vertex with at least one arc going out from it). Although according to this last description an LG could have only one "son", the normal would be that it has at least two because such relationship represents a decomposition of the DM in terms of content instruction, rather than an actual content taxonomy. This however is just a recommendation because from de DM point of view as well as from the other models that are described later, it is not problem working with a LG without nay "brothers".

SDG graphs also have the following two properties: they do not have multiple nodes, which means that each vertex is contained only once and; they are acyclic, which

means that in every possible arrangement represented by the graph, each vertex has a unique existence. Additionally to these two, there is another property for the proposed DM: just leaf LGs have actual content whereas the other ones are used only to build the structure domain knowledge. It does not mean that such "brunch" LGs does not play an important role in the system because in fact, as is described later in the SM and the TM, they are useful to represent student knowledge.

A DM general schema using the SDG approach is illustrated on figure 2.1. Notice that each LG has a unique identifier (it does not matter its format) that allows the verification of the two properties described earlier. A continuous arrow going out from LG_i to LG_j defines a subdivision of LG_i into LG_j and may be interpreted as "LG_i is divided in / is composed by / contains / has / ... LG_j" or, in the other way, "LG_j is a division of / is part of / is contained in / ... LG_i".
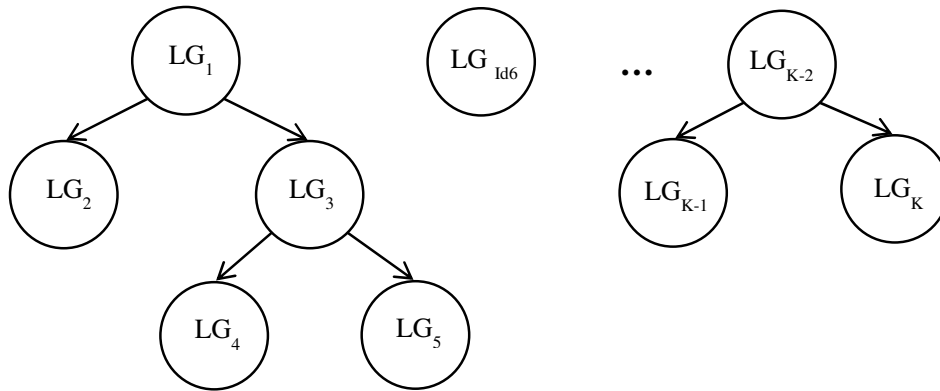
Figure 2.1: DM general schema

This approach grants DM flexibility, allowing the definition of typical structures like the ones presented on figure 2.2, as well as other more complex that are just combinations of those, like the one presented on figure 2.1.

(N-ary) Hierarchical tree structure
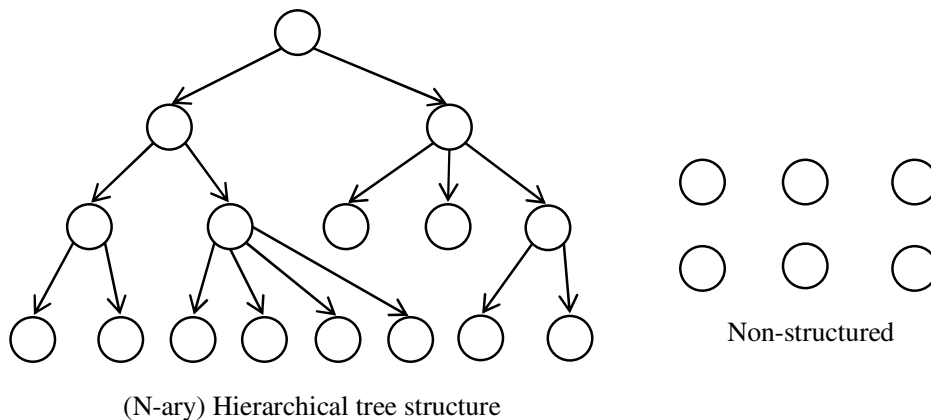
Non-structured

Figure 2.2: Typical DM schemas

As stated in (KNUTOV et al., 2009) this type of DM, where all the elements may be fine grained and hierarchically structured, makes adaptive presentation and navigation support come into play. In fact, most adaptive systems embrace DM schemas similar to the one presented here, the differences lie basically in the name of the elementary

fragments, in the connections restrictions or in the hierarchy depth. For example the study presented in (HATZILYGEROUDIS & PRENTZAS, 2004) proposes a four levels hierarchical structure composed by concept groups, concept subgroups, concepts and course units, these last ones constitute the learning material to be presented to the students in the form of Web pages. In (JIMÉNEZ, 2006) the author proposes two levels called learning basic units and instructional goals. In the work presented in (ARIAS et al., 2009) the DM may be seen as an extension of the previous one adding two more levels with which the whole structure is defined as learning basic units, topics, instructional goal and activities, these last ones contains the learning material which in this case refers to LOs.

Many other works agree with this proposal in the sense of using not a fixed but a N-levels structure using the notion of composite fragments. For example, in (CRISTEA & AROYO, 2002; CRISTEA & De MOOIJ, 2003; CRISTEA & CALVI, 2003) they define such fragments as concepts, similarly to the work presented in (DAGGER et al., 2005), whereas in (MOTZ et al., 2008) they are called topics.

Considering such approaches, the main contribution of the proposed DM is that it is general and flexible enough to cover most of such possibilities and therefore author decisions about domain knowledge structure going from independent items to simple sequential items, typical book-like structures, hierarchy trees with or without semantic meaning, etc.

2.2 Prerequisites structure

The DM schema described in the previous numeral defines the domain knowledge subdivision, but it does not stay the order in which a student must cover the LGs. For instance, according to figure 2.1 LG_2, LG_4, LG_5 and LG_6 are LG leaves, but it does not stay the order to cover them (the alphabetical order of the LG identifiers is not related at all with the sequencing).

DM in different implementations of ALS and ICAI differ in complexity about how they deal with the sequencing mechanism. For example some of the former AEHS developed for teaching practical university courses employed a simple vector approach (DE BRA, 1996; BRUSILOVSKY & ANDERSON, 1998), meanwhile some more modern ones use networked models with several kinds of links that represent different kinds of relationships between DM elements (BRUSILOVSKY, 2003).

In order to provide a flexible sequencing mechanism, and being consistent with many ALS and ICAI studies, a simple prerequisite structure is proposed in this thesis. Such mechanism defines prerequisite links between DM elements, in this case LGs, which represent the fact that one of the related LG has to be learned before the other. Besides of having pedagogical sense and being easy to understand by users of the implemented systems, prerequisite links support simple adaptation techniques as will be described later in chapter 4.

To define this relationship between LGs in the DM schema, a dotted arrow is used going out from LG_x to LG_y meaning that LG_x must be learned before LG_y or, in the other way, that LG_y cannot be developed without having learned LG_x first. See for example figure 2.3 which is a part of the figure 2.1. In this case DM defines four leaf LGs and stays that LG_4 is prerequisite of LG_5, whereas LG_5 is prerequisite of LG_6. LG_2

and LG_4 do not have any prerequisites so it means that a student could see them anytime depending on the navigation techniques adopted by the TM.

This approach has two interesting properties. First, a LG may have zero, one or more prerequisites, in the last case the relation works in the same way than in the unitary one described previously: if LG_x, LG_y, LG_z, … are prerequisites of LG_w it means that all of them (as a conjunction) must be learned in order to be able to develop LG_w. Second, prerequisite links may be defined for leaf LGs as well as for composite LGs, in this last case such relationship works in the same way than it works for leaves but involving all the LG sons.
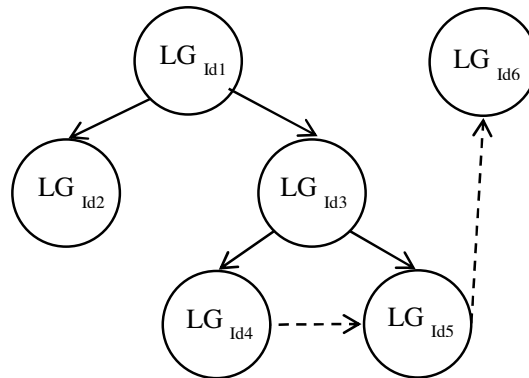
Figure 2.3: Example of DM prerequisite definition

Notice however that in both properties its use depends on application designer and ultimately on user decisions. About the first one for example, look in figure 2.3 that although it is not wrong to stay that LG_4 is prerequisite of LG_6, it would be unnecessary because LG_6 has LG_5 as prerequisite, which at the same time has LG_4 as prerequisite. In other words there is a transitivity rule implied. About the second one, even if conceptually there could be some "analogies", they do not work in exactly the same way depending on some SM and TM considerations. For example in figure 2.3 the prerequisite relationship between LG_5 and LG_6, considering that there are a relationship between LG_4 and LG_5, could be replaced for a relationship between LG_3 and LG_6. It would mean exactly the same depending on how TM determines the summative assessment for composite LGs (it is not necessarily the arithmetic mean of its subparts) and therefore updates de SM.

According to these examples it is important to emphasize that finally is the user in its role of author, usually the human teacher or domain expert, who determines the more appropriate prerequisites structure. In this sense, the proposal presented here just gives him/her a powerful and flexible mechanism to adjust proposed DM to his/her decisions.

2.3 Domain Model instantiation

Considering that there are not particular design decisions about the DM described in this chapter, it may be said that Doctus, the instantiation example that serves to fulfill the four objective of this dissertation, simply adopts the proposed general schema and prerequisite structure. However, thinking on the translation of such aspects to the implementation phase, there are some specific issues that Doctus addresses.

The first issue is the representation of the general schema, where the ideal scenario would be an interface that provides graphical manipulation of the LGs in a similar way to many CAD platforms for other purposes. Doctus however, at least in a first version, would not have such functionality so another representation technique must be used instead. The proposed alternative consists on using two tables, one to define LGs and their settings, and another one to define subdivision relationships. To illustrate the use of such tables, an example of a DM (suppose that is for certain topic in a history class) is presented on figure 2.4 whereas the corresponding representation in Doctus is presented on tables 2.1 and 2.2.
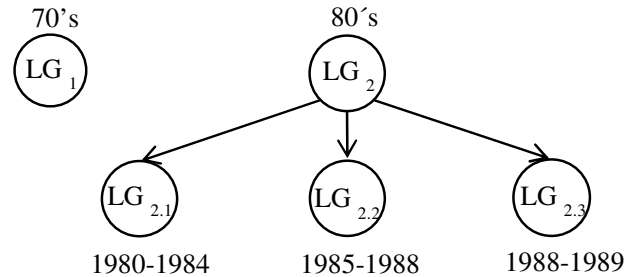
Figure 2.4: Example of DM

Table 2.1: Example of LG description table in Doctus

Identifier	Title	Description
LG 1	70's	Here, student would be able to know, analyze and discuss the historical facts about … that happened during the 70´s
LG 2	80's	…
LG 2.1	1980-1984	…
LG 2.2	1985-1989	…
LG 2.3	1988-1989	…

Table 2.2: Example of LG connections table in Doctus

Parent LG	Son LG
LG 2	LG 2.1
LG 2	LG 2.2
LG 2	LG 2.3

The use of these two tables does not mean necessarily that final user would have to manipulate them directly; instead Doctus could use a directory-like structure which is common in many other Web-based systems. The representation in this structure of previous example is presented on figure 2.5.
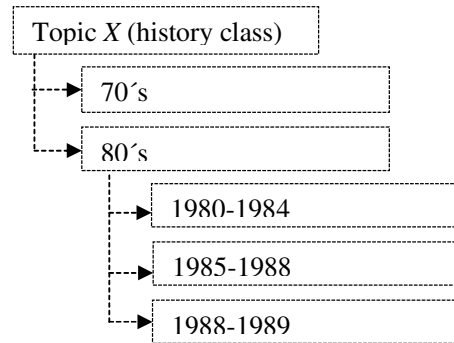
Figure 2.5: Example of DM using directory structure in Doctus

Notice in this point, the power of the proposed DM flexibility that was described in section 2.1. A lot of different arrangements may be used to structure domain knowledge according to user decisions and, in all cases, could be translated to the corresponding Doctus directory structure and tables. On figure 2.6 for example, a typical book-like structure is presented.
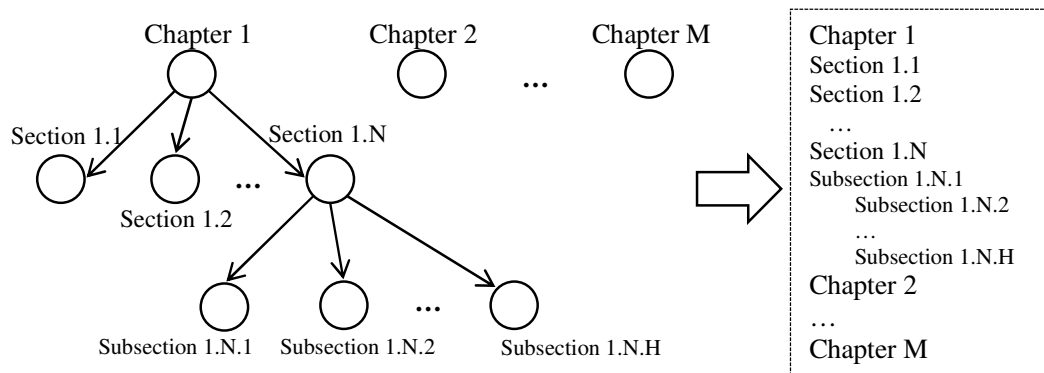
Figure 2.6: Examples of a book-like arrangement for DM

The second issue refers to the prerequisite structure. In this case Doctus also uses a table to define these relationships. Going back to the example, suppose that the prerequisites presented on figure 2.7 are required. In this case the corresponding prerequisite table is presented on table 2.3.
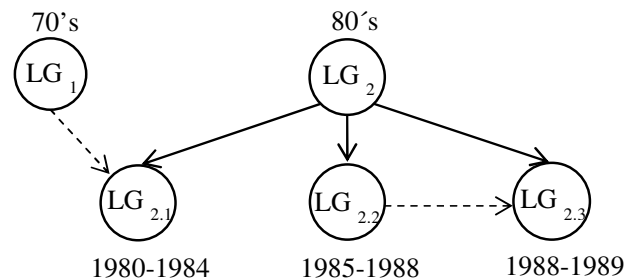
Figure 2.7: Example of DM with prerequisites

Table 2.3: Example of LG pre-requisites table in Doctus

Pre-requisite LG	Post-requisite LG
LG 1	LG 2.1
LG 2.2	LG 2.3

2.4 Chapter reflection

As mentioned at the beginning of this chapter, a well-structured DM is the basis for any AIES. Keeping this in mind, an extensive literature review for different approaches was made and, based on it, the DM presented on this chapter was proposed.

The main contribution of this model is that it is highly flexible thanks to the hierarchical LG schema and the prerequisites structure presented on sections 2.1 and 2.2 respectively. It means that this DM does not predefine a particular disposition for the courses that might be designed. Instead, it allows for using any arrange that teachers (but more general, AIES users) have in mind. In other words, this model can be seen as a construction playing set: it provides a set of pieces and connections, but the resulting design is as simple or as complex as the player wants.

3 STUDENT MODEL

As mentioned on section 1.2 the SM provides diverse information about the student in order to monitor him/her and to answer the question "To what may be adapted?". According to (JEANTY, 2005), this model must be robust enough in order to represent the whole student natural complexity. To reach such robustness, several kinds of information are considered on this chapter. In particular, next three sections describe personal, knowledge-related, and psycho-cognitive information which may be divided in major categories depending on several issues. For instance, personal and psycho-cognitive data may be considered as domain independent information (are inherent to the student) whereas knowledge an interaction data are obviously domain dependent. Other subdivision may be made according to data's updating frequency. In most systems personal data is retrieved just once during student's first interaction and is updated occasionally. In the other side of the spectrum it is located the Knowledge-related data which is expected to change on each interaction. This however is not necessarily a rule because for instance a student may just "open" the application without doing anything related to the learning process. Finally psycho-cognitive data in some systems, similarly to the personal data, is retrieved only once using forms or questionnaires, although there are also many others systems that consider mechanisms to update it.

3.1 Personal information

As in any other kind of system, certain basic information is required to identify the user that is using it. Although *Login* or its analogues is actually the only mandatory data to achieve unique user identification, there are a lot of typical data that may be included in this category like for instance: *Name*, *Gender, Country*, *City*, *Birth date*, *Language*, etc.

Notice that from all these data, some are for student identification only, whereas other may be used also for adaptation. As examples, *Language* may be used as an obvious preference parameter, whereas with *birth date* the age may be calculated and then some content may be presented according to the certain range that it belongs. In all cases, data is represented as a pair *attribute – value*, where the value may be in different formats (text, number, date, etc.) but as a scalar.

Formally speaking, if there are in total P attributes of personal information in the SM and Q of them may be used for adaptation, system could use attribute $SMPI_q$ ($1 \leq q \leq Q$) for adaptive presentation as is described later on chapter 4.

3.2 Knowledge information

Being the learning process the obvious focus of any CAL system, there has been a lot of researches in ALS as well as in ICAI fields about how to represent student's knowledge and, therefore, a lot of models have been proposed for this purpose (JEANTY, 2005; JIMÉNEZ, 2006, MARTINS et al., 2008). Some of the more referenced models are described here.

- Overlay model: in this approach the student knowledge is considered as a subset of the whole DM and it supposes that all differences between them are explained by a lack of such knowledge in the student.
- Differential model: may be considered as a modification of the overlay model and divides the student knowledge in two categories: the one that he/she should have and the one that he/she should not. Differently to the overlay model, the differential model recognizes and tries to represent in an explicit way the differences between student and tutor (in this case the DM).
- Perturbation model: combines the overlay model (correct knowledge) with a representation of the incorrect knowledge. This way, instead of being a subset, student knowledge is considered different to the one represented in the DM in quantity as well as in quality. The more common technique to implement this model is using expert systems to recognize the mistakes that are committed by most students and which may be divided into misconceptions and bugs.

A graphical abstraction of these three models is presented on figure 3.1.
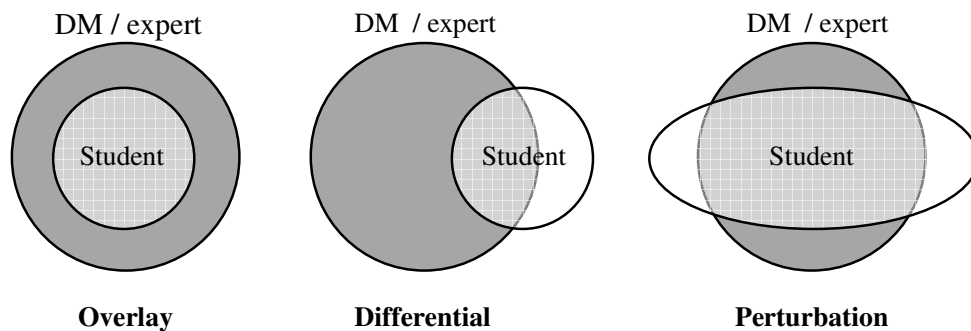
Figure 3.1: Overlay, differential and perturbation models

- Restrictions-based model: is a modification of the overlay model where the knowledge domain is represented with a set of restrictions about the states of the problems which are used to explain it. This way, student is represented as the list of restrictions that he/she violates in the resolution process for those problems.
- Stereotypes model: as its name implies, this model is based in the classification of the students into a series of groups which are generalized according to the characteristics that represent them. Typical cases of that kind of groups are for example: "Outstanding", "Average", "Deficient", etc.

From all these approaches, the overlay model is used in this proposal due to its simplicity and for being the most compatible one with the DM described in the previous chapter. Additionally, as (BRUSILOVSKI, 2003) points out, this model is powerful, flexible and it can measure independently the student's knowledge of different elements of the DM.

While some successful educational AEHS and ITS, specially the older ones, use the classic binary form of overlay model which consist in tag every DM element with "approved" or "not-approved", "known" or not known", the majority of systems uses a weighted overlay model that can distinguish several levels of student's knowledge of such elements. Some of them use qualitative values like "good", "average", etc. (BRUSILOVSKY & ANDERSON, 1998; GRIGORIADOU et al., 2001), others use integer or float quantitative value within some range like 0-100, 1-5, etc. (BRUSILOVSKY et al., 1998; DE BRA & RUITER, 2001), and others use a probability value to represent a belief about student's knowledge (HENZE & NEJDL, 1999; SPECHT & KLEMKE, 2001).

Being generalization one of the guiding principles of this thesis, a continuous value between 0 and 1 is proposed to measure student's knowledge level for each LG of the DM. This alternative covers all the previous ones and therefore may be translated to any of them using simple scaling, categorization and rounding operations (except in the last alternative, the probability value, in which case translation is direct).

According to this, the representation of knowledge information is quite simple and consists in a table for each student where, given a DM, the list of all the LG along with the corresponding inferred knowledge value is presented. A general representation following this format is presented on table 3.1.

Table 3.1: General knowledge information in the SM

LG	Knowledge level
LG_1	
LG_2	
…	
LG_K	

Depending if the system incorporates some mechanism to measure student's previous knowledge, the initial values of these levels for each student will be 0 (if it do not), or the corresponding value of such measure.

3.3 Psycho-Cognitive information

Before going any further, it is important to start defining what cognition is. This term, from Latin *cognoscere*, "to know", "to conceptualize" or "to recognize", refers to the process of thought. Being this definition that broad, its usage varies in different disciplines; for example in psychology and cognitive science, it usually refers to the information processing view of an individual's mental functions; whereas interpretations in other fields link it also to the development of concepts, as well as of individual or social reasoning. In this thesis' concern, cognition is referred as the process of thought

but with particular interest in its relation with learning and specifically with individual/social knowledge construction.

Notice however that the title of this section is "psycho-cognitive information", instead of merely "cognitive information", so what does the psychological aspect refer? Well, during learning not only cognitive process are involved. For example, the mood of the student, from psychological nature, may affect the way he/she internalizes new knowledge. With these issues in mind, psycho-cognitive information refers in this dissertation to any information related to mental and psychological process involved in learning and that allows making a student profile within this context.

In the opinion of many researchers any educative practice, CAL or classical, is not meaningful if it does not consider this kind of information to enrich teaching / learning process. Although in first attempts in CAL such considerations were not included because systems were too simple, modern ALS and ICAI approaches are including them with the help of multiples areas like pedagogy, neurology and others. Within these considerations there have been lots of works that incorporates one or several alternatives that are derived of different theories and perspectives like cognitive styles, learning styles, multiples intelligences, psychological and psycho-technical profiles, among others.

This abundance of alternatives means sometimes an inconvenience because it is difficult for an instructional designer to know the details of all of them as well as the corresponding required pedagogical considerations, with the additional problem that exist several different models for each one. For example, only in the case in which learning styles are used as the main adaptation parameter, there are more than 70 different models in use (COFFIELD et al., 2004). Some of such models and systems that use them are listed on table 3.2. For a deeper description of those and other models, reader can review appendix A.

Table 3.2: List of learning styles models in implemented systems

Learning style model	Systems
Dunn and Dunn's Learning Styles Inventory	iWeaver (WOLF, 2003)
Witkin's field dependence/independence model	AES-CS (TRIANTAFILLOU et al., 2003)
Kolb's Learning Style Inventory	INSPIRE (GRIGORIADOU et al, 2001)
Felder-Silverman's Index of learning Styles	CS388 (CARVER et al., 1999)
	CAMELEON (LAROUSSI, 2001)
	MAS-PLANG (PEÑA et al., 2002a)
	ILASH (BAJRAKTAREVIC, 2003)
	TANGOW (PAREDES & RODRIGUEZ, 2003)
	WHURLE (BROWN & BRAILSFORD, 2004)
	CIA (MORENO et al., 2009)
VARK	SICAD+ (DUQUE, 2009)

In the scope of this work, the discussion of which alternative is more adequate for AIES is not included; instead, a proposal for how to deal with them from the systems point of view is presented. Further information about such alternatives and their use in educative systems may be found in several works, in particular the work presented in

(STASH, 2007) is recommended for the topic of cognitive and learning styles integration in AHS.

About the representation of psycho-cognitive information in the SM, considering that most of the mentioned alternatives use several dimensions to describe some student characteristic rather than a punctual valuation, an array representation instead of a scalar as the ones used in previous two sections is proposed. More specifically, if *R* characteristics are considered, a student may be described with *R* arrays as:

$$SMCI_r\ (1 \leq r \leq R) = \{dimension_1,\ dimension_2,\ \ldots,\ dimension_D^{(r)}\}$$

Where each one of the $D^{(r)}$ dimensions corresponds to the quantitative value for that student that is obtained with the respective measuring mechanism (test, interview, self-valuation, etc.) for the characteristic *r*. In the case that such mechanism uses qualitative descriptions instead of qualitative, a simple discretization process would be necessary in order to be compatible with the adaptation process described later on chapter 4. Another consideration about such compatibility is that for comparative purposes, all values must be in a similar scale. The simplest way to do that is scaling each array to the range $0 - 1$ using *(X-min)/(max-min)*, where *X* is the value of each dimension and *min*, *max* are the corresponding minimum and maximum of the measured values for the specific characteristic.

3.4 Other information

Besides the information described in sections 3.1 to 3.4, SM may contain a lot more information about the student to enrich the personalization process. The reason for not including such other perspectives in this proposal is because it is beyond its scope to present the "ultimate" adaptation system, which would violate the "keep it robust but at the same time simple" principle stated in the research problem section. Instead, the aspects that were considered as the more fundamental and relevant, from a personal perspective, were included.

However, it must be said in favor of this proposal, that its systematic approach allows designers to extrapolate the aspects and adaptation techniques presented here, to such other information as long as they use the pair *attribute – value* format described in section 3.1 or the array format of section 3.3. How such formats are related with the adaptation process is explained in detail in the next chapter.

After a broad review of many researches in adaptation, some of such other kind of information was identified and is summarized on table 3.3.

Table 3.3: Other feasible information in the student model

Type	Example
Contextual	Access device, operative system, bandwidth, desktop resolution, etc.
Affective	Anxiety level, motivation , etc.
Cultural	Region, race, etc.
Physical	Vision, audition, etc.
Environmental	Light conditions, acoustic conditions, etc.

3.5 Student Model instantiation

Different to the DM where there were no particular designing decisions for Doctus, in the SM there are in did several decisions that are the focus of this section. The exception to this statement is the knowledge information where there are not such decisions with regard to the representation described on section 3.2.

1) Personal information

$P = 7$ attributes are considered in Doctus to identify student. They are shown in detail on table 3.4 using a representation that is similar to the one used for data base tables.

Table 3.4: Personal information in Doctus

Attribute	Format	Restriction	Mandatory
First name	Text (30)		X
Last name	Text (30)		X
Login*	Text (20)	≥ 3 characters	X
Password	Text (20)	≥ 6 characters	X
Gender	Text (6)	{male, female}	X
Birth date	Date		X
E-mail	Text (30)		X

*Unique identifier

2) Psycho-cognitive information

From all the possible alternatives that may be used for the student´s psycho-cognitive characteristics (some of them mentioned previously), $R = 3$ are considered in Doctus, all of them referred to learning styles: a) the Honey & Mumford's model, b) the VARK model and c) the Jackson's model. Why they were selected and how are they used is explained later in the corresponding adaptation techniques that consider them.

Before going any further in the description and formalization of these characteristics according to the specifications defined in section 3.3, it is necessary a brief introduction about learning styles. First, without the aim of detailing too much this topic nor encourage discussions that are more related to other kind of works, it is important to point out that there is considerable ambiguity in the literature concerning the terms learning styles and cognitive styles, and they have been used even interchangeably (SADLER-SMITH, 1996). According to some psychologists, most definitions of learning style as well as cognitive style illustrate variations in individual information processing. Cognitive style deals with the "form" of cognitive activity (i. e., thinking, perceiving, remembering), not its content, whereas learning style on the other hand, can be considered to cover a much broader range of approaches for learning. Cognitive styles have been studied extensively in academic research whereas learning styles have been studied mostly in conjunction with practical applications (LIU & GINTHER, 1999). After this brief comparison just rest to say that in this thesis, the definition of learning style presented in (KEEFE, 1979) is adopted, which states that they are

relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment.

In order to justify its inclusion inside the psycho-cognitive characteristics, it must be said that several researches show that matching/mismatching student's learning style with the design of an instruction can be an important factor with regard to learning outcome (STASH, 2007). In fact, a significant number of studies indicate that student's performance is much better if the teaching methods are matched to their learning styles (CHEN & MACREDIE, 2002).

Now, with regard to the methods that are used to 'capture' or 'estimate' the learning styles of a subject, two different approaches may be differentiated. The first one is based on using questionnaires where the styles are determined whether implicitly or explicitly. This approach is the more common, in fact, most of the implemented systems listed on table 3.2 use it, however is also largely criticized for being static in the sense that the measuring is made only once (usually at the beginning of the user interaction with the system). In a different way, the second approach is based on an automatic acquisition of the learning style based on a continuous monitoring of the student progress through the learning material. This in theory would provide a more accurate estimation but is more expensive in terms of computational effort. An example of an implemented system that follows this approach is presented in (MONTESERIN et al., 2010).

From these alternatives (a third one could be a hybrid of the two mentioned), Doctus follows the first one at least in its initial version. It is important to mention however that for the reference model point of view any estimation method could be used as long as the result is translated to the required notation.

a) Honey & Mumford's model

This model (HONEY & MUMFORD, 1982; HONEY & MUMFORD, 2000) defines four dimensions that may be considered as a pair of dichotomies in the light of the theoretical framework in which is based, the Kolb's experiential learning theory (KOLB, 1984; KOLB, 1999):

- Reflectors: prefer to learn from activities that allow them to watch, think, and review. They like for example lectures and case studies that provide explanations and analysis.
- Activists: prefer challenging experiences and situations in which new ideas can be developed without constraints of structure. They like for example problem solving and discussions.
- Theorists: prefer to explore methodically the associations and interrelationships between ideas, events and situations. They like for example readings and analogies. Talking with experts is normally not helpful.
- Pragmatists: prefer to apply knowledge to actual practice to see if they work, concentrating on practical issues. They like for example laboratories and simulations.

The measuring mechanism for this model is called Learning Styles Questionnaire which, differently to its predecessor, the Kolb´s Learning Style Inventory, does not ask

people directly how they learn (something that most people have never consciously considered), but give them a questionnaire which probes general behavioral tendencies rather than learning. This questionnaire has two versions: the 80-items which is the original version with 20 items per dimension and a reduced 40-item version with 10 items per dimension. In both cases each item must be answered with one of two choices 'agree' or disagree'.

For the sake of accuracy the 80-items version was selected for Doctus and, after have it completed, the result of a student consists in four values between 0 and 20. To transforms these results to the required array representation, dividing each value per 20 is just enough. For example if a student takes the questionnaire and obtains 16, 6, 14, 8 in the reflector, activist, theorist and pragmatist dimensions respectively; its array representation ($D^{(1)} = 4$) would be $SMCI_1 = \{0.8, 0.3, 0.7, 0.4\}$.

b) VARK model

Differently to the Honey & Mumford model that could be considered as related with processing preferences of the learner, the VARK model (FLEMMING & MILLS, 1992) focuses on the sensory preferences and defines four dimensions:

- Visual (V): this dimension could be rather called Graphic (G) because it describes a preference for information presented in this representation. Students with this dimension learn best for example from maps, diagrams and charts.
- Aural (A): describes a preference for information that is heard or spoken. Students with this dimension learn best for example from lectures, dialogs, tapes and group discussions.
- Read/write (R): describes a preference for information displayed as words. Students with this dimension learn best for example from
- Kinesthetic (K): by definition, this dimension refers to the preference related to the use of experience and practice. Although such an experience may invoke other modalities, the key is that people who prefer this mode are connected to reality. Students with this dimension learn best for example from demonstrations, simulations and videos real things.

The measuring mechanism for this model is a 13-items questionnaire, where each item is presented in a multiple choice format and consists in a question that attempts to place learners in a situation within their experience and asks for a perception of their preferred action. In four questions there are three choices, whereas the remainder ones have four choices.

This way, summing the answers for each dimension the result of a student consists in four values: 0 to 12 for Visual, 0 to 12 for Aural, 0 to 13 for Read/write, and 0 to 11 for Kinesthetic, 11. To transforms these results to the required array representation it is necessary to divide each value per its corresponding maximum. For example if a student takes the questionnaire and obtains 7, 3, 2, 3 in the four dimensions, its array representation ($D^{(2)} = 4$) would be $SMCI_2 = \{0.58, 0.25, 0.15, 0.27\}$.

c) Jackson's model

This model is based on a neuropsychological approach, specifically the Gray's theory (GRAY, 1982) and is intended to define learning styles for business and education, being understood as a sub-set of subject personality and having a biological basis (JACKSON, 2002). Four dimensions are proposed:

- Initiators: is thought to be linked with Gray's behavioral activation system, which initiates approaching behaviors when there is a chance of reward. Students with this dimension are usually impulsive and extroverted.
- Reasoners: is thought to have a basis in Gray's behavioral inhibition system which inhibits behaviors in response to cues associated with punishment. Students with this dimension are usually rational and intellectual.
- Analysts: is seen as a self-regulatory, goal-oriented tendency which serves to maintain interest in a problem so that it can be thoroughly understood. Students with this dimension are usually introverted, responsible, cautious, methodological and insightful.
- Implementers: no neuropsychological basis is claimed for this dimension, which is seen as a logically necessary addition if plans are to be carried out. Students with this dimension are usually practical, realistic and expedient.

The measuring mechanism for this model is called Jackson's Learning Styles Profiler which contains 80 items, 20 items per dimension and learners have to answer from the options 'yes', 'no' and 'cannot decide'. After have it completed, the result of a student consists in four values between 0 and 20. To transform these results to the required array representation, it is necessary to divide each value per 20. For example if a student takes the mechanism and obtains 4, 13, 16, 9 in the initiator, reasoner, analyst and implementer dimensions respectively; its array representation ($D^{(3)} = 4$) would be $SMCI_3 = \{0.2, 0.65, 0.8, 0.45\}$.

3.6 Chapter reflection

"The secret in education lies in respecting the student" - Ralph W. Emerson

And, what better way of respecting the students than recognizing their individual differences? With this idea as guiding principle, in this chapter a SM was presented considering three main components: personal, knowledge-related and psycho-cognitive information, which are described in sections 3.1, 3.2 and 3.3 respectively.

It is true that such a SM could be more robust incorporating other components as mentioned in section 3.4. However, with the aim of simplifying the adaptive processes described in next section only the three mentioned were kept. It does not mean that this proposal cannot be improved including new components. In fact, it can be seen as a starting point which is destined to become richer and richer as new ways of measuring student characteristics emerge.

4 TUTOR MODEL

This model may be seen as the "heart" of the system, not only because it provides a connection with DM and SM, but also because it incorporates the pedagogical considerations for the whole teaching/learning process.

As mentioned on section 1.2, this model answers the questions: "What to adapt?", "When to adapt?" and "How to adapt?", whose answers are the main focus of this chapter. The "What" refers to the processes in the educational context that are going to be modeled and adapted. On the other hand, the "When" refers to the events that trigger such processes, whereas the "How" to the methods and techniques that are used to achieve the adaptation.

In this thesis, as explained in the scope section of chapter 1, four main functionalities are considered: adaptive sequencing and navigation support; adaptive presentation; adaptive assessment; and adaptive collaboration support. The first two determines how the domain knowledge is going to be presented to the student; this is, in what order (section 4.1) and through what content (section 4.2). The third one determines how the student knowledge level is evaluated, what feedback is presented, and what may be done to help the student when such level is low (section 4.3). Finally, the fourth one determines how collaboration activities may be incorporated and in what processes. In all the cases, as their names imply, these functionalities have an adaptive nature and use as basis the domain structure from DM, along with the student characterization from SM.

4.1 Adaptive sequencing and navigation support

This section was called intentionally this way to emphasize the combination of two approaches: adaptive sequencing, more known as curriculum sequencing from ITS; and adaptive navigation support from AHS (and therefore from AEHS). Although in the section 1.7 it was said that they are analogous, in the sense that both deal with what and when instruction should be presented to each student, it is necessary to detail here that the former refers more to a high abstraction level, whereas the later to a low level details like the specific techniques to work with links and they relationship with content.

More specifically, the goal of adaptive curriculum sequencing in ITS according to (BRUSILOVSKY & PEYLO, 2003) is to provide the student with the most suitable individually planned sequence of topics to learn and learning tasks to work with; in other words, it helps the student to find an "optimal path" through the learning material. In order to do that, curriculum sequencing can generally be distinguished as either

knowledge sequencing or task sequencing (CHEN et al., 2006). The first determines next teaching element of DM to be presented, whereas the second determines the next task within a current element.

On the other hand, according to (BRUSILOVSKY, 1996) the idea of adaptive navigation support in AHS is to help users to find their paths in hyperspace by adapting the way of presenting links according to their specific characteristics and to do that five different kinds of techniques may be used:

- Direct guidance
- Sorting
- Hiding
- Annotation
- Map adaptation

Combining these approaches, this thesis also considers two sequencing levels: knowledge sequencing that in this case refers to the LG or the set of LGs that would be available for a student in certain time; and task sequencing that states for a specific LG what would be its development's order. In both cases one or several navigation support techniques could be used in order to guide the student through the course.

4.1.1   Learning Goals' specification

Although in the previous two chapters the notion of *LGs* was used making a brief description of what it means in terms of domain decomposition and pedagogical conception, this chapter presents in detail what do they mean from this proposal point of view, how they are defined, and how they are related with the whole teaching/learning process.

In order to achieve the "generic" principle of this proposal, and particularly what refers to being "domain free", a general *LG* representation was carefully chosen and is presented in this section. Domain free means that it should allow defining for example an *LG* for and art course as well as for a chemistry course. In order to achieve that, they are described throughout general activities which are finally determined by instructional designer.

Formally speaking, an *LG* is developed through one or more learning activities, from now on just referred as *activities*, where each one has the next attributes: *order*, *type*, *description*, *LOs* and *resources*. The *order* determines the sequence, *type* refers to the intention of the activity (i.e. if it is a lecture, a discussion, an experiment, etc.), whereas *description*, as it name implies, is used to describe the activity or when extra information about it, is required.

LOs and *resources* are used to relate contents (files) to the *activity*, in this case the cardinality of both is *0...N*, so there might be zero or more *LOs* or *resources* associated to an *activity*. It could be said that main difference between *LOs* and *resources*, independent of their actual content, is that the formers are described with metadata which allows using adaptation techniques. However from this proposal point of view, the conceptual difference lies in that *LOs* are used as the main learning instruments, whereas Resources, as their name implies, are more used to provide "extra" material, available for all students and related to the specific Activity. A much more detailed explanation of *LOs* is presented later in section 4.2. Taken into account this description, a general representation of an *LG* is presented on table 4.1.

Table 4.1: General specification for a LG

Order	Type	Description	LOs	Resources
1	*{Type 1, 2, …, N}*	*Activity 1*	*LO 1, LO 2, …*	*Res 1, Res 2, …*
2	*{Type 1, 2, …, N}*	*Activity 2*	*…*	*…*
…	*…*	*…*	*…*	*…*
M	*{Type 1, 2, …, N}*	*Activity M*	*…*	*…*

In order to clarify even more the LG notion presented here, imagine the example presented on table 4.2 where an LG is defined using as pedagogical consideration the Gagne´s nine events of instruction (GAGNE, 1985) but, for the sake of simplicity, only the first four events are covered.

In this case there are *M* = 7 *activities*. The first one does not contain any *LO* so only its description along with the *resources Res1* and *Res2* are presented to all students. The second one does not contain neither *LOs* nor *resources* so only its description is presented (considering the corresponding event, it is enough). The third one contains three *LOs* and no *resources* so it is necessary to apply an adaptation technique to determine which *LO* is presented to each student. Such technique refers to the adaptive presentation that is described later on section 4.2. A similar scenario is presented with third to sixth activities, whereas for the seventh one there is only a *LO* so necessarily it is presented to all students.

Table 4.2: LG definition example

	Order	Type	Description	LOs	Resources
Gaining learner's attention	1	*Information*	"Pay attention to the next videos about the module we are going to start …"		*Res1* *Res2*
Informing the objectives	2	*Information*	"When finishing this module you will be able of …"		
Stimulate recall of prior learning	3	*Exercise*	"Make the next exercise about the previously covered topics …"	*LO1* *LO2* *LO3*	
	4	*Scheme*	"Review the next scheme about what we have seen so far in the course …"	*LO4* *LO5*	
Presenting stimulus	5	*Explanation*	…	*LO6* *LO7* *LO8* *LO9*	
	6	*Experiment*	…	*LO10* *LO11* *LO12*	
	7	*Reflection*	…	*LO13*	
…		…	…	…	…

It is important to mention that another way this proposal is generic with regard to the pedagogical strategies that may be followed is that it does not specify the content within *LOs*. This way teachers could incorporate in them some strategy in particular, not necessarily the same that is used at *LGs* level.

4.1.2   Knowledge and task sequencing

Considering the DM prerequisite structure defined in section 2.2, knowledge sequencing becomes a simple task from system's point of view and is limited to determine which LGs are available to a student in a specific moment. To do that, it is necessary to look up in the knowledge information from SM and select the uncovered LG leafs that do not have prerequisites or whose prerequisites are already covered.

To clarify this process imagine again the example presented on figure 2.3 and suppose now that values that appear above LGs in figure 4.1 represents the corresponding knowledge level of a particular student (how to measure those values is described in detail on section 4.3). The symbol '-' means that there is not assessment value yet for that LG. In this case, assuming that approbatory level is *0.7*, from the four leaf LGs just *LG Id2* and *LG Id5* would be available for that student according to the previous criteria. The former because it does not have any prerequisites and has not been cover yet, whereas the later because it has not been cover either and its only prerequisite is already covered.
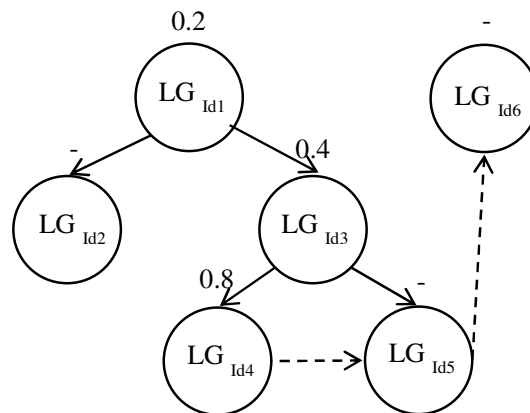
Figure 4.1: Example of DM prerequisite definition

Now, with regard to the navigation support techniques used to present those available *LGs*, this thesis proposes using a middle point between two polarized perspectives: delegating navigation control exclusively to the system, and giving such control completely to students' will. First case is typical of systems where sequencing is implemented strictly using a recommended link in the form of an adaptive 'next' button, whereas the second one of systems where navigation trough all contents is completely free.

Whether or not is better using one alternative than the other, both have advantages and disadvantages. A fixed structure, like for instance a hierarchy, although it could be very explanatory, is largely dependent on the ability of that structure to match the user needs. By the other hand, some authors argue that an unstructured nature provides richness and freedom (usually associated with hypermedia); however, navigating in

such structures exacerbates the well-known problem of cognitive load (LOWE & HALL, 1999).

In order to achieve the desired middle point, two techniques from previously mentioned Brusilovsky's taxonomy were selected: direct guidance and map adaptation. The first one is used to present a 'next' link to guide student to the following available LG or, when there are two or more available, a link for each one of them. The second one is used to present a representation of DM to the student in order allow him/her the next options: 1) selecting the specific available LG that wants to see; 2) selecting again an already covered LG for reviewing purposes; or 3) seeing the whole DM structure including the unavailable LGs. Such map could exhibit different formats for each option (from there the "adaptation" feature) depending on particular implementation decisions.

Once a specific LG has been selected, it is time to determine how it will be developed or, in other words, with what *activities*. According to the *LG* representation described in section 4.1.1 each *activity* has an *order* which determines a sequence. In this case, direct guidance and map adaptation techniques are used in an analogous way to the one described for *LGs* but at *activities* level.

It is important to mention that both levels should incorporate in the direct guidance and the map adaptation a link formatting policy in order to help student during navigation. Such policy may consider several states for the navigation links, e.g. visited/unvisited, recommended, pending; and may use different formatting options according to designer decisions, e.g. a particular color scheme, font size or type, use of descriptive icons, enriched text options (italics, bold, underlined).

4.2 Adaptive presentation

Following the definition provided in (BRUSILOVSKY & PEYLO, 2003), the aim of the adaptive presentation is to adapt the content that is presented by system to the student characteristics stored in the SM. While this definition refers in many systems to the selection and formatting of multimedia content, in this thesis it is focused exclusively in the selection of the objects that are used at last instance for the instruction process, i.e. the LOs.

4.2.1   Incorporation of Learning Objects

As mentioned in a very rough way on section 1.2.11, LOs may be defined as digital resources that are used to support teaching/learning process. To extent this definition, and with the aim of differentiate them from the notion of "simple" resources that were also mentioned on last section, it may be said that LOs have a particular instructional purpose (or they should) and are described in great detail using metadata.

This proposal does not specify which standard or specification must be used for LO metadata because that is a designer decision which mainly depends on the detail level and specificity he wants. What this proposal does specify is the minimum information that such metadata must contain and how such information is used in the adaptation process. As mentioned on last chapter, there are two sources from the SM that are considered for adaptation: 1) some of the personal information measured with scalar values from different formats and 2) psycho-cognitive information measured with array

values. In both cases there must be at least one attribute in the *LO* metadata for each characteristic, not necessarily with the same name, but with the same meaning.

In order to clarify this idea, consider an example where *age* and *language* data from *SMPI* are considered for adaptation ($Q = 2$), then the *LO* metadata should contain at least two attributes that refers to those two characteristics. Apart of that, in the psycho-cognitive information, it is used a particular learning style model with five dichotomies along with some particular psycho-technical model with three profiles ($S = 1$, $D^{(1)} = 5$, $D^{(2)} = 3$), then the *LO* metadata should contain also at least two attributes with scaled array values that refers to those two characteristics. For this example, a match between a hypothetic student and a hypothetic *LO* is illustrated on figure 4.3; the detailed adaptation technique that is used to perform such matching is presented in the next section.
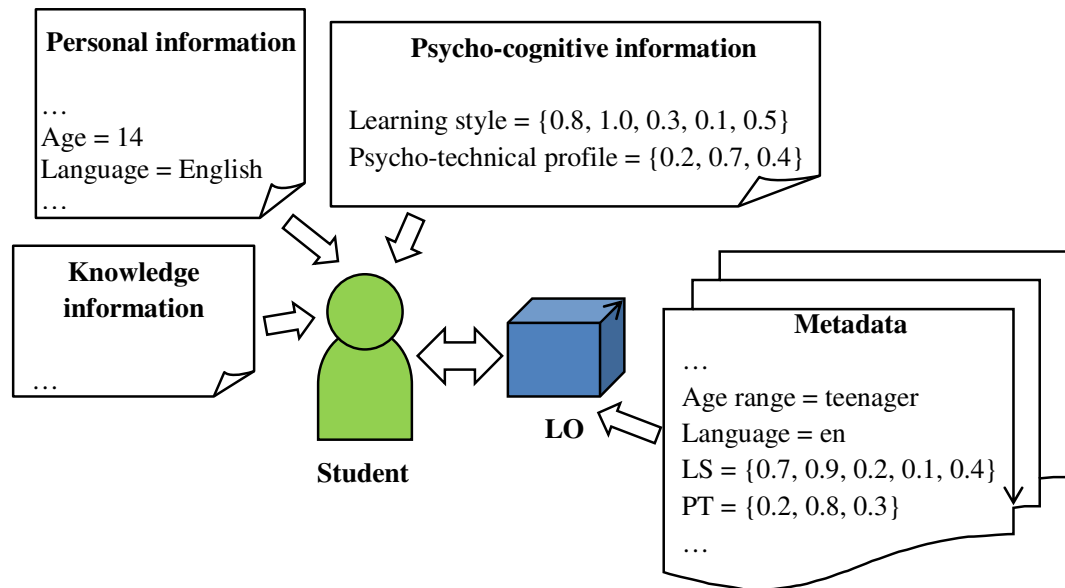
Figure 4.2: Student – LO matching example 1

A very important consideration in this point is that attributes values in the *LO* metadata that are used for adaptation must be determined carefully whether by the *LO* author, system administrators or teacher users, hopefully with some pedagogical guidance.

4.2.2 Selection of Learning Objects

Once the knowledge and task sequencing process have been performed according to the procedure described in section 4.1, it is necessary to determine which *LO* (one or and ordered subset) would be presented to student when a specific Activity has been selected and it contains more than one *LO*. As mentioned on chapter 3, the two sources from the *SM* that are considered for adaptation are the personal and the psycho-cognitive information that in both cases has a one-to-one relationship between student's characteristic and LOs attributes as it was stated in previous section. With this in mind, a sequential process is proposed where, for each specific *activity*, the list of available *LOs* are filtered according to student personal information and later, from the *LOs* that

pass such filter, the more appropriates are presented to student according to his/her psycho-cognitive information.

In the first part, once such relationships are defined according to designer decisions, simple IF <antecedent> THEN <consequent> adaptation rules may be defined. The antecedent determines a specific category or range for the student characteristic and the consequent the corresponding desired attribute of the *LO*. Going back to the example presented on section 4.2.1, imagine the next rules for the *age* characteristic:

> IF student age ≤ 12 THEN *LO* should be for "children"
> ELSE IF 12 < student age ≤ 17 THEN *LO* should be for "teenager"
> ELSE IF 17 < student age ≤ 22 THEN *LO* should be for "young"
> ELSE THEN *LO* should be for "adult"

Those rules implies that at least one of these four values must be present in the corresponding *LO* attributes for that example: "children", "teenager", "young" and "adult". Similar rules could be defined for the *language* characteristic:

> IF student language = "spanish" THEN *LO* language should be "es"
> ELSE THEN *LO* language should be "en"

In this simple example it is clear that in this case for each *activity* at least eight *LOs* would be necessary to cover all possible student alternatives with regard to the corresponding characteristics. In general, if there are *Q* characteristics and each one has $C^{(1)}$, $C^{(2)}$, … , $C^{(Q)}$ categories or ranges, the minimum number of LOs that would be required to cover all possible student's alternatives is:

$$C^{(1)} \times C^{(2)} \times ... \times C^{(Q)}$$
(Equation 4.1)

For example, if *S = 3* characteristics are considered for adaptation from personal information of SM and each one has four categories, such number would ascend to *4×4×4 = 64*. This is an issue that designer must consider carefully because it affects directly the difficulty of the courses construction. In Duque's words:

> "This is one of the problems that construction of adaptive systems exhibits: the exponential growth of resources when adaptation components increase" (2009, p. 38).

Once this first filter has been done and a subset of all available *LOs* for a specific *activity* has been selected, the second part starts where the psycho-cognitive information criterion is used. In this case, the IF THEN rules approach is not used. A mathematical approach is proposed here instead, taking advantage of the array representation of these student characteristics.

For doing so, it is necessary to remember that there are *R* psycho-cognitive characteristics represented trough arrays $SMCI_r$ for each student. A subset of *S1* (*S1* ≤ *R*) characteristics may be used in this point, each one having $D^{(s)}$ dimensions with scaled values in the range *0 – 1*. Figure 4.2 shows examples of the graphical representation of such arrays for $D^{(s)} = 1$, *2* and *3*.

$D^{(s)}$ = 1 dimension $\quad\quad$ $D^{(s)}$ = 2 dimensions $\quad\quad$ $D^{(s)}$ = 3 dimensions
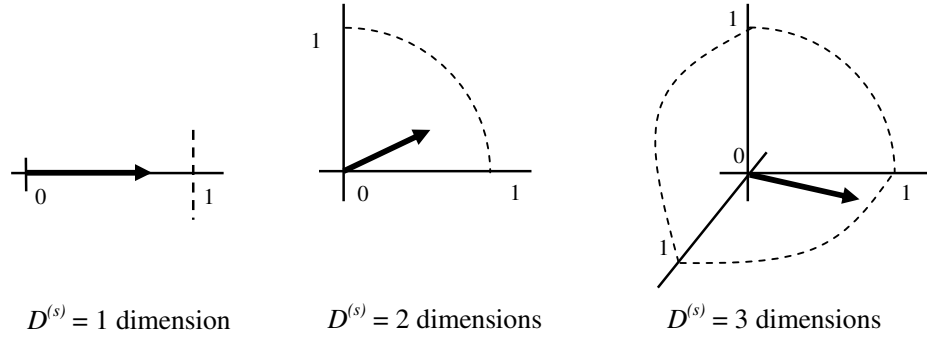
Figure 4.3: Graphical representation of the psycho-cognitive characteristics

For example, if in a particular system the Gardner' Multiples Intelligences Theory (GARDNER, 1999) was considered within student's psycho-cognitive information, each one of the considered particular *LOs* in such a system should have an array representation for the corresponding dimensions: Verbal – Linguistic, Logical – Mathematical, Visual – Spatial, Bodily – Kinesthetic, Musical, Interpersonal, Intrapersonal, Naturalistic and Existential. In this hypothetical case, an activity like "Storytelling" could have a general array like {*1.0, 0.1, 0.7, 0.1, 0.0, 0.4, 0.4, 0.1, 0.1*}, whereas another like "Physics experiment" could have one like {*0.3, 1.0, 0.3, 0.7, 0.0, 0.0, 0.0, 0.5, 0.1*}. Although this example was presented only for explanatory purposes, readers interested on this particular theory and its applications on content design could consult (KELLY & TANGNEY, 2006; VISSER et al., 2006).

Once the psycho-cognitive characteristics have been defined for the *LOs*, the comparison with the student may be performed using the typical Euclidian distance. However, due to arrays may have different dimensions numbers, it is necessary to unify the distance measure dividing for the corresponding $D^{(s)}$ square root (maximum distance between two vectors in $D^{(s)}$-dimensional space inside range *0-1*). In more detail, if for a specific *activity* there are *H LOs*, the next distance formula for each *LO* must be calculated with regard to the student's characteristic *s*:

$$DLO_{hs} = \frac{\sqrt{\sum_{d=1}^{D^{(s)}}(SMCI_s.dimension_d - LO_h.dimension_d)^2}}{\sqrt{D^{(s)}}}$$

(Equation 4.2)

In the case of *S1 > 1*, all *s* distances could be summed for each *LO* in which case the value of the sum would be inside the range *0 – S1*. With the aim of incorporating designer considerations about relative importance of each characteristic, a pondered sum is proposed instead to calculate the total distance:

$$TDLO_h = \frac{\sum_{s=1}^{S1}\alpha_s DLO_{hs}}{\sum_{s=1}^{S1}\alpha_s}$$

(Equation 4.3)

This way such final value would be inside range *0 – 1*, where in the extreme cases a value of *0* would mean a total compatibility between student characteristics and the corresponding *LO*, whereas a value of *1* would mean a total dissonance. Once this value has been calculated, the sorting technique is as simple as presenting all *m* activities in ascending order with regard to that value.

An important issue about this procedure is that, differently to the IF THEN rules for the personal information criteria, it does not exclude any *LO*; instead it allows giving them a relative importance order. This is very important because it means such procedure does not have the "dimensionality curse" explained with equation 4.1 and then, it may be used considering any number of characteristics whether there are just one, two or thousands of available *LOs*.

In order to clarify more the whole *LO* adaptation process presented on this section, consider the hypothetical example presented on figure 4.4 where just one personal information data ($SMPI_1$) and two psycho-cognitive characteristics ($SMCI_1$ and $SMCI_2$) are used from SM as the adaptation criteria. Consider also that for a specific *activity* there are three available LOs with the corresponding attributes (assume that order is the same than in the student's characteristics).
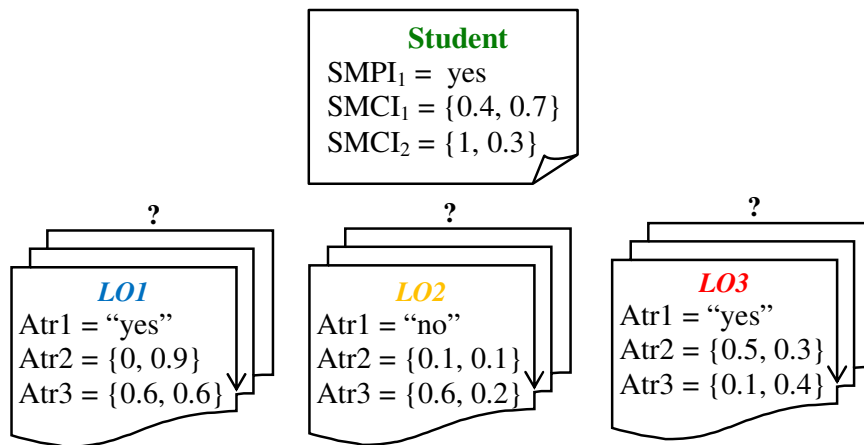
Figure 4.4: Student – LO matching example 2

To select which of the LOs is more appropriate in that moment for that student, the personal information filter must be accomplished first. In this case, assuming that a simple categories rule exists, *LO2* would be discarded. From the remaining two LOs the distance measure described in equation 4.2 must be calculated. Such values along with the vectors that represent student and LOs are presented on figure 4.5.
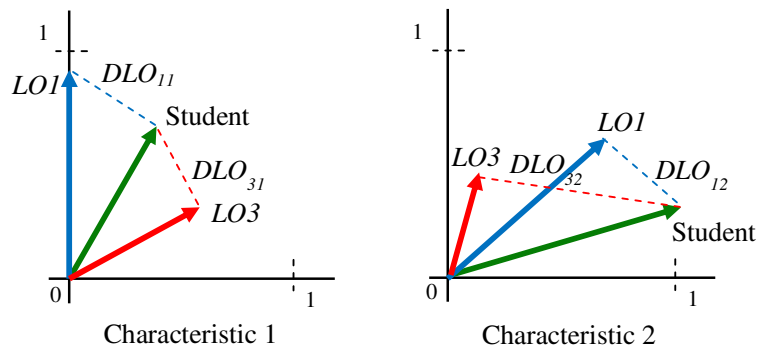
Figure 4.5: Graphical representation of student and LOs from example

In this case $DLO_{11} \approx 0.32$, $DLO_{12} \approx 0.35$ for *LO1*; and $DLO_{31} \approx 0.29$, $DLO_{32} \approx 0.64$ for *LO3*. Using these values on equation 4.3 and giving the same importance to both characteristics ($\alpha_1 = \alpha_3$) the total distance for the two LOs are $TDLO_1 \approx 0.33$ and $TDLO_3 \approx 0.47$, with which it may be concluded that *LO1* would be more appropriate for that student considering the three criteria of this example. This does not mean that finally only *LO1* would be presented to the student in this example (the same apply for a general case), because it is an implementation decision whether select only the more appropriate one, or the two more appropriate, or the three, etc., having the opportunity this way of using a particular technique from the Brusilovsky's taxonomy: sorting.

Once a subset of the available LOs has been selected, it is also an implementation decision defining how to present them in terms of links and, for doing so, a formatting policy should be considered in a similar way that for curriculum links described in section 4.1.2.

4.3 Adaptive assessment and feedback

In CAL, as well as in traditional face-to-face education, the assessment is an indispensable part of teaching/learning process, not only because it allows determining the efficiency of such a process throughout observable measures, but also because those measures could help to determine the more adequate guidance for each student. Aware of this issue, in many ALS and ICAI applications such an assessment is an integral part of systems architectures but it is not always done following the same principles they use for other processes, this is, in an intelligent (precise) and adaptive way. As Jiménez mentions:

> "In the adaptive educational systems is very common to find that adaptation is only focused in the structuring and sequencing of the knowledge domain contents, expecting that it is the only way to improve the learning strategy. However the possibility of making other aspects, like assessment process, more flexible is not considered." (2009, p. 11)

In order to solve in part this limitation this section presents an alternative which is based in two well-known approaches that are explained next.

4.3.1 Computerized Adaptive Testing and Item Response Theory

In CAL context, the Computerized Adaptive Testing (CAT) differs from the static nature of traditional tests approach because its construction process is dynamic and the quantity of questions is not predefined. The idea behind a CAT is quite forward: to apply to each examinee only those items useful to know his/her proficiency level. As a consequence of this, CAT is usually more efficient than conventional, i.e. fixed-items, tests, providing more precise measurements for same length tests or shorter test for same precision measurements (PONSODA, 2000).

From the examinee's perspective, the difficulty of the generated test seems to tailor itself to his/her knowledge level (that is why in early systems it was called 'tailored testing'). For example, if an examinee performs well on an item of intermediate difficulty, there should be a high probability for the next question to be more difficult question. Or in the other way, if he performed poorly, a simpler question would be the

more adequate next step. This does not mean that intention of CAT is neither to facilitate assessments for students presenting them easier questions because their knowledge level is low, nor to complicate assessments for the ones who answer correctly because they master topics. What CAT really looks for is to avoid the students' boredom when they have to repeat issues they already proved to know, as well as the frustration of those who block themselves mentally when facing a difficult test.

In order to achieve this aim, the general CAT procedure consists in an iterative algorithm with the following steps (THISSEN & MISLEVY, 2000):

1. The more adequate assessment item is searched from the items bank, based on the current estimate of the examinee's ability.
2. The chosen item is presented to the examinee, who then answers it correctly or incorrectly.
3. The ability estimation is updated, based upon all prior answers.
4. Steps 1 to 3 are repeated until a termination criterion is met.

According to this procedure the fundamental four elements of CAT are: a) an assessment item bank, b) a criterion to select items, c) a procedure to estimate student's knowledge level, and d) a stopping criterion. A good item bank must contain a large number of correctly described items, obviously the more items the better performance of the test. The stopping criterion may takes different forms like when the estimation reaches certain threshold, when a limit time is reached, etc.

Now, with regard to elements b) and c), several applications from AEHS, ITS and AIES (Inspire (PAPANIKOLAOU et al., 2003), SIETTE (CONEJO et al., 2004), AHA 3.0 (DE BRA et al., 2007), CIA (JIMÉNEZ et al., 2008), Flip (BARLA et al., 2010)) define them based on an approach known as Item Response Theory (IRT). Formerly known as 'Latent Trait Theory', the IRT tries to provide some probabilistic bases to the problem of measuring non-directly observable traits (latent traits). Its name derivates from considering the item or question as the test's fundamental unit, instead of the total score as it was common in traditional testing approaches.

According to this theory the relationship between the trait θ (that may be understood as the examinee ability or knowledge level) and the subject answer to each item (question) may be explained through an increasing monotonous function, known as Item Characteristic Curve (ICC) that establishes the probability of a right answer. Depending on the nature and parameters of such function, there are several models that may be used. Some of the more popular are (TRAUB & WOLFE, 1981):

- The Rasch model, also known as 1PL for having just one parameter: difficulty; and a logistic shape.
- The Normal ogive or logistic, with two item parameters: difficulty and discrimination. Its logistic version is the more common and is known as 2PL.
- Normal ogive or logistic with three item parameters: difficulty, discrimination, and guessing. Its logistic version is the more common and is known as 3PL.

The formulas for the ICC in the 1PL, 2PL and 3PL models are presented in equations 4.4, 4.5 and 4.6 respectively.

$$P(\theta) = \frac{1}{1 + e^{(\theta - b)}}$$

(Equation 4.4)

$$P(\theta) = \frac{1}{1 + e^{-a(\theta - b)}}$$

(Equation 4.5)

$$P(\theta) = c + \frac{1 - c}{1 + e^{-a(\theta - b)}}$$

(Equation 4.6)

In order to illustrate how these functions work as well as the meaning of the involved parameters, figure 4.6 presents a 3PL curve. As it may be seen in the previous equations, the 3PL is the more general from the three, so its explanation may be extrapolated to the other two. The domain of this function is the open interval $(c,1)$ being both values its asymptotic limits. The range is $(-\infty,\infty)$ but for practical purposes only the interval $[-3,3]$ is considered.
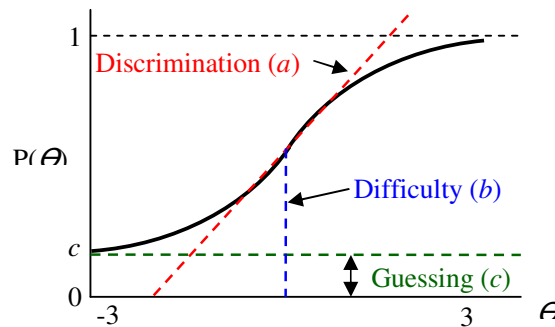
Figure 4.6: 3PL typical ICC

In the IRT context, the guessing c defines the probability of a right answer without considering examinee's ability. In other words this parameter is inherent to the item nature, for example in a true or false kind of question all students have a 0.5 probability of success if they just guess. The difficulty b defines how that item suits the examinee ability. In graphical terms it defines how long to the right the item meets high-ability examinees or reciprocally, how long to the right the item meets low-ability ones (it defines the location of the curve's inflection point along the θ scale). The discrimination a defines how well an item can differentiate between examinees having abilities below the item difficulty and those having abilities above it. This parameter essentially reflects the steepness of the ICC in its middle section: the steeper the curve, the better the item can discriminate; whereas the flatter the curve, the less the item is able to discriminate between two examinees whose abilities are close (it defines the slope of the curve at its inflection point).

To clarify even more the impact of these parameters over the ICC, specifically a and b that could be harder to interpret, figure 4.7 shows different curves varying them whereas the other ones remain fixed (note that c is zero in these examples).
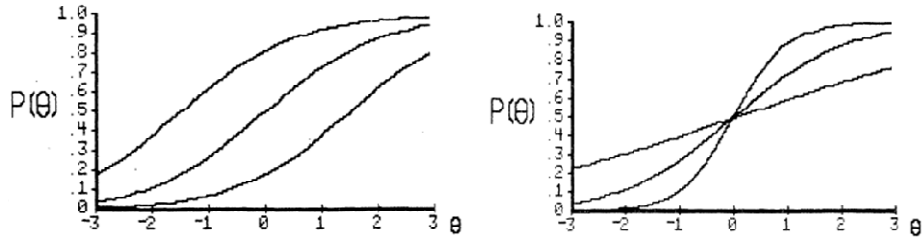
Figure 4.7: 3PL ICC varying parameters *b* (left) and *a* (right) (BAKER, 2001)

4.3.2   Assessment process

When talking about the assessment process, two main categories may be mentioned, namely summative and formative. Summative assessment is used to grade students in order to demonstrate their achievement about global objectives and is done usually at the end of the courses. By the other hand, formative assessment is done continuously, generally when finishing determined milestones of the domain content, and may be used as a diagnostic tool for students and teachers to identify and improve areas of weakness.

In this proposal the formative approach is adopted and in order to do so, the LGs from the DM are used as the milestones. This is, when a student finishes a LG (when he/she develops all activities according to the process described in section 4.1) an assessment is available for him/her and its result becomes the corresponding knowledge level in the SM.

Such an assessment is generated following the CAT procedure and using the IRT, described previously. From the available models to represent the ICC, the 3PL was chosen for being the more general one. However, with the aim of making it compatible with the knowledge level, a slight modification should be done: after determining θ, it must be scaled to range [0,1], which can be done easily using the formula:

MIN(1, MAX(0, (θ+3)/6))   (Equation 4.8)

With regard to the parameters of the 3PL model, the next guidelines were defined. First, considering that *c* depends on the type of question, i.e. the format in which it is formulated and not on the question itself, its value may be determined automatically based on the number of possible answer options. Such values for the most common types of questions, not just for CAT but for computer based testing in general, is presented in table 4.3.

Table 4.3: Guessing probabilities with regard to the type of question

Type of question	Considerations	*c*
True-false	None	0.5
Multiple choice unique answer	n: number of options	n^{-1}

Multiple choice multiple answers	n: number of options	$\left[1 + \sum_{i=1}^{n-1} \frac{n!}{i!\,(n-i)!}\right]^{-1}$
Pairing	n_A: number of the ordered elements n_B: number of the disordered elements ($n_B \geq n_A$)	$\left[\frac{n_B!}{(n_B - n_A)!}\right]^{-1}$
Ordering	n: number of elements to be ordered	$(n!)^{-1}$
Free answer	None	0

Second, parameter *b* may be understood as the item difficulty independently of its formulation. For example in a high school context the item "when did Columbus discover America?" is relatively simple even if it is formulated using multiple choice unique answer or even free answer types of questions, whereas another item like "what is the atomic weight of Barium?" could be a lot more difficult even if it is formulated using a true-false type of question. Considering this, a subjective value defined by the teacher is proposed.

Third, considering that desirable situation would be having neither too steep nor too flatted ICCs, a fixed value of 1.0 is proposed for the parameter *a*.

Once the items model has been clarified, it is necessary to define the other elements of CAT, this is: the criterion to select items, the procedure to estimate student's knowledge level, and the stopping criterion.

The item selection criterion is based on the amount of information provided by a determinate item at a given ability level. In order to calculate such a value the Item Information Function, which is computed directly from the corresponding ICC, may be used. For the 3PL model, such a function takes the form (BARLA et al., 2010):

$$I_i(\theta) = a^2 \left[\frac{Q_i(\theta)}{P_i(\theta)}\right]\left[\frac{P_i(\theta) - c_i}{1 - c_i}\right]^2$$

(Equation 4.8)

So, given an estimative of θ for a student, the more appropriate item from the bank (with *V* items) is obtained as:

$$\max_{i\{I_i(\theta)\}} \quad \text{for } i = 1 \text{ to } V$$

(Equation 4.9)

Now, the more common way to estimate student's knowledge level is based on the maximum likelihood function, which basically consists in finding the value of θ that maximizes the function defined by:

$$L(u|\theta) = \prod_{i=1}^{n} P_i(\theta)^{u_i} Q_i(\theta)^{1 - u_i}$$

(Equation 4.10)

Where Q_i is the probability of failing the item i $(1-P_i)$ and $u = (u_1, ..., u_W)$ is the answers array given by the student. For $i = 1, ..., W$, u_i is 1 if the answer to question i is correct, and 0 otherwise.

An alternative to find such a value is known as the a priori method (BAKER, 2001) which uses the known values of the items parameters and an a priori value for the examinee ability, and then uses an iterative procedure guided by the formula:

$$\theta_{s+1} = \theta_s + \frac{\sum_{i=1}^{W} a_i(1 - c_i)(u_i - P_i(\theta_s))}{\sum_{i=1}^{W} I_i(\theta_s)}$$

(Equation 4.11)

Such a procedure starts with an arbitrary value of θ_s and stops when $|\Delta\theta|$ reaches a tolerance value close to 0.

For the last element of the CAT procedure, the stopping criterion, an alternative composed by the disjunction of the next two conditions is proposed: the estimation of the student's knowledge level is equal or larger than 2.95 and the number of presented questions to the student reaches a value predefined by teacher.

Now, once the student's knowledge level has been estimated for the corresponding LG, it is necessary to define how such value would be propagated trough the knowledge information of the SM. In order to do so, two cases must be considered: when such LG is part of a composite LG (it has a "parent") and when it is not. Second case does not require any further process than updating the corresponding value in the SM for that specific LG, whereas in the first it is necessary not only to update that value but also the value of its parent if all its other "sons" have been estimated as well. In this case, and as mentioned in section 2.2, several alternatives may be used to calculate the knowledge level of a composite LG with regard to its sons, being some of them: the arithmetic mean, the pondered mean, the maximum value and the minimum value. From all of them the pondered mean is proposed with the aim of incorporating the perception of the teachers about the relative importance of the LGs to master certain knowledge. To clarify how it works, figure 4.8 shows an example of a composite LG with three 'sons', where the estimated knowledge levels appear on the top of each LG.
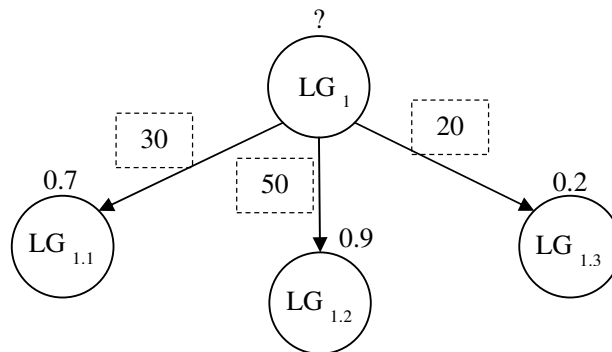

Figure 4.8: LG composition example

Using the corresponding weights presented as dotted rectangles, the estimated knowledge level for LG_1 would be 0.7.

Notice that this operation may produce an iterative process when a son LG makes the knowledge level of its parent updates and that parent has a parent as well. An important implication of this updating process is that after it, other LGs could become available for the corresponding student depending on the DM prerequisites structure. For doing so, it is necessary that designer, or ultimately teacher, defines the approving level. This value obviously depends on the requirement level that they judge as appropriate. Just as a suggestion, and considering the implications of this variable in the underlying approach used in assessment (IRT), a value between 0.6 and 0.7 is recommended.

4.3.3 Feedback process

After completing the four steps of the CAT procedure, and with the aim of providing an appropriate feedback, a final fifth step was added: Presenting results to student. In order to do so, two important issues must be attended: how the knowledge level is presented to student? and what should be done if a student does not approve?

The first issue refers to the presentation format of this variable, where the alternatives are diverse and may incorporate or not some pedagogical guidelines. For example, the more simple option is presenting the estimated value roughly, i.e. as numeric value within range [0, 1]. Another option is to scale and to round that value with the aim of presenting a more familiar measure for students; an example of this are grades within [0, 5] using one decimal digit or percentage values between 0 and 100%. Other options include translating that value to categories which are defined using ranges. Usual examples of this are grades using letters ('A', 'B', 'C', etc.) or even labels ("excellent", "good", "regular", etc.). Any combination of options is also possible, for example a number grade accompanied by the corresponding category.

The second issue is related to a very important question: how the student can be helped when a problem in his/learning process has been detected (using the knowledge level as observable variable). Here a clear advantage of the adopted formative approach for assessment comes into surface: an appropriate guide can be presented just when and where students needed it the most. In this thesis such a guide is provided by two ways: a reviewing process and a suggestion of a peer for assistance, in both cases with regard to the specific LG.

The reviewing consists not only in presenting again the corresponding LG activities and contents again, but in taking advantage of the adaptive navigation support and more specifically of the links formatting process to make emphasis in what the student should review, and into present extra material accordingly. More specifically, the next actions should be taken during presentation: to highlight the LG that the student should see again; and to present extra LOs that were not listed previously to student or to highlight those that were not seen before.

As a complementary process to the individual review, an "extra help" process is proposed, taking advantage not only of the SM information from the student who requires it, but also from information of all other students. This process refers to the

classmate search for learning assistance that is explained later in section 4.4.1 for being part of the adaptive collaboration support techniques.

4.4 Adaptive collaboration support

In spite of the importance collaborative activities, Fung & Yeung (2000), cited in (POLLALIS & MAVROMMATIS, 2009), found after a research with 15 adaptive educational systems which were reviewed to check their adaptivity level, that none of them reported the incorporation of adaptive collaboration support. Although this study was done almost a decade ago, the described panorama has not changed too much nowadays according to the literature review performed during this thesis.

To solve in part this gap, two processes that are involved in collaborative activities are considered in this section: the colleague search for learning assistance and the group composition. In both cases the adaptivity does not refer to the activities themselves, but to the mentioned related processes.

4.4.1 Colleague searching for learning assistance

In a traditional face-to-face classroom when a student faces a learning problem, i.e. when he/she does not get certain topic well, a very common practice is looking for help among the classmates. In CAL however this practice is a little more complicated because students usually do not have too much contact between them and are not aware of the expertise of their classmates.

With the aim of facilitate this process, allowing that a student who need some assistance for a particular topic (in this case an *LG*) finds an appropriate classmate who may help, a typical alternative would be recommending to contact the student that demonstrated a higher knowledge level. This solution however has two main problems: the first one and more obvious is that in a large group a unique student would be "bombed" with a lot of assistance petitions. The second one, and quite less obvious by the way, is that not necessarily a student *X* with an adequate knowledge level is the more appropriate one to explain something to a student *Y*. Imagine for example that such student *X* has a notorious global learning style whereas the student *Y* has a notorious sequential one. In this hypothetic case is highly probable that student *X* tries to explain what he/she knows in the way that understands it better (this is, with a global vision) and therefore is highly probable also that student *Y* simply does not get such an explanation.

With the aim of solving these two problems, a two stages method is proposed here. First stage starts dividing all the students from who the corresponding *LG* knowledge level has been already estimated into two groups. A group *G* with the ones to demonstrated the understanding of the LG, this is, the ones whose estimated knowledge level is above the approving level and a group *F* with the ones who did not. In other words group *F* contains the students who require help, and group *G* the ones who may provide it. After this separation, for each student *f* in group *F* a sub group of *n* students from group *G* is selected using as criterion the first *n* lower values obtained when applying the next formula:

$$\left| \begin{array}{l} (knowledge\ level\ of\ g - knowledge\ level\ of\ f) - \\ (maximum\ knowledge\ level - approving\ level) \end{array} \right| \qquad \text{(Equation 4.12)}$$

With the aim of clarifying this procedure, figure 4.9 shows a graphical representation.
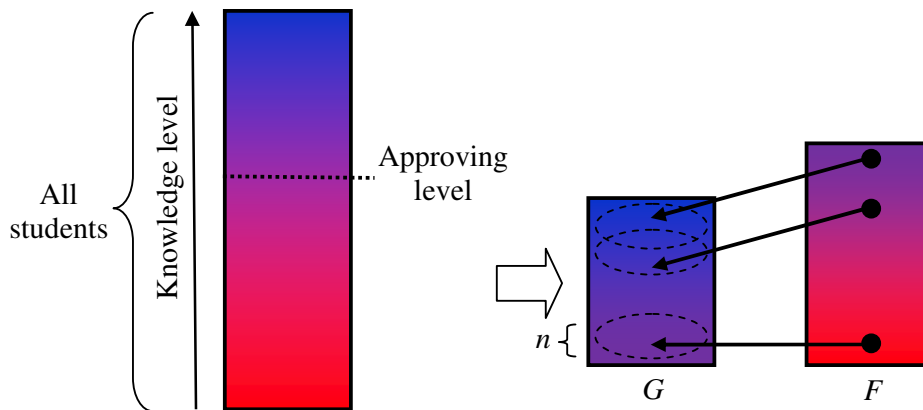
Figure 4.9: First stage in searching for learning assistance

Besides avoiding that just one or few students get overwhelmed with all assistance petitions, there is an underlying idea behind this procedure. A student who did not reach the approbatory level but was close to it, probably has a good understanding and would require just to clarify certain punctual issues, being the ones who demonstrated higher knowledge levels the more appropriates for that task. By the other side, a student who got a very low level probably did not understand the general idea and someone who does (without necessarily knowing specific details or having more refined skills) could be appropriate to help him/her.

This does not mean that students who obtain lower levels do not "deserve" assistance for the ones in the other extreme. In fact, this procedure may be seen as progressive because once a student gets that help, he/she would probably improve and, if that improvement is not enough yet (still does not demonstrate a knowledge level above the approbatory one), this time that student would receive help of a student who is "higher" in the ranking, getting this way more advanced assistance each time.

Starting from this filtered list of n candidates, the second stage consists in finding the more adequate partner with regard to some characteristics in common, in this case of psycho-cognitive kind. For doing that, a procedure similar to the one to match a student with a *LO* is proposed, considering again a subset of *S2* (*S2* $\leq$ *R*) psycho-cognitive characteristics from the SM. In fact, both subsets could be equals. In this case the distance between a student *f* with a student *g* is calculated as:

$$DE_{gs} = \frac{\sqrt{\sum_{d=1}^{D^{(s)}}(Student\ f\ SMCI_s dimension_d - Student\ g\ SMCI_s dimension_d)^2}}{\sqrt{D^{(s)}}}$$

(Equation 4.13)

If $S2 > 1$ all s distances could be summed for each one of the n student from group G in which case the value of the sum would be inside the range $0 - S$. Again, with the aim of incorporating designer considerations about relative importance of each characteristic, a pondered sum is proposed:

$$TDE_g = \frac{\sum_{s=1}^{S2}\beta_s DE_{gs}}{\sum_{s=1}^{S2}\beta_s}$$

(Equation 4.14)

Once the n values have been calculated, the student who corresponds to the minimum value is selected and recommended to the student f.

4.4.2   Group composition for collaborative learning activities

The main goal of the Collaborative Learning is to achieve a synergy of individual learning within a group by means of discussion and a joint knowledge construction (BARKLEY et al., 2005). In order to do so, it is common to use some techniques, known as collaborative learning activities, which define a sort of protocols with one or more underlying pedagogical considerations.

As mentioned before, and with the aim of keeping the generic approach of this thesis, the adaptation in this point is not focused in the activities themselves, whose choice and development would depend on designer and ultimately on teacher decisions, but in a very important process that is common to all of them: the groups composition. According to that, a collaborative learning activity in the TM corresponds to a specific type of the ones that may be used to develop a LG, so it can contain resources and even *LOs*, but with the particular feature that its description should contain the corresponding protocol.

Having adequate groups allows a good interaction among students and is fundamental for obtaining the expected learning results. However, groups composition is made in many cases without any criterion at all, using simple random selection (HUXLAND & LAND, 2000), which could lead to a well-known phenomenon: just few groups are able to achieve a good performance whereas the other ones are far from reaching expected outcomes. To avoid such a problem it is important to use group formation methods that look for general performance of each group but also for adequate results of students with different characteristics. In other words, the ideal situation should be having groups as similar to themselves as possible (inter homogeneous), but empowering students' individual differences inside of them (intra heterogeneous).

Even if at first sight this task may seem quite simple, it is actually very complex, first because the considered characteristics may not be directly proportional between each other and second because the combinatory explosion that is related to the number of students and groups that is willing to be formed. These two issues together produce that the possible number of grouping alternatives is factorial, making this a NP-hard

problem. Several works try to solve it but considering a limited number of particular characteristics. For example, the work presented in (LIN et al., 2010) focus on two students' characteristics: knowledge levels and interests; and uses a particle swarm optimization approach for the grouping method. Hwang et al. (2008) consider also two characteristics: the number of already known concepts of certain course domain and the score of a pre-test (although authors mention that other characteristics could be considered making some modifications); and uses an enhanced genetic algorithm approach. A former study presented in (BEKELE, 2000) considers quite more characteristics: gender, group work attitude, interest for mathematics, achievement motivation, self-confidence, shyness, English performance and mathematics performance; and uses a vector space model approach, experimenting with three different algorithms to compose groups.

In contrast to those studies, this thesis proposes a generic group composition method considering an arbitrary number of students' characteristics. In order to do that, the translation of the group composition problem into a multi-objective optimization problem is proposed, where each objective consists in reaching the highest similarity level possible with regard to each student characteristic between the mean of each group and the mean of the total students' sample. Such translation and the subsequent solving procedure involve the next steps:

1. To define each student in terms of the attributes used in the grouping criteria.
2. To define the representation of the feasible solutions for the group composition problem.
3. To define the solution fitness function considering the inter-homogeneous and intra-heterogeneous approach.
4. To define a solution search procedure based on the optimization of the corresponding fitness function.

First step starts defining the characteristics that will be considered and that may come from any component of the SM: knowledge, psycho-cognitive or even personal information. To clarify this, imagine for example that a designer could be interested in considering for this purpose gender and learning style, whereas another one could be interested in age and the estimated knowledge level of a particular LG.

Once such characteristics have been selected, they are used to form an array for each student following two principles. The first one is that all of them have to be numeric. This does not mean that categorical attributes cannot be considered; just that in this case a previous numerical discretization process should be used, for instance attribute gender with categorical values "male" and "female" may be changed by the numbers 0 and 1 respectively. The second one is that when using psycho-cognitive characteristics, it should be defined what dimensions exactly would be considered and each dimension separately becomes an attribute in the array.

To clarify this characterization consider the second example given two paragraphs before where a designer is interested in using age, knowledge level of a particular LG and a particular learning style model that uses two dimensions. In this case an hypothetic student could be translated to the array: {0, 0.7, 0.55, 0.9}, meaning that such student is male, with an estimated knowledge level of 0.7 and with a value of 0.55 in the first dimension of the considered learning style model and 0.9 in the second one.

When all students have been translated to these arrays, a M x N matrix is obtained, where M is the number of students and N is the number of resultant attributes. Data in such matrix must be scaled in a common range in order to avoid perturbations in the fitness function calculation that is explained in third step. A simple way to do this is using: $(Z - Z_{min})/(Z_{max} - Z_{min})$ so all data fit a $[0,1]$ range, being Z_{min} and Z_{max} the minimum and maximum values of the corresponding attribute. Such procedure is not necessary when attributes are already in that scale, which is the case of the presented example.

For second step, a feasible solution means a defined setting of groups, each one with a maximum number of students. The simpler way to represent such setting is using a matrix whose rows' quantity corresponds to the number of wanted groups T and the columns' quantity to the maximum size of each group M/T. In this way, each element that composes the whole solution encoding contains the identifier of a student, and its position inside the matrix defines the group to which it belongs.

In this grouping problem, as well as in many other combinatorial problems, a feasible solution cannot have repeated elements. It means that each group element must be placed in one and just one position of the solution matrix representation. For instance if there are 12 students and 3 groups are needed, each one would contain exactly 4 different students. In this case a feasible individual, if the 12 students are numbered sequentially, could have students 1 to 4 in row (group) 1; 5 to 8 in row 2; and 9 to 12 in row 3.

For step 3, considering that we want to obtain homogeneous groups with regard to the total sample of students, it is necessary defining a measure of such homogeneity for a feasible solution. In order to do that it is necessary to calculate first the mean of each attribute for all students (the whole population's mean):

$$\overrightarrow{PM} = \{\overline{A_1}, \overline{A_2}, ..., \overline{A_N}\}$$

(Equation 4.15)

Then, for each group t ($1 \leq t \leq T$) of a solution, the mean of each attribute must be calculated. As a solution i is represented with a matrix X^i, such solution's mean may be obtained as:

$$\overrightarrow{SM^i_t} = \{\overline{X^i_{t,1}}, \overline{X^i_{t,2}}, ..., \overline{X^i_{t,N}}\}$$

(Equation 4.16)

Later the sum of the squared differences with regard to the N characteristics between each group t of the individual i and the whole students' population (the Euclidian distance between them in the N-dimensional space) is calculated as:

$$D^i = \sum_{t=1}^{T} \begin{bmatrix} \gamma_1 * \left(\overline{A_1} - \overline{X^i_{t,1}}\right)^2 + \\ \gamma_2 * \left(\overline{A_2} - \overline{X^i_{t,2}}\right)^2 + \\ ... \\ \gamma_N * \left(\overline{A_N} - \overline{X^i_{t,N}}\right)^2 \end{bmatrix}$$

(Equation 4.17)

In this formula, a pondering term γ is used with the aim of incorporating the designer perception about the relevance of each attribute.

The lower value of this measure (with a minimum of zero), the more similar each group of such solution would be in average with regard to the whole population of students. In order to clarify this measure, as well as all the concepts that have been explained so far, consider the next example, where there are $M = 4$ students and $N = 2$ attributes with the same relevance ($\gamma_1 = \gamma_2$), as it is presented in table 4.4.

Table 4.4: Example data with four students and two attributes

ID	A_1	A_2
1	30	0,52
2	40	0,26
3	20	0,78
4	10	1,04

After scaling these values according to the procedure described in step 1, the table 4.5 is obtained.

Table 4.5: Example of scaled values

ID	A_1	A_2
1	0,66	0,33
2	1	0
3	0,33	0,66
4	0	1

Now, suppose that $T=2$ groups are needed to be formed so each one would have exactly 2 students. Two feasible solutions for this case are presented on table 4.6.

Table 4.6: Example of feasible solutions

Solution 1		Solution 2	
1	2	1	3
3	4	2	4

Applying equation 4.15 $\overrightarrow{PM} = \{0,5\ 0,5\}$ is obtained, whereas $\overrightarrow{SM^i_t}$ is calculated according to equation 4.16 as:

$$\overrightarrow{SM^1_t} = \begin{bmatrix} 0.83 & 0.16 \\ 0.16 & 0.83 \end{bmatrix} \text{ and } \overrightarrow{SM^2_t} = \begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$$

When using equation 4.17, the fitness values $D^1 = 2.94$ and $D^2 = 0$ are obtained. In this case it is possible to observe that grouping represented with solution 2 accomplishes perfectly with the inter-homogeneity, intra- homogeneity criteria because each group with regard to each characteristic is equal to the whole sample of students but in their interior students are quite different.

Even if in this example a global optimum is reached (the fitness value was zero), due to the clear proportionality in the attribute values, it is important to state that this situation is not usual in most of the multi-attribute grouping problems. Here is where the fourth step enters, answering the question: how to find a feasible solution with an adequate fitness value? Notice that it was said "adequate" instead of "optimal" value due to two reasons. The first one is that, as mentioned before, the possible number of grouping alternatives grows in a factorial proportion depending on the number of students and groups, so exhaustive search methods become banned for most cases. The second one is that for practical purposes, the difference between the optimal groups setting and an adequate one (a close one in terms of the fitness value) is insignificant.

Considering these two issues, the use of a heuristic search method is proposed instead. In this point there are many alternatives, from the simpler ones like a random search, to other more complex ones like simulated annealing, taboo search or genetic algorithms. The implementation of one or another is a designer decision. However it is important to mention that the described other three steps of the multi-objective optimization approach constitutes already big part of the problem solution, so this last step should not be a problem.

With the aim that reader does not think that a more detailed description of an alternative in such fourth step is being presumptuously "skipped", a general random search procedure is presented next:

1. Calculate $\overrightarrow{PM}$ according to equation 4.15
2. Generate a random feasible solution
3. Calculate D for that solution according to equations 4.16 and 4.17
4. If the obtained fitness value D is below a predefined precision value, or if the number of iterations reaches a maximum, procedure stops; goes back to 2 otherwise

4.5 Tutor Model instantiation

Being the TM the denser model in this proposal, it is not a surprise that here is where more particular design decisions must be taken. According to what has been presented on this chapter, designer must decide the next issues, which are the aim of sections 4.5.1 to 4.5.6 respectively.

About adaptive presentation:
1) What personal characteristics from the SM would be used for adaptive presentation?, which categories or ranges would be used for that? and what would be the corresponding IF THEN rules?

2) What psycho-cognitive characteristics from the SM would be used for adaptive presentation?
3) What metadata standard for the LOs should be used and how the selected personal and psycho-cognitive characteristics would be incorporated on it?

About adaptive collaboration support:

4) What psycho-cognitive characteristics from the SM would be used for adaptive colleague searching?
5) What characteristics from the SM would be used for the adaptive group formation?
6) What heuristic search method would be used in the group formation procedure?

4.5.1   Personal characteristics used for adaptive presentation

Although there are $P = 7$ attributes considered for the personal information and some of them may be used for adaptation, none is considered in Doctus beyond user's description ($Q = 0$). Doctus is designed in this way for the sake of simplicity (for the author user point of view) because, as it was explained in section 4.3.3, the more aspects are considered for adaptation the more educational resources (and therefore effort) are required.

4.5.2   Psycho-cognitive characteristics used for adaptive presentation

From the $R = 3$ considered characteristics in Doctus, the first two, the Honey & Mumford learning styles and the VARK learning styles, are used for the adaptive presentation ($S1 = 2$). The reason to do so relies in that both models "see" different issues of the learning processes or, according to the classification of learning styles models made by different researchers (CURRY, 1987; VERMUNT, 1998; COFFIELD, 2004), they are situated in different levels of modeling that are relevant for the content presentation.

In the classification made by Curry, one of the first works about it that has served as reference for further studies, he uses the analogy of an onion, differencing three layers or levels of models as presented on figure 4.10.
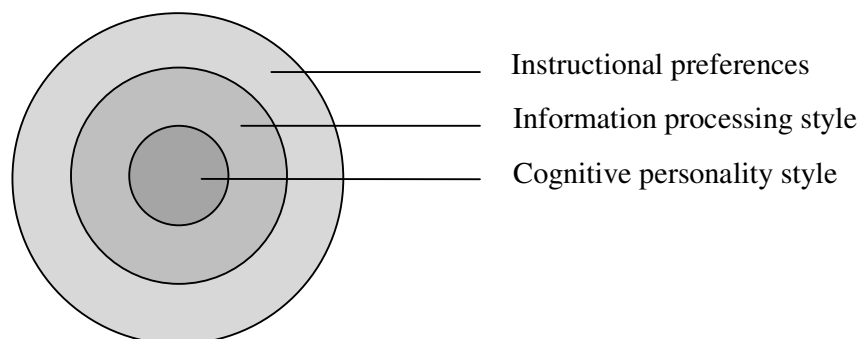

Figure 4.10: Curry's Onion model of learning styles (CURRY, 1983)

According to this classification, the Honey & Mumford model is situated in the middle layer which is based on the preferences about how information is processed by learner, whereas the VARK model is situated in the inner layer which is related to the

preferences related to the personality. In this way, what is intended to do is to capture the way learner understand better (the reflective, activist, theorist, pragmatist dimensions of the Honey & Mumford model) and through what kind of representation (the visual, aural, read/write, kinesthetic dimensions of the VARK model).

4.5.3   Metadata standard for the Learning Objects

As mentioned previously on section 1.2.5 there are several standards and initiatives to specify the LO metadata and, from all of them, the Learning Object Metadata (LOM) was selected for Doctus. To take that decision it was considered that LOM is the more referenced standard in literature and is used in many LO repositories. For example, in (ROY et al., 2010) they analyzed nine well known repositories, and found that six of them use LOM.

LOM considers in total 45 attributes, some of them atomic other composed, grouped in nine different categories as presented on table 4.7.

Table 4.7: IEEE LOM categories

Category	Description	Number of attributes
General	description of the learning object as a whole	8
Lifecycle	the history and current state of this learning object	3
Meta-Metadata	information about the metadata instance	4
Technical	technical requirements and technical characteristics	7
Educational	educational and pedagogic characteristics	11
Rights	intellectual property rights and conditions of use	3
Relation	the relationship with other learning objects	2
Annotation	comments on the educational use of the learning object	3
Classification	relation to a particular classification system	4

In order to incorporate the considered psycho-cognitive characteristics the attribute 'Description' of the 'Educational' category is proposed. According to the standard IEEE 1484.12.1-2002 (IEEE, 2002) such an attribute can have a maximum of 10 items, where each one corresponds to a character string with a maximum size of 100 characters, so it is ideal to contain the arrays set for the two considered characteristics for adaptive presentation.

To clarify how exactly it would be used, considered a hypothetical LO which was described by a teacher in the two characteristics as {0.8, 0.2, 0.9, 0.1} and {0.2, 0.0, 1.0, 0.0}. According to those values it could be presumed that such a LO is intended for reflector-theorist students with a highly pronounced read/write preference. Again, although it should sound repetitive already, such a LO characterization would be a responsibility of the authors or teachers and there is not a magical formula to make it. There are however several works that proposes how to match the LO proprieties with particular learning styles models. In (PEÑA et al., 2002b) for example, they show how to relate the LO format (if it is a slide, a video clip, etc.), interactivity level (if it is an animation, an exercise, etc.) and other proprieties with the four dichotomycal

dimensions given by the Index of Learning Styles model (FELDER & SILVERMANN, 1988). As a personal opinion I consider that such kind of matching should be used only as a start point rather than ultimate guidelines for two reasons. First, it only considers an external view of the LO, not its actual content. And second, many LOs do not have a low granularity level, i.e., they are not single graphics or text blocks; instead they are composed of different elements that give them a multi-dimensional nature. Think for example in a document that contains text but also graphics, presents theory concepts but also exercises, etc. In this case, the facto of knowing that it has a "PDF" format does not say too much as its content does.

Returning to the example, a XML representation of the corresponding LOM using the mentioned attribute would be something like:

```xml
<?xml version="1.0" encoding="UTF-8" ?>

...

  <educational>
    <description>
      <value>"{Honey-Mumford: 0.8, 0.2, 0.9, 0.1}"</value>
      <value>"{VARK: 0.2, 0.0, 1.0, 0.0}"</value>
    </description>
  </educational>

...

</lom>
```

With the aim of clarifying how other student characteristics (personal or psycho-cognitive) could be considered inside the LO metadata, appendix B presents several examples not only for LOM, but also for other well-known standards.

4.5.4   Psycho-cognitive characteristics used for the colleague searching

Considering that the aim of the colleague searching is to find a partner who may provide help to a student with problems in learning a LG, it has sense that such helper not only has some expertise on that LG but also has an appropriate "fashion" to explain it. As mentioned in section 4.4.1, such a fashion is defined in terms of shared psycho-cognitive characteristics of the two students.

In Doctus the same subset of characteristics used for adaptive presentation and described in section 4.5.2 are used for colleague searching ($S1 = S2$) obeying one simple reason: usually the way a student learns something better is the same way in which he/she is able to explain it. To clarify this issue, think for example in a student who is reflective-pragmatic according to the Honey & Mumford's learning style model and visual according to the VARK learning style model. If such student were asked to explain something, he/she would probably do it by means of real life situations using diagrams or other graphical representations. And who would understand better that explanation? Of course, another student with similar learning styles.

4.5.5   Characteristics used for the group formation

From all the alternatives that could be used to pick the students attributes for the group formation method described in section 4.4.2 only the next are considered in

Doctus: the accumulated knowledge level of the LGs that teacher considers pertinent to perform the corresponding collaborative activity and the four dimensions of the Jackson's learning style model.

The reason of incorporating the knowledge level is quite obvious. Whenever is necessary to have certain knowledge to perform the activity, there should be as many members as possible on each group with that knowledge. If not all of them have it, at least the ones who do can give explanations to the others.

The four dimensions of the Jackson model are considered with the aim of provide different personality types on each group looking for a synergy among them. In this way, if the student population is heterogeneous enough, the idea is that each group should have initiators to encourage the activity steps execution, as well as reasoners that think solutions, analysts that plan strategies and finally implementers that keep the group foot in the earth.

Using these two characteristics and considering the four dimensions of the second one, a student can be defined as a five attributes array. For example a student with the array {0.8, 0.2, 0.3, 0.9, 0.1} could be interpreted as a student with a good proficiency level and with a pronounced analyst learning style.

For each one of these attributes a different weight may be defined. For example, if a teacher considers that the knowledge level should weight 40% in the group formation and the four dimensions of learning style the remaining 60%, the values of γ (the pondering term) would be $\gamma_1 = 40$, $\gamma_2 = 15$, $\gamma_3 = 15$, $\gamma_4 = 15$ and $\gamma_5 = 15$ or any scalar factor of them.

4.5.6 Heuristic search method for the group formation procedure

Although at the end of section 4.4.2 a general random search is described as an alternative to perform the required heuristic search for the group formation procedure, a more sophisticated alternative is used in Doctus with the aim of achieving better performance in terms of obtaining more balanced groups: a genetic algorithm based approach. A brief description of such an approach is presented here, although a more comprehensive explanation may be found in (MORENO et al., 2011).

Without entering in too much detail, it may be said that Genetic Algorithms are considered a computational family of models inspired by the Darwin evolution principles and are often viewed as function optimizers, although the range of problems to which they have been applied to is quite broad (WHITLEY, 1994). The common feature of these algorithms is that they encode the potential solutions of the problem they face through a chromosome-like data structure, generally an array (for this proposal a matrix), and apply recombination operators looking for the preservation of critical information that guides to a satisfactory solution (GOLDBERG, 1989).

A general schema of a Genetic Algorithm is presented on figure 4.11 and it can be observed that is quite similar in general terms to the random search previously described. The starting point is an initial population of individuals, generally random, where an individual is understood as a feasible solution. Each individual is represented as a chromosome composed of genes and each gene makes reference to a portion or sequence of such a solution (like the examples presented in figure 4.7). Then, those individuals are evaluated using a fitness function (for this proposal such a function is defined in equation 4.16) and several genetic operators are applied in order to obtain a new population until a certain fitness value is fulfilled or until certain number of generations is reached.
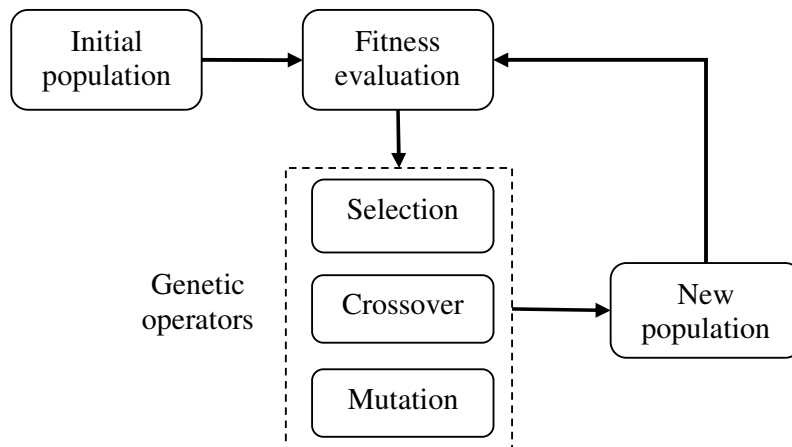
Figure 4.11: General genetic algorithm schema

4.6 Chapter reflection

Finalizing this chapter was a hard and exhausting labor. It was due to the fact that the TM is, as mentioned at the beginning of the chapter, the 'heart' that links the DM with the SM incorporating the pedagogical considerations for the whole teaching/learning process; but also because each of the four main processes considered (adaptive sequencing and navigation support, adaptive presentation, adaptive assessment, and adaptive collaboration support) was developed as rigorously as possible. It was done so from a conceptual and mathematical point of view, but without forgetting the generic perspective.

In this journey, a lot of contributions from different authors were adopted. Of course, as it is always encouraged in academic field, one must always be "stand up over the giant's shoulders". For example, for the adaptive sequencing and navigation support many techniques gathered in Brusilovsky's studies were used (BRUSILOVSKY, 1996; BRUSILOVSKY, 2001; BRUSILOVSKY, 2003); for the adaptive assessment the general IRT procedure complied by Baker (2001) was followed; and so on.

However, it is important to mention that there are also a lot of contributions in the TM by its own. Such contributions are presented mainly in the shape of algorithms or methods that use data from DM and SM. Most of them are quite simple (the selection of LO for example), but it does not mean that they are less valuable because of that. In fact, from computational and even practical points of view, one could argue that the simpler the better.

5 IMPLEMENTATION AND VALIDATION

As mentioned in the first chapter, the last two objectives of this thesis are the instantiation of the reference model followed by its implementation and validation. The instantiation was described conceptually at the penultimate sections of the last three chapters using as example a particular application called Doctus and now, in this chapter, it is time to present a deeper description of such an application as well as an explanation of its implementation and validation. Before doing so, and with the aim of providing more information about the purpose of Doctus, it may be pointed out that it has a specific purpose: to serve as an authoring tool for the creation, management, and development of on-line adaptive courses. By the way, "Doctus" is a Latin word that means taught, instructed, learned or tutored.

Although it is clear that the implementation part of a doctoral thesis is usually considered aside so the theoretical and methodological contributions do not get shadowed, it is important to mention that Doctus differentiates itself of other implementations that are result of research works mainly in two aspects. First, it has a free use license so the academic community may take advantage of it for study cases or real applications. Second, the authoring nature of Doctus allows non programmer users for employing it based on their specific needs and expertise levels.

5.1 Hardware and software architecture

Considering the current trends not only in educational but also in commercial platforms, Doctus was implemented as a Web application so users can access it easily through a Web navigator. In this sense, and according to the taxonomy of CAL approaches defined in section 1.2, Doctus may be considered as an AIWBES because it provides the AEHS and ITS functionalities described in previous chapters and runs in a Web environment.

As presented on figure 5.1, Doctus has a client - server architecture and was developed using several tools: MySQL as the Data Base Management System and Apache Tomcat as the Web Server containing the Java Server Pages (JSP) and Servlets. Such tools not only encourage the use of open source software but also, confer interoperability allowing Doctus for running in different operating systems.
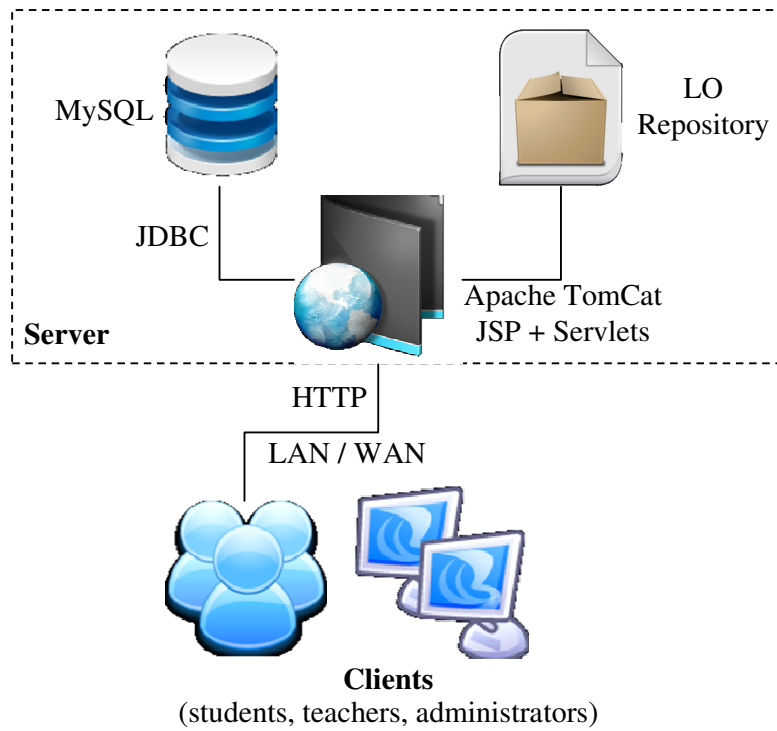
Figure 5.1: Doctus architecture

A summary of the Doctus relational database is presented on Figure 5.2. Notice that SM is represented by tables in light green (personal, knowledge, and psycho-cognitive information) whereas DM is represented by tables in dark blue (a course is developed through LGs which are composed of activities that contains LOs and resources).
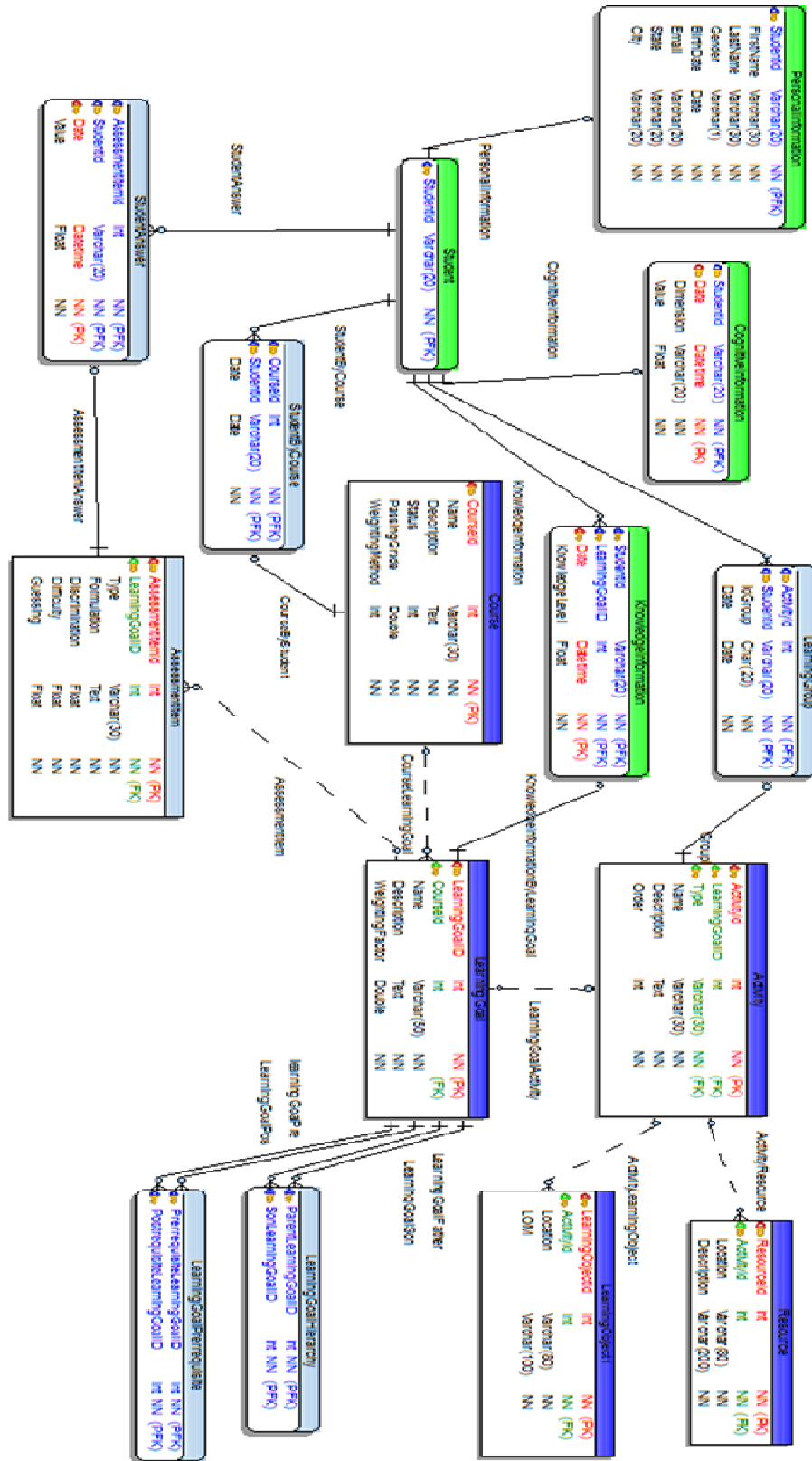
Figure 5.2: Entity-relationship model of Doctus database

5.2 Application features

Doctus is an instantiation of the reference model described in the last three chapters and therefore its core has been sufficiently described already. Considering that, no further explanations are required and what this section presents instead, is how all the described functionalities "looks" in Doctus focusing in the interaction with the target users: teachers and students.

Figures 5.3, 5.5, and 5.6 present some of the main interfaces for teachers with an example course called *Literatura Colombiana.* Figure 5.3 for example shows the LG tree structure and the LG prerequisites schema which represent the DM as described in Section 2.3. In this case what is presented is the title of the LGs, not their descriptions which should be defined, as mentioned in chapter 2, in terms of expected learning outcomes. Notice here that Doctus allows for creating as many LG composition levels as wanted as well as prerequisite links, so teachers are able to construct their courses in the fashion they want: linear, hierarchical, free, or mixed. Figure 5.4 presents a graphical representation of the relationships for this example course (the titles of the LGs have been abbreviated).

Figure 5.3: Learning goal composition and prerequisites structure in Doctus
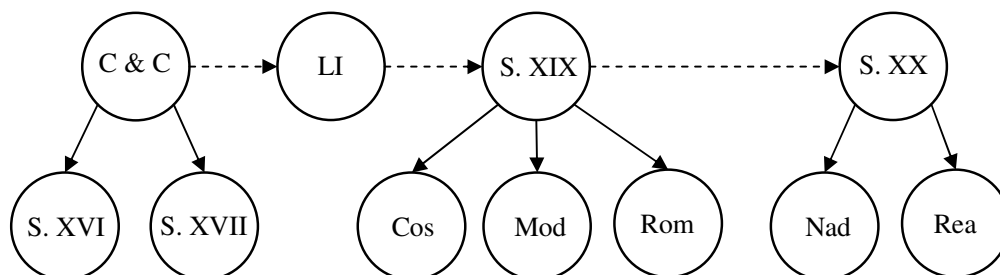
Figure 5.4: Structure of the example course

Figure 5.5 shows the development of a LG through a series of activities. In the example course, there are three activities for the LG *Costumbrismo* and for the first activity there are three associated LOs and no resources. Notice that a teacher may describe each activity as detailed or summarized as he/she wants, and may associate as many LOs as pertinent.

Figure 5.5: Activities definition in Doctus

Figure 5.6 shows the creation of the assessment item bank for a specific LG. In Doctus all the types of questions presented on Table 4.4 were implemented and the free answer type was divided into two subtypes: free numeric and free text. This was done because each subtype has its own particularities: the precision level (in decimal points) in the free numeric and the upper/lower case restrictions in the free text.

Figure 5.6: Assessment item bank creation in Doctus

Figures 5.7 to 5.10 present some of the main interfaces for students. In this case with the same example course than for teachers (this way the "other side of the coin" is presented). Figure 5.7 shows for example the initial interface that is presented to a student when enters a course. Notice here, that the knowledge sequencing mechanism described in section 4.1.2 and used to navigate the LG structure is performed in the shape of a map adaptation where the student not only sees a general picture of the course, but also his/her progress. In this example, the student can observe which LGs has already approved, which LGs he/she is able to see, and which are blocked until the corresponding prerequisites are achieved.

Continuing with the adaptive sequencing and navigation support, Figure 5.8 shows how the task sequencing, i.e. the development of a specific LG, is presented to a student. Such process corresponds to the navigation throughout the different activities that compose the LG. In this case, the student may use the direct guidance mechanism (the navigation buttons that appear in the lower section of the interface) or select directly the activity he/she wants to develop. Notice that in this figure another critical functionality is presented: the content adaptation in the shape of a LO recommendation. In this case, from the three available LO, the one that suits better the student is presented first, whereas the remaining ones are left as additional material.

D⬤CTUS

Inicio   Estudiante: Pedro Perez (Salir)

Curso: Literatura Colombiana

Descripcion: El curso de Literatura Colombiana, busca hacer un recorrido por la literatura colombiana desde la epoca de la conquista hasta la actualidad con dos intereses principales: primero, que el estudiante desarrolle herramientas basicas de analisis textual para aplicarlas en una lectura analitica a los diversos textos propuestos para el curso y para futuras incursiones en los estudios literarios. Segundo, se intenta fortalecer una lectura reflexiva de la cultura colombiana vista en sus letras.

- Conquista y colonia (85/100) ✓
  - Siglo XVI (83/100) ✓
  - Siglo XVII (87/100) ✓

- Literatura de la independencia (76/100) ✓

- Siglo XIX ➡
  - Costumbrismo ➡
  - Modernismo (81/100) ✓
  - Romanticismo ➡

- Siglo XX 🔴
  - Nadaismo 🔴
  - Realismo magico 🔴

Figure 5.7: Course presentation in Doctus

D⬤CTUS

Inicio   Estudiante: Pedro Perez (Salir)

Actividad de Aprendizaje: Lectura y reflexion: Historia y autores del Costumbrismo en la literatura Colombiana

Descripcion: Revise atentamente este contenido y tome notas

Recursos:

Objetos de Aprendizaje:

Recomendado: El costumbrismo en Colombia (PPT)

Adicionales:
El costumbrismo en Colombia (JPG)
El costumbrismo en Colombia (PDF)

Figure 5.8: Activity deployment and content presentation in Doctus

Figure 5.9 shows the presentation of a particular kind of activity: a collaborative activity. In this case, along with the corresponding LOs and resources (there are zero and one respectively in the example), the student may view the other group members so

they can get in touch to perform the activity. To arrange such a groups Doctus uses formation mechanism described in section 4.4.2.

Figure 5.9: Collaborative activity in Doctus

Once a student has developed all the activities that compose a LG he/she should take the corresponding evaluation as presented on Figure 5.10. Such evaluation is performed using the mechanism described in section 4.3 so the assessment items are presented progressively, according to previous student's knowledge level estimation and the answers he/she provides. Notice that once the evaluation has finished the final grade is presented to the student and, in the case that such grade does not reach the approbatory level (defined by teacher), a learning partner is recommended using the mechanism described in section 4.4.1.

Figure 5.10: Assessment process in Doctus

5.3 Validation

Part of the last objective of this thesis is the preliminary validation of the application that was implemented based on the reference model, i.e. Doctus, and that is precisely what is presented in this section. "Preliminary" means that such an evaluation is focused in the usability of the application rather than in the performance, in terms of students' performance, of the implemented adaptation techniques in real educational environments. It is important to mention however that some in-deep analysis were made

in did, but are not presented here because they are beyond the scope of this thesis. The results of those analyses were published as described in the next chapter, although not all of them were made using Doctus but separately (Doctus was not already finished by the time the analyses were made).

The validation presented in this section was done with a sample of 51 subjects, 27 males and 24 females, mean age 34,61 with standard deviation 7,42. All subjects were attending the course *Taller TICs y Educación en Ciencias I* of the post-graduate program *Maestría en Enseñanza de las Ciencias Exactas y Naturales* at the *Universidad Nacional de Colombia –Medellín* during semester 2012-1. Such a validation was performed in four hours of attendance, plus an estimate of four to eight hours of homework within a period between April 14th until April 28th.

The attendance sessions was divided in two, of two hours each. Both sessions were recorded on video and uploaded to youtube in the next urls: http://www.youtube.com/watch?v=Tc5D7ebORLM for the first session, and http://www.youtube.com/watch?v=5yCesjGNk8U for the second session. This way all attendants could review them as many times as needed. An actual photo taken during one of these sessions is presented on Figure 5.11. For the homework sessions, additional material to the one delivered in the attendance sessions was available for all subjects. Such a material comprises of a set of video tutorials (14 in total) that were uploaded to youtube (http://www.youtube.com/playlist?list=PLBC443D547B3B3CED).

Figure 5.11: Validation session

The validation process consisted in five stages, being the first stage a brief introduction to Doctus, along with a description of the aim of the validation. The second stage consisted in a lecture where some of the main concepts of AIES were presented as well as their corresponding instantiation in Doctus. These two stages were covered during the first attendance session.

In the third stage the subjects interacted with Doctus (http://doctus.medellin.unal.edu.co) in the student role through a test course. Such a course (the same described in section 5.2) allowed for experiencing firsthand how a student would see the adaptive functionalities. This stage was started during the first attendance session and finished in the homework time.

In the fourth stage the subjects interacted with Doctus using the teacher role creating their own courses from the scratch, or at least part of them. In this stage they could experimented (with appropriate guidance) what an adaptive course implies, i.e., how much effort its construction involves. This stage was started during the second attendance session and finished in the homework time.

In the fifth stage a usability test was performed in order to gather the perceptions of the subjects about Doctus functionalities and the underlying ideas. This stage was introduced during the second attendance session but performed in the homework time. In order to quantify the opinions of the subjects, a questionnaire was designed for the usability test using five Likert scales: an integer value between one (the lowest) and five (the highest). The questions are presented on table 5.1 and in all cases they start with the phrase "According to your previous interaction experience in both roles, as a student as a teacher, how would you score …" Besides the quantitative measures, all subjects were encouraged to express their qualitative judgments about each issue expressed on every question. This was done adding a space after each question with the comment: "if you have any comment, please write it down here". An actual copy of the whole questionnaire (written in Spanish, as presented to all subjects), including the informed consent letter is presented on Appendix C.

Table 5.1: Usability test questionnaire

Question	Formulation
1	the definition of the knowledge domain based on learning goals (atomic or composed)
2	the definition of the prerequisites structure (when necessary)
3	the consideration of an student model (personal, knowledge and psycho-cognitive information)
4	the navigation in a course level (through learning goals according to the prerequisites structure) and in a learning goal level (through the activities)
5	the definition of the learning activities and the possible incorporation of the pedagogical strategies for their development
6	the selection of learning objects (contents) based on the psycho-cognitive characteristics of the students (learning styles)
7	the specification of the psycho-cognitive characteristics within the learning objects (the valuation of the learning styles when an object is associated to an activity)
8	the creation of the assessment items bank
9	the adaptive assessment procedure compared to traditional

		computer aided testing
	10	the definition of collaborative activities and the group formation procedure
	11	the procedure for the recommendation of a colleague when a student exhibits a deficiency during the assessment
	12	Doctus in general as platform to create adaptive virtual courses

The quantitative results of the usability test questionnaire are presented on Figure 5.12, whereas a summary considering common descriptive statistics is presented on Table 5.2
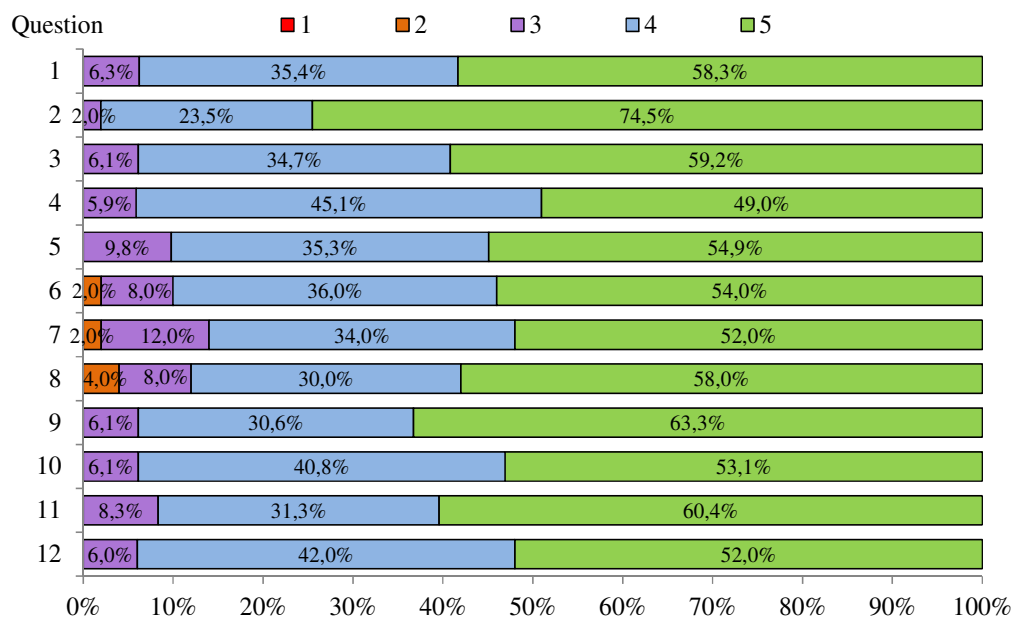
Figure 5.12: Results of the usability test questionnaire

Table 5.2: Results summary of the usability test questionnaire

Measure	Question											
	1	2	3	4	5	6	7	8	9	10	11	12
Answers	50	53	50	53	53	52	52	52	51	51	50	52
Mean	4,52	4,70	4,52	4,42	4,45	4,42	4,37	4,42	4,57	4,45	4,48	4,46
Standard deviation	0,61	0,50	0,61	0,60	0,67	0,72	0,77	0,80	0,61	0,61	0,68	0,61
Variance	0,38	0,25	0,38	0,36	0,44	0,52	0,59	0,64	0,37	0,37	0,46	0,37
Typical error	0,09	0,07	0,09	0,08	0,09	0,10	0,11	0,11	0,09	0,09	0,10	0,08

Confidence level	0,17	0,14	0,17	0,17	0,18	0,20	0,21	0,22	0,17	0,17	0,19	0,17
Median	5	5	5	4	5	5	5	5	5	5	5	5
Mode	5	5	5	4	5	5	5	5	5	5	5	5
Kurtosis	-0,13	0,84	-0,13	-0,61	-0,38	1,21	0,43	1,60	0,26	-0,50	-0,24	-0,47
Asymmetry coefficient	-0,90	-1,35	-0,90	-0,48	-0,83	-1,17	-1,01	-1,41	-1,10	-0,63	-0,95	-0,66

In general, as it can be seen from results presented on figure 5.12 and table 5.2, most individuals gave high scores (4 and 5) to all functionalities, meaning that those individuals liked the ideas and procedures behind them, but also the way that such ideas and procedures were implemented in Doctus. A more in-depth analysis of these results is presented next.

In questions 1 and 2, related to the definition of the domain knowledge, subjects expressed that they felt comfortable organizing their courses with the proposed structure. For example, regarding question 1 someone said:

"It is very helpful when structuring knowledge", male, 30 years old.

Regarding question 2, which refers to the prerequisites structure, comments in general were also positive:

"It easily allows to articulate and control processes", male, 53 years old.

"It is very pertinent to provide a sequence to a course", female, 27 years old.

In question 3, related to the student model, subjects expressed that it is important to have complete and relevant information of their students, and most subjects felt relieved of platform taking care of all this information:

"This issue calls particularly my attention: to have the possibility of knowing the kind public we have in a classroom in an agile, efficient and systematic way", male, 28 years old.

Being the tutor model the densest of the three, questions 4 to 11 are related to all its components. In question 4 for example, which refers to the adaptive sequencing and navigation support, many subjects said that it was appropriate but many would have like that the interfaces were more appealing:

"It is very intuitive", male, 36 years old.

"It would be interesting to improve the interface, but it is very functional", male, 33 years old.

"It could be more attractive, more dynamic", male, 31 years old.

In question 5, related to the definition of the learning activities and the incorporation the pedagogical strategies, subjects expressed that they found this issue important and interesting:

"It is important because it makes us think and re-think about our pedagogical labor, our way of making activities and evaluate them", male, 53 years old.

However, some of them felt a bit frightened of the extra work it implies:

"It implies more work for us as teachers, however once done everything would be better", female, 27 years old.

Questions 6 and 7 are related to the adaptive presentation, and more specifically to the selection of LOs based on the students' psycho-cognitive profile. These questions were the ones that provoke more discussion. For one side, most subjects found this functionality as one of the most important of the whole platform (question 6):

"It is very interesting keeping in mind each student's characteristics", male, 31 years old.

"It is excellent because considers the great variety of students we have", female, 27 years old.

"It allows developing contents directed to the students, having this way more chances for success in the learning process", male, 53 years old.

However, they found very difficult to define which LOs were more adequate for each profile (question 7):

"Sometimes it is complicated", male, 30 years old.

"It is very subjective because most times two opposite learning styles are considered and it is not easy to make an exact or correct classification", male, 46 years old.

"I consider that it is very difficult to plan a content for each of the student profiles, even more when you have 40-45 students per classroom", female, 32 years old.

Questions 8 and 9 are related to the adaptive assessment. More exactly, question 8 refers to the task that teachers must do: the appropriate creation of an assessment items bank; whereas question 9 to the way that students are assessed. From all questions, question 8 were the one with lower mean and higher standard deviation. In fact, it received the more percentage of negative scores. According to the subjects, even if they

realized that this process is important and necessary, it is hard and requires a lot of effort:

"It requires a lot of work because we are not used to categorize assessment items by levels, even if it is the ideal scenario", female, 31 years old.

However, once the assessment items bank is created, many subjects believed that the proposed adaptive procedure is better than traditional (question 9):

"I liked because the system is who looks for suiting to the student and not otherwise", female, 35 years old.

"It is nice to keep in mind the capacity of each student", male, 31 years old.

Although there are some subjects who do not trust on such a procedure completely:

"I do not share the fact that some students receive lower level questions than others", female, 27 years old.

Questions 10 and 11 are related to the adaptive collaboration support. In question 10, which refers to the group formation procedure for collaborative activities, most subjects shared the enthusiasm of having "balanced" groups:

"In theory it seems very 'Solomon-like' it groups students that somehow complement to each other", female, 35 years old.

"It might be very productive when having a reliable analysis of each student", female, 29 years old.

Even though there were some who preferred traditional group formation mechanisms, or at least the option of using them:

"It should be a free choice", female, 27 years old.

Finally, in question 11 when asking subjects about their general opinion about the platform, many of them expressed great interest in having a tool to enrich their practices in real classroom environments. However, many of them also expressed their concerns about the interface limitations that the platform still have:

"It is a powerful tool, to which it is necessary to enhance some issues yet", male, 45 years old.

"Excellent platform. It can be used in my labor", female, 32 years old.

"I think that it is a good option. It is an agile, complete, easy to use and allow for adapting and having into account the students' cognitive profile and varying the options that we may offer them", male, 53 years old.

"In the future its capacity should be enhanced, specially to upload files or videos", male, 43 years old.

"I see great potential on it. Teaching a course could be improved significantly when individualizing learning. Besides, with additional modifications, the platform could provide very appropriate statistics to generate research proposals. This way the teacher would transform into a researcher and his/her impact would be bigger.", male, 34 years old.

5.4 Chapter reflection

The next two paragraphs are the only case in this dissertation in which I took the liberty of writing in a personal manner. Although I am aware that it is not appropriate for academic writing, I did not find any other way to express this chapter reflection.

When defining the thesis objectives I had a large discussion (in the good sense of the word) with my advisors about what the validation should include. Checking several dissertation theses about reference models for designing systems in other fields I mostly found that their validations consisted in an application case of those models, i.e. in the design of an actual or hypothetical system following the reference model. If we would have go that far, the validation of the model proposed on this thesis would have been covered already in the last three chapters, more specifically in their last sections which refer to the instantiation case. However we finally decided to go further –for which I am happy now- and validated the design also with an implementation. But we did not stop there and went even further making an evaluation of such an implementation (Doctus) with the better subjects we could possibly have wish: actual teachers from different formation levels.

Such an 'extra' validation was the focus of this chapter, and we are proud of saying that it was satisfactory, not only academically speaking, but also for having the opportunity of sharing this research with the people who could be really interested on it. Even, with those who in the future could use the implementation or the reference model as a basis in their own researches.

6 CONCLUDING REMARKS

After the extensive work of concluding this thesis document (even if the thesis itself actually never finishes) there are several remarks to share. The aim of the first section of this chapter is to present how the initial objectives were fulfilled, whereas the second section presents what future work is foreseen. Finally, the chapter ends with a list of related publications.

6.1 Conclusions

After a wide comparison of models and implementations, we found that the complexity in the design and implementation of educational systems increases as they have more adaptive features which allow them to provide a more individualized learning experience. With this panorama, the main goal of this thesis was to offer a reference model without having too much complexity, but detailed enough to facilitate subsequent implementations.

As a result, this document presented a reference model with two general contributions. First, it is supported by LOs at the level of the educational content which provides flexibility and reusability. And second, it is generic in the sense that it allows for using different pedagogical and technical considerations. Being more detailed, the specific thesis objectives were successfully fulfilled in the following way.

The first objective proposed to specify a flexible DM in order to structure the knowledge to be learned. An extensive literature review was needed to determine the characteristics of the elements that should comprise such a model, as well as the relationships that could be present between them. As a result, a DM was specified with the next features: a) it is fine grained, using the notion of LGs as elementary components; b) it provides a hierarchical schema with n levels of aggregation; and c) it offers a prerequisite structure that allows for (but does not force) making continuity links between the LGs.

The second objective attempted to define a rich SM considering diverse kinds of information. After a comprehensive process of exploration and elimination, such information was limited to three kinds: personal, knowledge-related, and psycho-cognitive. In the first one, basic data of the students are collected: name, age, gender,

etc. Even if some of these may be used for adaptation, its main use is to characterize students as system users.

The knowledge-related information is used to determine how much the student has learned with regard to the corresponding DM. In this case, the overlay model approach was adopted for being the most compatible with the implemented DM structure and because it allows for representing the student knowledge in a flexible and scalable manner.

Finally, about the psycho-cognitive information, two conclusions can be extracted. First, and in line with the opinion of many researches from different fields, such information must be considered in order to ensure an effective teaching/learning process. Second, there are many theories and models related to this information. In this sense, the reference model presented in this thesis does not specify which ones of them should be used or why. Instead, it provides a generic, array representation of such information which allows for using the adaptive techniques defined in this thesis.

Now, the third objective aimed to describe a TM which, in concordance with the previous two and considering LOs as fundamental components, supports the teaching/learning process in an adaptive way. For doing so, four main sub-processes were considered: the adaptive sequencing and navigation support, the adaptive presentation, the adaptive assessment, and the adaptive collaboration support.

The proposed adaptive sequencing and navigation support resulted as the combination of two approaches: the adaptive sequencing, more known as curriculum sequencing from ITS; and the adaptive navigation from AHS. Although both deal with what and when instruction should be presented to each student, the difference lies in the abstraction level. The former refers to the high abstraction level, i.e., moving from one LG to another; whereas the later to the low abstraction level, i.e., moving within a LG throughout the learning activities that compose it.

With regard to the adaptive presentation, four contributions of the proposed content selection method may be mentioned: a) it considers not just one but multiple students characteristics; b) it connects the world of LOs (with all the advantages it implies) with the world of AIES in a simple manner; c) it does not suffer of the dimensionality curse with regard to the psycho-cognitive characteristics, i.e., it works equally fine even if there are hundreds or only a couple of available LOs; and d) it does not suppose a predefined characterization of the LO according to their type of format being aware that they could incorporate several dimensions.

For the adaptive assessment, two approaches were adopted: the general CAT procedure to manage tests and the IRT to characterize and select assessment items. In the last case, from all the available models to represent the ICC, the 3PL was chosen for being the more general one. Using these approaches, the proposed assessment method allows for having tests which, from the examinee's perspective, seems to tailor itself, on the basis of the difficulty, to his/her knowledge level.

In the adaptive collaboration support two practices were considered: the group formation for collaborative activities and the recommendation of a learning partner when a deficiency is detected. The main contribution in the first case is that translating the grouping problem into a multi-objective optimization problem allows for considering as many student characteristics as wanted, guaranteeing either way an

adequate distribution (not necessarily the optimal but a good one) without too much computational effort. In the second case, the main contribution is that the algorithm proposed does not only focus in the academic performance but also in psycho-cognitive characteristics. This allows for recommending learning partners who can really become useful for those who need help, avoiding at the same time that just a bunch of the "good" students get overwhelmed by assistance petitions.

The fourth objective intended to instantiate the proposed model with the design of a particular system. This was reached with the development of a system called Doctus, described across chapters 2 to 4, which turned to be an authoring tool to create and monitor adaptive on-line courses. Such an instantiation was very helpful, not only because it served to exemplify in a clear way all the components and their relationships of the model proposed, but also because it allowed for refining them to their current state.

The fifth and final objective attempted to validate the design performed in the previous objective, throughout the implementation and preliminary evaluation of a computational prototype. The prototype corresponded to the implementation of Doctus, which was developed as a web platform (http://doctus.medellin.unal.edu.co) using a client - server architecture and several open software tools: MySQL, Apache Tomcat, JSP and Java Servlets. It was validated with 51 subjects who interacted with Doctus in two different roles: student and teacher, and later gave their opinions through a usability test questionnaire both quantitative and qualitatively. Such a validation demonstrated that the implementation was a good reflect of the reference model but also that test subjects (mostly teachers) felt enthusiastic about the adaptive features provided.

6.2 Future work

Once the thesis objectives were satisfactorily achieved, it was impossible not to dream about what follows and what else can be done to enhance this research. Such "dreams" can be divided in two categories: the improvement of the reference model, and the implementation and validation of further applications.

In the first category several upgrades of the considered adaptive sub-process are visualized. In the adaptive sequencing and navigation support for instance, the variation in number and shape of learning activities according to the student learning style could be included. An example for this case could be presenting more exercises and practical cases to an 'active' student, or presenting them not only after an explanation but in different times. This however would increase the complexity of the courses designed so its development should be carefully carried out.

In the second category there are a lot of applications foreseen. One of them is taking the experience with Doctus and translate it into the implementation of an authoring tool for adaptive courses but embedded in a commercial, open source alternative like Moodle. This approach would be useful for the developers because it would mean counting with a world-wide support community. At the same time, it would be useful

for final users (teachers and students) because they could have all adaptive functionalities but in a platform that is usually more familiar to them.

Finally, another application is having a more direct exploitation of the advantages of LOs, making a direct connection between the authoring tool (Doctus or any other) with a widely-used repository. This however would only be possible if at least one of these conditions is present: a) the repository manages explicit metadata about the criteria used for adaptation, e.g. psycho-cognitive characteristics, and b) such metadata, if not available, may be properly estimated from other.

6.3 Scientific divulgation

As a result of this thesis development, several publications were made with the aim of exchanging ideas and outcomes with the academic community. A list of those publications is presented next.

Indexed journal papers:

- MORENO, J., GÓMEZ, S. Uso de tests de aptitud y algoritmos genéticos para la conformación de grupos en ambientes colaborativos de aprendizaje. *Revista Avances en Sistemas e Informática.* Volumen 6, Número 1. pp. 165-172. June 2009. ISSN: 1657-7663, Category C in Publindex – Colciencias.
- MORENO, J., OVALLE, D., VICARI, R. Hacia una taxonomía en la educación asistida por computador. *Revista Educación en Ingeniería.* Número 9. pp. 27-36. June 2010. ISSN: 1900-8260, Category C in Publindex – Colciencias.
- MORENO, J., OVALLE, D., VICARI, R. A genetic algorithm approach for group formation in collaborative learning considering multiple students' characteristics. *Computers & Education.* Volume 58, Issue 1. pp. 560-569. January 2012. ISSN: 0360-1315, Category A1 in Publindex – Colciencias, Category A1 in Qualis – CAPES.
- MORENO, J., OVALLE, D., VICARI, R. Design and Validation of an Adaptive Assessment Model based on the Item Response Theory. *Revista Ingenierías - Universidad de Medellín.* ISSN: 1692-3324, Category A2 in Publindex – Colciencias (In evaluation).
- MORENO, J., OVALLE, D., VICARI, R. Método para la recomendación de compañeros de estudio en ambientes virtuales considerando desempeños académicos y estilos de aprendizaje. *Itinerario Educativo.* ISSN: 0121-2753, Category C in Publindex – Colciencias (In evaluation).
- MORENO, J., OVALLE, D., VICARI, R. Implementation of adaptive on-line courses: a teachers' perspective. *International Journal on E-Learning - Corporate, Government, Healthcare, & Higher Education.* ISSN: 1537-2456, Category B in Publindex – Colciencias, Category A2 in Qualis – CAPES (In evaluation).

Book chapters:

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- MORENO, J., GÓMEZ, S. Análisis del desempeño de grupos de estudio colaborativos conformados a partir de un método de búsqueda heurística. *Tendencias en Ingeniería de Software e Inteligencia Artificial*. Vol. 4. Zapata, Carlos Mario, Giraldo, Gloria Lucía y Velásquez, Juan David (Eds). ISBN: 978-958-44-5820-9. pp. 147-154. February 2011.

Event proceedings:

- MORENO, J. Conformación de grupos de estudio colaborativos heterogéneos. *XIV Taller Internacional de Software Educativo – TISE*. Santiago de Chile, Chile. December, 2009.
- MORENO, J., OVALLE, D., VICARI, R. Método para la selección de objetos de aprendizaje a partir de características cognitivas del estudiante. *XXI Simpósio Brasileiro de Informática na Educação – SBIE*. João Pessoa, Brazil. November, 2010.
- MORENO, J., OVALLE, D., VICARI, R. Doctus: Plataforma para la Creación de Cursos Virtuales Adaptativos Soportados en Objetos de Aprendizaje. *Séptima Conferencia Latinoamericana de Objetos y Tecnologías de Aprendizaje – LACLO*. Guayaquil, Ecuador. October 2012.

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APPENDIX A

COMPARISSON OF LEARNING STYLES MODELS

In view of the large quantity of learning styles models in literature, this appendix presents a brief description in chronological order of some of the more used and referenced, focusing into two key issues from the AIES perspective: the dimensions they consider and the corresponding measurement mechanism. "Key" because, by one side, the larger amount of dimensions, the larger amount of content presentations (in this thesis context it refers to *LOs*) would be needed to cover them exhaustively; by the other side, the more complex the mechanism, the more accuracy but also the more difficult in its use.

If reader wants to go even deeper in learning styles models there are several interesting works where some of such models are described, analyzed, compared, classified and even verified in real educational environments (CURRY, 1987; HICKCOX, 1995; CASSIDY, 2004; COFFIELD et al., 2004; PASHLER et al., 2008; LIU et al., 2010).

Model: Myers & Briggs's personality types (MYERS, 1962; MYERS & MCCAULLEY, 1986; MYERS et al., 1998).

Considerations: It is based on the Jung's theory of psychological type (JUNG, 1968) and considers four bipolar scales, producing 16 possible styles.

Dimensions: Extraversion – Introversion

Sensing – Intuition

Thinking – Feeling

Judgment – Perception

Measurement mechanism: it is called Myers-Briggs Type Indicator (MBTI) and in its more referenced version includes 93 items with only two possible answers each.

Model: Kagan's learning styles (KAGAN, 1966).

Considerations: It evaluates the individual differences in the speed and accuracy of information processing.

Dimensions: Impulsive - Reflective

Measurement mechanism: It is called Kagan's Matching Familiar Figures Test (KMFFT) and contains 14 items. Each item contains one standard shape of a common object and six variants, one identical to the standard and the remaining five slightly different. Examinee must select the one that is identical and the answering time is measured. The idea is that reflective subjects spend more time and have more hits than impulsive subjects.

Model: Riechmann & Grasha's learning styles (GRASHA & RIECHMANN, 1974).

Considerations: It focuses on the students preferences with regard to their interactions with classmates and teachers and considers three bipolar dimensions which produce 8 possible styles.

Dimensions: Independent – Dependent

Competitive – Collaborative

Participant - Avoidant

Measurement mechanism: a 60-item test with five options each: strongly disagree, moderately disagree, undecided, moderately agree and strongly agree.

Model: Kolb's learning styles (KOLB, 1976; KOLB, 1985; KOLB, 1999).

Considerations: It is based on the experiential learning theory (KOLB, 1984) and is designed to help individuals identify the way they learn from experience. The considered dimensions are bipolar so the choice of one pole involves not choosing the opposite one, which produces 4 possible styles.

Dimensions: Active – Reflective

Concrete - Abstract

Measurement mechanism: its current version, called Kolb's Learning Style Inventory (KLSI 3.1) contains 12 sentences with four endings that individuals must rank according to what best describes the way they learn (4 = "most like you", 1 = "least like you").

Model: Witkin's cognitive styles (WITKIN et al., 1977; WITKIN & GOODENOUGH, 1981).

Considerations: It focuses in two opposite cognitive styles related with how learners process information (globally or analytically).

Dimensions: Field dependent - Field independent

Measurement mechanism: it is called Group Embedded Figures Test and is based on finding common geometric shapes in larger designs. There are several versions; the most common ones have 18 and 25 items respectively.

Model: Dunn & Dunn's learning styles (DUNN & DUNN, 1978; DUNN et al., 1984).

Considerations: This model places a strong emphasis on biological and developmentally imposed characteristics. It considers that the learning style is divided in five major strands called stimuli and each one of them has several related factors.

Dimensions: Environmental (sound, light, temperature, environment design)

Emotional (motivation, persistence, responsibility, need for structure)

Physiological (perceptual preference, food and drink intake, time of day, mobility)

Sociological (group learning, support from authority figures, working alone or with peers, motivation from parents/teachers)

Psychological (global, analytic, impulsive, reflective)

Measurement mechanism: Over the years authors have developed several instruments. In its most known version is called Dunn & Dunn's Learning Styles Inventory (DDLSI) intended for school students in US grades 3 to 12 (usually in ages from 9 to 18). It comprises 104 self-report items, with three options (true, uncertain, false) for students in grades 3 and 4 and five options (strongly disagree, disagree, uncertain, agree, strongly agree) for students in grades 5 to 12.

Model: Gregorc's mind styles (GREGORC, 1982; GREGORC, 1984; GREGORC, 1985).

Considerations: According to this model minds interact with their environments through four channels (related to the corresponding dimensions) that are said to mediate ways of receiving and expressing information.

Dimensions: Concrete – Abstract

Sequential - Random

Measurement mechanism: a 10-item self-report questionnaire called Gregorc's Mind Style Delineator (GMSD) in which a respondent rank four words in each item from the most to the least descriptive of his or herself.

Model: Keefe & Monk's learning styles (KEEFE & MONK, 1987; KEEFE, 1988).

Considerations: It is intended for grades 6-12 students, measuring 23 factors grouped in three factors.

Dimensions: Cognitive skills (analytic, spatial, discrimination, categorizing, sequential processing, memory)

Perceptual response (visual, auditory, emotive)

Environmental (early morning, late morning, afternoon, evening, grouping, posture, mobility, sound, lighting, and temperature)

Measurement mechanism: a 126-item test called Keefe & Monk's Learning Style Profile (KMLSP).

Model: Felder's learning styles (FELDER & SILVERMANN, 1988; FELDER, 1993; SOLOMAN & FELDER, 1996).

Considerations: It is based on how learners usually process better the information they receive and considers four bipolar scales, producing 16 possible styles.

Dimensions: Active – Reflective

Sensing – Intuitive

Visual – Verbal

Sequential - Global

Measurement mechanism: a 44-item test called Felder's Index of Learning Styles (FILS). Each item has two options and the whole test is designed to provide 11 scores on each bipolar dimension.

Model: Hermann's thinking styles (HERMANN, 1989; HERMANN, 1996).

Considerations: It provides a four-category classification of mental preferences based on several studies of the brain functions.

Dimensions: Theorists

Organizers

Innovators

Humanitarians

Measurement mechanism: a 120-item test called Herrmann's Brain Dominance Instrument (HBDI).

Model: Allinson & Hayes's cognitive styles (ALLINSON & HAYES, 1996).

Considerations: It is designed for use with adults and only considers one bipolar dimension, which authors contend underpins other aspects of the learning style.

Dimensions: Intuition - Analysis

Measurement mechanism: a 38-item test called Allinson & Hayes's Cognitive Styles Index (AHCSI). Each item has three options: true, uncertain and false.

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APPENDIX B

INCLUSION OF ADAPTATION CHARACTERISTICS IN LEARNING OBJECTS METADATA

In section 4.5.3 it was presented how the psycho-cognitive characteristics considered for Doctus (learning styles) can be incorporated in the standard LOM. However, how other characteristics of the SM could be included? And, how would it be if instead of LOM, other metadata standard were used? This appendix tries to answer these two questions presenting a list of LOM attributes (standard IEEE 1484.12.1-2002 (IEEE, 2002)) that can be used for adaptation purposes and therefore that can be extrapolated to several LOM-based initiatives like some of the ones listed on table 1.3.

Attribute: General - Language

Description: The primary language or languages used in the Learning Object.

Permitted values: language code – <subcode>, according to the code sets ISO 639:1988 and ISO 3166-1:1997. If the learning object had no verbal content (as in the case of a picture, for example), then the appropriate value for this data element would be "none".

Example: "en-GB", meaning that the Learning Object is written or spoken manly in Britain English and therefore is intended for learners that speak that language whether it is their native language or not.

Attribute: General - Coverage

Description: The time, culture, geography or region to which the Learning Object applies.

Permitted values: a text string with up to 1000 chars.

Example: ("es", "Colombia - Región pacífica"), meaning that the Learning Object is manly intended for learners situated in the Colombian pacific region. In this case it is supposed that vocabulary, signs and other features of the Learning Object content should be appropriate for that region.

Attribute: Learning – Interactivity type

Description: Predominant mode of learning supported by the Learning Object.

Permitted values: "active", "expositive", "mixed".

Example: "expositive", meaning that the Learning Object is mainly intended for learners who prefer expositive content (displays information but does not prompt the learner for any semantically meaningful input).

Attribute: Learning – Learning resource type

Description: Specific kind of Learning Object.

Permitted values: "exercise", "simulation", "questionnaire", et al.

Example: "lecture", meaning that the Learning Object is mainly intended for learners who have a preference for this kind of objects.

Attribute: Learning – Interactivity level

Description: The degree of interactivity that characterizes the Learning Object. Interactivity in this context refers to the degree to which the learner can influence its aspect or behavior.

Permitted values: "very low", "low", "medium", "high", "very high".

Example: "very high", meaning that the Learning Object is mainly intended for learners who like to interact a lot with content (for example doing an experiment or simulation).

Attribute: Learning – Semantic density

Description: The degree of conciseness of the Learning Object, which may be measured in terms of its size, span or duration.

Permitted values: "very low", "low", "medium", "high", "very high".

Example: "low", meaning that the Learning Object is mainly intended for learners who prefer concise material.

Attribute: Learning - Context

Description: The principal environment within the learning object is intended to take place.

Permitted values: "school", "higher education", "training", "other".

Example: "higher education", meaning that the Learning Object is manly intended for learners taking higher education courses.

Attribute: Learning - Typical age range

Description: Age of the typical intended user.

Permitted values: a text string with up to 1000 chars.

Example: "18-", meaning that the Learning Object is manly intended for 18 years old or less learners.

Attribute: Learning - Difficulty

Description: How hard it is to work with the learning Object for the intended target audience.

Permitted values: "very easy", "easy", "medium", "difficult", "very difficult".

Example: "very difficult", meaning that the Learning Object is manly intended for highly experienced learners.

Attribute: Learning – Typical learning time

Description: Approximate or typical time it takes to work with or through this learning object for the typical intended target audience.

Permitted values: a duration value.

Example: "1H30M", meaning that the typical time that a learner would take studying the Learning Object is 1 hour and 30 minutes. In this case it is supposed that vocabulary, signs and other features of the Learning Object content should be appropriate for that region.

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APPENDIX C

CONSENT AND QUESTIONNAIRE FORMS

The following is an exact copy of the forms that were used for the usability test.

CARTA DE CONSENTIMIENTO INFORMADO

La investigación "Modelo de referencia para sistemas educacionales inteligentes y adaptativos soportados por objetos de aprendizaje" corresponde a una tesis para optar al título de Doctor en Ingeniería – Sistemas de la Universidad Nacional de Colombia – Medellín, es realizada por Julián Moreno Cadavid.

Una de las etapas finales de dicha investigación es la evaluación de un prototipo de software donde se implementan los modelos propuestos en la tesis.

A usted se le está invitando a participar en esta etapa de la investigación como informante, diligenciando para ello una encuesta de usabilidad. Sin embargo, antes de decidir si participa o no, debe conocer y comprender cada uno de los siguientes apartados. Este proceso se conoce como consentimiento informado. Siéntase con absoluta libertad para preguntar al investigador sobre cualquier aspecto que le ayude a aclarar las dudas que pueda tener.

1) Su decisión de participar en el estudio es completamente voluntaria.
2) No habrá ninguna consecuencia desfavorable para usted, en caso de no aceptar la invitación.
3) Si decide participar en el estudio puede retirarse en el momento que lo desee, pudiendo informar o no, las razones de su decisión, la cual será respetada en su integridad.
4) No tendrá que hacer gasto alguno durante la investigación.
5) No recibirá pago por su participación.
6) Las respuestas suministradas por usted serán digitalizadas y empleadas de manera agregada junto con las de los demás participantes para fines estadísticos.
7) Su participación es anónima. Por tanto, en caso que alguna de las respuestas suministradas por usted sea presentada en alguna publicación de manera individual, o utilizada para investigaciones futuras, esta solo podrá ser acompañada por información general como profesión, sexo y/o edad.

Si usted está dispuesto a participar en esta investigación, por favor firme donde corresponda.

Yo, _____ convengo en participar en esta investigación. He leído y comprendido la información anterior y mis preguntas han sido respondidas de

manera satisfactoria. He sido informado y entiendo que los datos obtenidos en el estudio pueden ser publicados o difundidos con fines científicos.

Firma participante: _____

Firma investigador: _____

Fecha: _____

Encuesta de usabilidad, aplicativo DOCTUS

Edad: _____

Sexo: M ____   F _____

De acuerdo a su experiencia previa tanto con el rol de estudiante como con el de profesor, califique de 1 a 5, y sin utilizar cifras decimales (siendo 1 la calificación más baja y 5 la más alta), los siguientes aspectos. En cualquiera de ellos, si tiene comentarios, por favor escríbalos en el espacio correspondiente.

1. La definición del dominio de conocimiento a partir de temas (atómicos o compuestos): _____

Comentarios: _____
_____
_____
_____

2. La definición de la estructura de prerrequisitos (cuando se considere necesaria): _____

Comentarios: _____
_____
_____
_____

3. La consideración de un dominio del estudiante (información personal, de conocimiento y cognitiva): _____

Comentarios: _____
_____
_____
_____

4. La navegación tanto a nivel de curso (a través de los temas según el esquema de prerrequisitos) como a nivel de temas (a través de las actividades): _____

Comentarios: _____
_____
_____
_____

5. La definición de actividades de aprendizaje y la posible incorporación de estrategias pedagógicas para su desarrollo: _____

Comentarios: _____
_____
_____
_____

6. La selección de objetos de aprendizaje (contenidos) empleando las características cognitivas de los estudiantes (estilos de aprendizaje): _____

Comentarios: _____
_____
_____
_____

7. La especificación de las características cognitivas al interior de los objetos de aprendizaje (la valoración de los estilos de aprendizaje a la hora de asociar un objeto a una actividad): _____

Comentarios: _____
_____
_____
_____

8. La creación del banco de ítems de evaluación: _____

Comentarios: _____
_____
_____
_____

9. El procedimiento de evaluación adaptativa comparada con la evaluación tradicional: _____

Comentarios: _____
_____
_____
_____

10. La definición de actividades colaborativas y el procedimiento para la conformación de grupos: _____

Comentarios: _____
_____
_____
_____

11. El procedimiento para la recomendación de compañeros de estudio cuando un estudiante evidencia una deficiencia en una evaluación: _____

Comentarios: _____
_____
_____
_____

12. Doctus en general como plataforma para la creación de cursos virtuales adaptativos: _____

Comentarios: _____
_____
_____
_____