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Résumé

L'omniprésence des technologies de l'information et de la communication et l’augmentation de l'efficacité des méthodes d'acquisition et de traitement des données, ont rendu l'amélioration de la qualité d'apprentissage des systèmes d'apprentissage en ligne attrayante. Les travaux présentés dans cette thèse portent principalement sur deux enjeux des environnements e-learning conventionnels :

D'une part, ils traitent de la provision de contenus éducatifs personnalisés, adaptatifs et centrés sur l'apprenant. De ce point de vue, les systèmes hypermédias éducatifs adaptatifs (SHEA) se sont révélés être une solution efficace pour fournir des parcours d'apprentissage personnalisés et des interventions appropriées dans la sélection et l'affichage de chaque objet d'apprentissage ou activité en fonction des différences individuelles des apprenants telles que le niveau de connaissances, les objectifs, la motivation, etc.

La première étape vers l'adaptabilité consiste à sélectionner une bonne taxonomie des caractéristiques de l'apprenant. Nous avons préconisé la création d'un modèle d'apprentissage, qui prend en compte les caractéristiques psychologiques de l'apprenant et conforme aux normes internationales, améliorant ainsi la réutilisabilité, le partage et l'interopérabilité. La phase suivante consiste à créer une structure flexible pour le modèle de domaine en partitionnant le contenu en fragments, qui peuvent être utilisés à des fins d'apprentissage ou d'évaluation. En d'autres termes, le cours sera composé de plusieurs chapitres, chaque chapitre comprend une ou plusieurs sections et chaque section est constituée d'un ou plusieurs objets de connaissance. Un objet de connaissance peut prendre différentes formes telles qu'une définition, un exemple, une question, etc.

En ce sens, nous avons réussi à mettre en œuvre les composantes principales de notre SHEA. A savoir, un module fournissant des formulaires et des paramètres permettant la récupération des données personnelles de l'apprenant, de son style d'apprentissage et de ses préférences. Un second module permettant la création de nouveaux cours respectant l'architecture du modèle de domaine et un troisième utilisant les préférences récupérées du premier pour adapter le contenu et la présentation d'une page de cours au profil de l’apprenant.

D'autre part, cette thèse fait face à la carence des laboratoires d'enseignement en ligne, vu que l'expérimentation et les travaux pratiques jouent un rôle essentiel dans la formation notamment dans les enseignements technologiques qui nécessitent la manipulation des équipements réels.

Nous avons réussi à mettre en œuvre une plateforme de télé-TPs permettant de relever des mesures en temps réel sur des machines électriques afin de tracer leurs caractéristiques électriques et mécaniques. Ensuite, nous avons développé une méthode pour comparer et évaluer les perceptions des étudiants sur cette plateforme grâce à une enquête et à l’évaluation des rapports des manipulations.

Mots-clés : E-learning, Systèmes hypermédias adaptatifs éducatifs, Modèle de l'apprenant, Styles d'apprentissage, Télé-TPs.

Abstract

With the pervasiveness of the emerging information and communication technologies and the increased efficiency of data acquisition and processing methods, the improvement of the learning quality of e-learning systems became appealing. The work presented in this thesis deals mainly with two issues of conventional e-learning environments:

On the one hand, it deals with the provision of personalized, adaptive, and learner-centered educational material. From this perspective, Adaptive Educational Hypermedia Systems (AEHS) proved to be a suitable and effective option for providing personalized learning paths and appropriate intervention in selecting and displaying each learning object or activity in line with the learners' individual differences such as the knowledge level, goals, motivation, individual differences, etc.

The first step towards providing adaptivity is selecting a good taxonomy of learner characteristics. We advocated the creation of a Learner Model accommodating learner's psychological features and compliant with international standards, thus enhancing reusability, shareability, and interoperability. The next consists of creating a flexible structure for the domain model partitioning the content into fragments, which may be for learning or evaluation purposes. In other words, the course will be composed of several chapters, each chapter include one or more section and every section is made up of a knowledge object, which may be in different forms such as a definition, an example, or a question.

In this sense, we managed to implement three main components of our AEHS. Namely, a module providing forms and settings allowing the retrieval of learner's personal data, learning style and preferences, a second one allowing the creation of new courses respecting the architecture of the domain model and a third using the preferences retrieved from the first one to adapt the presentation of a page of the course.

On the other, this thesis copes with the deficiency of online educational laboratories as laboratory experimentation plays a critical role in the education of engineers and practical work within engineering educational programs focus mainly on handling real equipments.

We managed to implement a real-time measurement RL for electrical engineering curricula that allows to take measurements in real time on electric machines in order to track their electrical and mechanical characteristics and developed a method for comparing and assessing students' perceptions about the implemented RL through a survey and laboratory report grading.

Keywords: E-learning, Adaptive Educational Hypermedia Systems, Learner Modeling, Learning Styles, Remote Laboratories.

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List of Abbreviations

AEHS	Adaptive Educational Hypermedia System (s)
AHS	Adaptive Hypermedia System (s)
AI	Artificial Intelligence
AM	Adaptation Model
CALS	Computer-Assisted Learning Systems
CEHL	Computer Environments for Human Learning
DM	Domain model
EO	Evaluation Object
FSLSM	Felder Silverman Learning Style Model
HS	Hypermedia System (s)
ICALE	Interactive Computer-Assisted Learning Environments
ICALS	Intelligent Computer-Assisted Learning Systems
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IMS-LIP	IMS Learner Information Packaging
ITS	Intelligent tutorial systems
KO	Knowledge object
LM	Learner Model
LMS	Learning Management System(s)
LO	Learning Object
LS	Learning style
MOOC	Massive Open Online Course
PW	Practical Work
RL	Remote Laboratory
UML	Unified Modeling Language
VL	Virtual Laboratory

General Introduction

Formerly, learning was based exclusively on a face-type education which consisted of classroom learning, individually or in groups, and under the supervision of a teacher. Nowadays, e-learning emerged as a way of enhancing the quality of education and providing accessible distance learning. E-learning is commonly defined as the use of the Internet to access learning materials, cooperate with other learners and to interact with the instructor and obtain support during the learning process in order to acquire further knowledge, skills and competencies. This type of training allows learners to study outside of school hours without teachers or mentors by providing the necessary resources and services but requires the development of a dedicated computer environment or the use of one of the free, open-source or commercial existing learning systems.

One of the main issues with the existing e-learning systems is the lack of educational content adaptation for all learners as most platforms don't pay attention to learners' diversity, even if people differ in abilities, skills, learning styles, interests and preferences. They succeed in allowing learners to retrieve a large set of learning material and resources that theoretically match a specific learning goal, but they usually omit providing the most relevant learning material that meets the needs of individual learners.

On the one hand, e-learning systems are expected to support better learner-centric instruction and enable more self-paced and self-directed learning. On the other, the provision of educational environments and content that take into account individual characteristics such as learning preferences, abilities, skills and knowledge is referred to as personalized learning or adaptive instruction.

At present, while Learning Management Systems (LMS) and Massive Open Online Courses (MOOCs) are struggling to meet these needs of adaptivity, Adaptive Educational Hypermedia Systems (AEHS) represent a smart and effective solution.

Adaptive Educational Hypermedia research is over two decades old. This period of time saw the development of a mass of new systems and the implementation of adaptive features onto existing ones. These systems integrate learner characteristics such as knowledge level, learning goal, learning style, affective state and competencies to constructs tailored learning paths and provide personalized learning experiences.

Learner modeling is an important aspect in adaptive e-learning systems as it concerns the way learner characteristics are represented, stored and maintained. While adaptive methods and techniques are no less important as they specify the way that information is presented and sequenced to meet the needs of learners.

In addition to the applications still being developed and upgraded, more and more researchers are formalizing AHS and producing models and frameworks for specifying these systems. Their objective is to increase the interoperability between approaches.

Another issue with the existing e-learning systems, especially those addressing scientific and technical disciplines, is the absence of means online environments that allow not only courses, lectures or exercises delivery, but also practical work (PW) conduction.

PW represents a considerable burden as engineering training programs focus on putting into practice the acquired theoretical knowledge and the manipulation of real equipments. The scarce financial resources, the increasing and high student enrollment, as well as the binding timeframe on which the conventional labs can be accessed, have guided the scientific research to look for new forms of interactive laboratories.

Hence, the need to introduce a new form of laboratory which can be accessed remotely to meet the real issues of: i) expensive industrial equipments that cannot be moved or duplicated ii) realism of the local representation of the industrial environment, iii) risk and safety while handling high voltage equipments, iv) in terms of pedagogical needs, the number of equipments needed is far outweighed by the large number of students.

Advancements in telecommunication practices have made learning from remote locations feasible, thereby granting real-time access to information and education for people who would not otherwise have the privilege.

Actually, one of the solutions adopted by institutions is to provide learners with relevant online practical experiences. In the case of measurements in electrical engineering, learners should act on real devices to retrieve reliable measures and gain targeted hands-on skills. Unfortunately, virtual labs cannot provide such kind of dynamic and realistic perspective.

Remote Laboratories (RLs) go further than virtual labs, based only on simulations, use real physical equipment which can be operated remotely (Saenz *et al.*, 2015) and grant distance access to this equipment through the Internet, allowing their configuration, supervision, and measurement retrieval (Rodriguez-Andina, Gomes and Bogosyan, 2010). Remote experimentation has been available from nearly two decades via the Internet (Aktan *et al.*, 1996) and the advent of mobile and connected devices increased their attraction and interest.

RLs provide learners with real-time access to hands-on learning materials with no time or place restrictions. They grant access to a larger audience on the Internet other than the original targeted population as workbenches can be shared with students of other institutions. Plus, in terms of risk management, RLs provide a safer platform by avoiding the mishandling of high-voltage equipment. On the one hand, considering that simulators cannot always operate in exactly the same way as real equipment as they cannot include all the parameters of the real experimentation, RLs allow effective measures acquisition whereas virtual labs use simulated data. On the other hand, they offer the possibility of working in the remote mode, which represents a requirement of great importance in the professional field.

Such a solution offers several advantages such as: i) remote manipulation of real equipments and synchronous telemetry offer real data acquisition over the Internet instead of using simulated data, ii) real-time demonstrations during lectures, iii) all class students can do the PW despite the large number of students comparing with the number of workbenches, iv) students can access the PW from home, v) workbench can be shared with students from another institution, vi) safer platform by avoiding the mishandling of high voltage equipments, vii) allowing real-time delivery of laboratory material and ensuring a global access to a large audience on the Internet other than the original targeted population (e.g. On a national scale, the project aims to create a remote PW center accessible to different schools and universities).

RESEARCH QUESTIONS

Since this thesis presents research concerning adaptation in e-learning systems in which learning material can be personalized and appropriately sequenced to meet the needs of individual learners and present research concerning Remote Laboratories, it takes a cross-disciplinary approach that draws from the fields of education and computer science. In this sense, this study seeks answers to the following questions:

RQ01: What are the learning theories and what are the different types of computer-assisted learning systems developed until now?

Learning theories are used to provide explanations of what happens during the learning process. Chapter 2 addresses this question by providing a comparative study of the most influential learning theories cited in the literature and outlines the different types of computer assisted systems developed until now.

RQ02: What are Adaptive Educational Hypermedia systems and what are the main components of any AEHS?

Adaptive Educational Hypermedia Systems are hypertext and hypermedia systems that uses the characteristics of the user incorporated in the Learner Model (LM) and the available rich educational resources to offer personalized and tailored courses. Chapter 3 describe in details all the concepts related to AEHS.

RQ03: What are the most import Adaptive Hypermedia reference models?

Adaptive Hypermedia reference models abstractly specify the components and mechanisms that can be used for building adaptive hypermedia systems. The most influential Hypermedia frameworks are discussed in Chapter 3.

RQ04: What is the point of incorporating a learner model in AEHS?

The learner model is a structure that represents knowledge of system about a learner. It allows the provision educational resources in a way that meets the needs and expectations of each learner. The usefulness of the learner model is introduced in Chapter 3 and presented in details in Chapter 4.

RQ05: Which learner's characteristics are best to be modeled to provide an accurate adaptation?

Different adaptive systems store different data about users according to the objective of the adaptation. A description of the most relevant learner characteristics according to the literature is presented in Chapter 4.

RQ06: What are the learner model standards?

Learner characteristics should be well defined to ease their use in different platforms of e-learning. Standards allow reducing variability in data models and promote reuse and interoperability. A benchmark of the most important learner modeling standards is done. This question is addressed by Chapter 4.

RQ07: What are the most frequently used modeling techniques?

The constituents of a learner model are arranged differently in accordance with the design of the environment. There are several techniques for modeling the learner and refining this model such as overlay, fuzzy logic or ontologies. Chapter 4 outlines the most frequently used modeling techniques.

RQ08: What is the most suitable learning style for use in AEHS?

Learning styles designate learners' preferences of acquiring and processing new information and each learner has a strong preference for a particular learning style. Several styles arise in the literature (i.e. Felder-Silverman, Kolb, Myers-Briggs, etc.). A comparative study of the most influential ones is conducted as shown in Chapter 4.

RQ09: What are the different types of online laboratories?

Thanks to the advancement in information technology, conventional hands-on laboratories structure and processes have been redesigned and expanded to virtual and remote laboratories. A comparison of the different types of laboratories is provided in Chapter 7.

RQ10: What are the advantages of RLs?

Remote Laboratories use real physical equipment which can be operated remotely and grant distance access to this equipment through the Internet, allowing their configuration, supervision, and measurement retrieval. Chapter 7 presents an exhaustive rational for remote laboratories.

RQ11: What are the limitations and perspective of current research?

Chapter 8 draws the main conclusion and lists the different perspectives of our research.

RESEARCH METHODOLOGY

Since the scope of this research relates mainly to Adaptive Educational Hypermedia Systems, the work began by analyzing the previous literature to identify and classify major learning theories and the computer-assisted education overtime. Then, an investigation of the issues related to reusability, interoperability, standardization and adaptation based on knowledge and psychological features, especially, learning style in e-learning systems was carried out.

A conceptual design of the framework which draws on the aforementioned studies was proposed. Fragments of the AEHS were implemented in order to validate the proposed framework by taking into account its different components such as the domain model, learner model and adaptation model.

Another spectrum covered by this thesis is that of Remote Laboratories. The work within this side of our research was conducted simultaneously with AEHS starting from a literature review of the Remote Laboratory experimentation, through the development and upgrade of our proposed platform, to the final evaluation of its the effectiveness.

LIST OF PUBLICATIONS

A number of research papers which resulted from this work were peer-reviewed, accepted and published in journals indexed in acknowledged databases and the others were subject of oral presentation in national and international conferences. These papers are listed below:

Zine, O., Derouich, A. and Talbi, A. (2019) 'A Comparative Study of the Most Influential Learning Styles used in Adaptive Educational Environments', *International Journal of Advanced Computer Science and Applications*, 10(11), pp. 520–528. doi: 10.14569/IJACSA.2019.0101171.

Zine, O., Derouich, A. and Talbi, A. (2019) 'IMS Compliant Ontological Learner Model for Adaptive E-Learning Environments', *International Journal of Emerging Technologies in Learning (iJET)*, 14(16), p. 97. doi: 10.3991/ijet.v14i16.10682.

Zine, O., Derouich, A. and Talbi, A. (2019) 'SEITI RMLab: A costless and effective remote measurement laboratory in electrical engineering', *International Journal of*

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THESIS STRUCTURE

This thesis is comprised of six chapters in addition to this **General Introduction** where we discuss the motivation and problem statement of the thesis, outlining the research issues that will be investigated and the **Conclusion and Perspectives** where we conclude the thesis by summarizing the work, reflecting upon the main contributions of this research, highlighting the limitations of this study and pointing to possible future research avenues.

Chapter 1 presents the theoretical foundations of learning and outlines several key learning theories. A description of the evolution of the Computer-Assisted Education and the fundamental characteristics regarding this type of learning is included to identify how this field evolved over time.

Chapter 2 gives an overview of the state-of-the-art in adaptive educational hypermedia systems. Several aspects are covered, including background information, their technical components, adaptation sources, and adaptation techniques and methods. Some examples of adaptive hypermedia reference systems are also included.

Chapter 3 discuses all the key concepts related to learner modeling and reviews the most important international standards for constructing and classifying learner's data. It mainly presents our proposal of an IMS compliant ontological learner model that takes advantage of international standards and ontologies to model the learner data in a formal way in order to enhance the reusability, the interoperability and the extensibility of this model.

Chapter 4 explores the concept of learning style as learners differ in their approaches to learning, and presents a comparative study of the most influential learning styles according to the literature as this concept is relevant to learning and to the present study.

Chapter 5 deals with the design and implementation of our system. It outlines the adopted methodological choices, describe the different UML design diagrams, explain the technical choices and depicts the implementation of the different modules implemented regarding the proposed system.

Chapter 6 presents our proposal of a platform for an efficient and cost-effective remote measurement laboratory in electrical engineering that we named SEITI RMLab after our research team (Team SEITI). On the one hand, it compares of the different types of laboratories and outlines the motive behind the creation of this kind of laboratories in electrical engineering. On the other, it presents all the followed steps for the realization of the remote laboratory (expression of needs, formulation of objectives, definition of pedagogical contents and development procedure of the platform).

Chapter 1: Learning Background

1.1 INTRODUCTION

Given the infinite complexity of the human brain and its operating modes, understanding and defining the learning process in humans is not trivial. For several decades, psychological theories have contributed, among other things, to the enrichment of the concepts of teaching methodologies and learning practices, which involves the use of certain strategies using resources specific to the learning context.

Learning theories are used to provide explanations of what happens during the learning process. On the one hand, they provide a conceptual framework for the interpretation of what we observe, and, on the other, they offer directions for finding solutions to the problems encountered.

No one can deny that it is crucial when designing and implementing e-learning systems to identify how people learn while understanding the different characteristics of learning is also vital to meet learners' requirements. The direct application of a learning theory makes it possible to formulate working hypotheses and methods for research in more systematic teaching.

This chapter presents the theoretical foundations of learning. It recalls some definitions of teaching and learning. Then, it identifies and synthesizes the main theories of learning, namely behaviorism, cognitivism, constructivism, and socio-constructivism as well as the fundamental concepts used in this field. Finally, it historically presents the evolution of Computer-Aided Education over time, indicating the fundamental characteristics of this type of education.

1.2 TEACHING VS LEARNING: SOME KEY POINTS

Teaching and learning are simply two inseparable concepts; One does not go without the other. If there is no learning, there is no teaching. Before tackling the various theories, it seems interesting to answer the following questions:

- What is teaching?
- What is learning?

1.2.1 Teaching

The classical conception defines teaching as the act of transmitting knowledge or a message whereas the current dictionary of education defines it as "a process of communication in order to stimulate learning". From this perspective, the act of teaching becomes a more extensive concept, since teaching is no longer just the fact of transmitting information but above all, it deals with provoking, organizing, facilitating, and managing learning.

Indeed, the teacher can be considered both as an engineer and a craftsman. He develops projects, designs action plans, painstakingly prepares sequences, thinks ahead of time about activities, organizes progressions, offers students strategies for getting around difficulties, etc. All this refers to what is now called educational engineering.

"Teaching is not telling", teaching is the management of learning which includes both facilitation and organization of learning. In 1919, Freinet had already laid the foundations for his completely innovative educational experiments. He was able to demonstrate that pedagogy should respect the child's pace, his biological rhythm as well as the different components of education (cognitive, social, and emotional). He advocated the transition to an active pedagogy where the child is the actor of his learning. And a good teacher must be an organizer of learning situations and a manager who coordinates the activities of learners in order to achieve defined objectives.

Teaching can convey three different meanings depending on the type of relationship favored:

- When the emphasis is on knowledge, teaching refers to the transmission of knowledge by presenting it as clearly and precisely as possible; this is the transmissive model of teaching in which what is important is the quality of the knowledge transmitted. The problem that then arises is that of didactic transposition, in other words how and with what tools, methods and ways to make this knowledge accessible to students to facilitate the task of learning. In other words, the quality of what is said through the way it is said is critical to the quality of what is received and understood.
- When the emphasis is on acquiring automation, teaching would mean instilling professional behaviors, attitudes, reactions, and gestures. It is a question of getting the learners to produce the expected answers according to the problems

encountered. The effort is thus, mainly focused on the conditions of activation, on the tactics and strategies to make the learner work from the perspective of bringing him to modify his behaviors. This places us in the behaviorist approach.

- When the emphasis is on the learner, teaching is like tutoring, guiding, and accompanying during the proposed activity. It is a question of privileging the processes of acquisition of knowledge, not the learners. This amounts to emphasizing the ways of appropriating this knowledge, of mastering a skill. This sets us in a double theoretical reference, namely constructivism, and socio-constructivism.

To summarize, three keywords should be noted to define the act of teaching: transmit, instill, and build. It should also be specified that only the objectives set, the content to be worked on and the conditions available allow the teacher to make the best choices and the best ways to accomplish his mission.

1.2.2 Learning

Learning is an unobservable process of reorganizing cognitive structures. This process is finalized aiming to acquire new knowledge, skills, attitudes, or to modify previous knowledge, which results in a lasting change in behavior whose objective is to adapt to oneself and its environment (Raynal and Rieunier, 2010).

Quite differently, learning is taking knowledge, it is going from the known to the unknown in order to build new skills, to change the way we act and think. In other words, it can be defined as a process of acquiring and consequently altering knowledge, attitudes, skills or behaviors (Bransford *et al.*, 2000) and relies on features such as the content to be learned, the context in which learning occurs, The teachers, as well as learners characteristics, knowledge level, motivation, engagement and affective state (Anderson, 2008).

Jean Houssaye's ingeniously presented the different components of education through a triangle, that he called the educational triangle *(see Figure 1.**1**)*, and which he defines as the space between three vertices of a triangle: the teacher, the student, knowledge (Houssaye, 2014).

- Regarding the teacher/knowledge axis, if it is too strong, the teacher is focused on the subject, while the learner is forgotten and risks settling in passivity and heckling; If it is weak, the content is relegated to the second degree.
- Considering the learning/knowledge axis, we understand that the teacher plays the role of a guide if we opt for a pedagogy of discovery of the constructivist type. On the other hand, there is a risk of excluding the teacher if we consider that the self-training is suitable, or of excluding the learner if his personal dynamics are denied.
- As for the teacher/learner axis, it promotes the consideration of learners, their attention skills, their work rhythms as well as their different levels. If this axis is too weak, these same needs risk being neglected.
- In the case of non-directive teaching where the pedagogical relationship is essential, knowledge is either non-existent or reinvented.

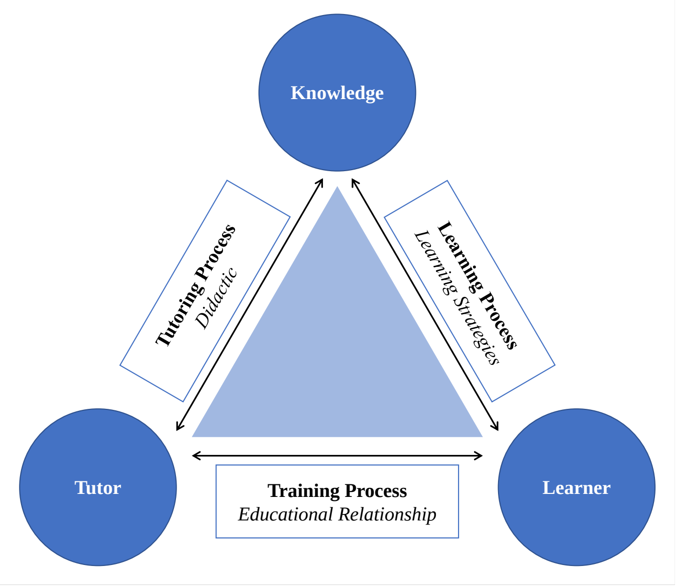

Figure 1.1: Jean Houssaye's Pedagogical Triangle (Houssaye, 2014)

1.3 LEARNING THEORIES

In order to get a clearer and more complete picture of what learning is, it is necessary to discuss the most relevant theories in this area. The theories of learning have been determined, largely from philosophical currents basing their analysis of human behavior on the separation of matter and spirit, but also from the natural sciences and psychology. They make it possible to understand the factors likely to favor the transmission and acquisition of knowledge. Thus, the study of the psychology of learning makes it possible to identify the tools, concepts, and models helping the teacher in the implementation of various teaching/learning devices.

1.3.1 Behaviorism

As the first major learning theory, behaviorism strongly influenced the fields of teaching, education, training, and research during the first half of the 20th century. It is a psychological science that is only interested in observable human behavior. Behaviorists view the human brain as a black box of which nothing can be observed. Thus, behaviorists are particularly interested in the observable behaviors of individuals and do not concern themselves with the internal mental processes which intervene in learning.

I. Pavlov (Pearce, 1987), JB Watson (Watson, 1913, 1957), and BF Skinner (Skinner, 1984) were the forerunners of behaviorist thought. Pavlov and Watson considered that each attitude is a reaction to a stimulus (i.e. an event provoking a given reaction) and were known for the psychological theories of stimulus-response (i.e. classical or responding conditioning), while Skinner when studying animal behavior in the context of practical experiments, introduced the operative conditioning (i.e. instrumental conditioning).

The behaviorism approach believes that motivation is essentially extrinsic to the learner and that behaviors that are reinforced by the environment are more likely to recur than those who are not or those who have been reproved. Therefore, she/he will seek reward and avoids punishment.

From the behaviorist perspective, learning occurs when a learner acquires new or changed behavior in response to a stimulus. Two distinct elements can be observed during the learning journey. The first element brings together the causes that provoke learning: sets of activities or repeated experiences. The second element is the learning outcome: "lasting behavior change".

From an educational point of view, behaviorists see learning as a lasting change in behavior resulting from specific training. To induce learning, the student's behavior must be modified by positive reinforcement. Learning occurs when the student gives a correct response to a given stimulus. This is why the central idea of the behaviorist is often illustrated by the relation (Stimulus -> Response), signifying a direct response of the organism to a stimulus coming from the environment. The learning targeted in behaviorist type teaching is often about memorizing and recalling facts, defining and illustrating concepts, or even the automatic execution of procedures. The assessment of learning is generally done by exams where the student must simply demonstrate that he knows the correct answer.

However, by exclusively considering the observable behavior of the individual (i.e. response) and how the environment (i.e. stimulus) shapes that behavior, Behaviorism underestimates what is going on in the learner's "black box". The result is mechanical learning, by trial and error, of procedural knowledge, not based on the reflection of the individual.

In another sense, reducing complex learning to a series of simpler learning sequences risks delivering erroneous results; Indeed, even if the learner satisfies all the intermediate stages of learning, he might not master so well / or not at all the complex learning initially targeted.

1.3.2 Cognitivism

In opposition to behaviorism, cognitivism is concerned with what is going on inside the individual's brain (black box), between input stimuli and output responses (West, Farmer and Wolff, 1991). It proposes to explain human behavior from the hypothesis of internal variables: motivation, cognitive expectations, patterns, and structures. If, in behaviorism, attention is directed to the observable behavior of the individual, cognitivism highlights and tries to explain cognition.

Cognitivism can be defined as the set of internal activities and processes inseparable from the acquisition of knowledge, information, memory, thought, creativity, perception, as well as understanding and problem-solving. Cognition can be described as knowledge and process by which an organism acquires awareness of events and objects in its environment. And Cognitive can be outlined as concerning knowledge, the mental processes at work in its acquisition.

From a more pragmatic point of view, cognition can be defined as the set of mental functions that allow us to process information such as memory, sense, perception, and language. The terms cognitive systems and cognitive processes can designate knowledge systems and information processing procedures used by the human mind to adapt to the environment.

Proponents of the cognitive approach seek, unlike behaviorists, to understand the internal processes of learning. According to them, the learner is an active information processing system such as a computer; the subject is not satisfied with assimilating the raw data, but perceives the information coming from the outside, tries to select it, to store it in memory, to format it then to recover it if necessary to elucidate and understand the environment or solve problems.

According to this theory, learning can be defined as a change in the learner's mental structures. The Cognitivist Current is associated with cognitive psychology, which is concerned with how the human mind mentally manipulates and develops knowledge (images, representation, symbols, diagrams, etc.) to produce thoughts and actions. on the world, on others, and on oneself (Bertrand and Garnier, 2005).

The resulting conception of education highlights the importance of the learners' active mental commitment throughout the learning procedures to process information in depth and not only superficially. The teacher will then have to use teaching strategies aimed at:

- Helping the learner to select, to encode the information through underlining to identify the main ideas in a medium, while introducing him to mnemonic and elaboration strategies.
- Providing him with organizational diagrams when presenting new content, pushing him to make the necessary links with the knowledge acquired previously.
- Encouraging him to organize and integrate information, take notes, build meaningful mental images, make summaries, and question themselves constantly and permanently.

According to this theory, teaching methods must leave room for a variety of possible paths taking into account the different individual variables capable of influencing how information is processed by each learner. Besides, the cognitive teacher must be inclined to use ICT to promote greater interactivity with students.

1.3.3 Constructivism

It is an approach that recognizes, as the cognitive approach, that learning is a mental activity. This theory is mainly based on the work of Jean Piaget, who assumes that when faced with a situation, an individual is called upon to mobilize several cognitive structures which he calls operating patterns (Piaget, 1952; Wadsworth, 1996). However, for constructivists, and in contrast to cognitivists and behaviorists, there is no objective external reality; the only reality is that which exists in the heads of individuals.

Constructivism is a theory of learning based on the principle that knowledge is built by the learner based on mental activity. In other words, reflecting on our experiences allows us, according to constructivism, to build our own worldview. The rules and mental models that we produce allow us to give meaning to our experiences. Adjusting our mental models in order to adapt to new experiences is the very principle of learning.

Learning is, therefore, an active process of construction of this reality to which each gives a unique meaning according to his own experiences. Thus, the learner does not simply transfer or integrate knowledge from the external world into his memory, but rather, he builds his own interpretations of the world from his interactions with it.

There are two processes for learning these patterns, namely:

- Assimilation is considered as an integration of new information into the cognitive structure of the learner without modifying it. It integrates them by analyzing, connecting, and coordinating them with the knowledge previously acquired. From an assimilation perspective, understanding a problem means bringing it within the frameworks of understanding and knowledge that the individual currently masters. To know would then be to bring back the unknown to the known.
- Accommodation can be defined by the modification of the cognitive structure of the individual in the face of resistance to a new element or situation. In other words, the adaptation of the subject to these new situations, hence the modification of his mental frameworks and therefore the provocation of adjustments in his way of seeing, doing, thinking, in order to take into account these relatively disturbing new data.

In addition, A constructivist vision of education promotes active and non-directive teaching and gives priority to aspects such as a real learning context, teaching-support rather than teaching-intervention, guided discovery, encouragement to explore different points of view of a topic, collaborative learning, a project approach, etc. The student has a proactive role because he is a decision-maker in his knowledge-building process, although he is accompanied by the teacher, whose main task is to provide him with a rich and stimulating learning environment.

Constructivism seems promising regarding educational technologies. It favors tools giving great autonomy to the learner and allowing him to advance at his own pace (educational platform, teaching materials) using collaborative or cooperative tools. This model also promotes the development of computer-assisted problems.

1.3.4 Socio-constructivism

Based on Piaget's work, Lev Vygotski developed socio-constructivism (Vygotsky, 1980). This theory emphasizes the role of multiple social interactions in the construction of knowledge. Learning is, therefore, more considered as the result of socio-cognitive activities in relation to didactic exchanges between teachers/learners or learners/learners.

In the socio-constructivist framework, what is essential is both the conditions in which learners are put into, the development of the capacity to learn, understand, and analyze, as well as the mastery of tools. The teacher's role is not limited to simple transmission, but to the establishment of conditions promoting the interactivity through which knowledge is built. For Vygotski, the direction of thought development goes from the social to the individual.

Learning activities should guide the learner towards social interactions. The learner is encouraged to get involved in interactions with colleagues, in discussions, to exchange ideas and to work collaboratively.

Here there is a double construction of the higher psychic functions, each appearing twice or developing in two stages: first as a collective, social activity and therefore as an interpsychic function, then the second time as an individual activity, an interior property of thought, and therefore as an intrapsychic function. This means that, depending on the conditions of the situations and how individuals perform, an entire interpersonal process could be internalized, and consequently generate intra-individual coordination.

Mugny highlighted the role of social interactions as well as that of socio-cognitive conflict in the development of intelligence (Mugny, Perret-Clermont and Doise, 1981).

Confrontations are the basis of the construction of knowledge which takes place in alternating phases of interindividual confrontation, then of construction of cognitive schemas. Thus, new skills are acquired and give rise to an empowerment of the learner able at this stage to make new constructions.

According to socio-constructivism, the construction of knowledge takes place in dialogue with others, in the confrontation of its ideas, its representations, with those of others. Learning occurs through socio-cognitive conflict, in collaboration and interaction with other learning participants.

1.3.5 Connectivism

Behaviorism, cognitivism, constructivism, and socio-constructivism were developed in a context where technology had not reached the level of impregnation of everyday life that we know today. Social change, technological change, and increased availability of information have forced changes in learning practices. Consequently, several researchers have proposed the term connectivism to designate a new educational approach that would adapt to online training.

Developed by George Siemens and Stephen Downes, Connectivism can be defined as the learning theory in the networked digital age (Siemens, 2005). The increasing amount of information involves other learning methods. It is no longer a question of learning information "by heart", but of determining the links between this information.

This theory defines learning as the process of connections, incorporating neural connections, connections between people, computers, and the interconnection between different fields of knowledge. In other words, learning is the association of an item of information with a pre-established schema (Lévy, 1990), which allows the storing of information in long-term memory for later reactivation. Establishing these interconnections is not only an efficient means of storage, but it also allows better access to knowledge and helps to overcome short-term memory limitations.

Connectivism is close to socio-constructivism since learning is defined as a process of building connections between specialized nodes (sources of information). At the same time, the connections between the nodes are not made at random. Reasoning on the links built between nodes associates connectivism to cognitivism. Thus, obtaining accurate knowledge with the ability to update it is the intention of learning based on connectivism.

1.3.6 Comparison of the theories

The provision of proper consistency between learner, content, and instructional strategies is critical to ensure an optimal learning outcome.

Behaviorist theories are advantageous for effectively exploiting certain learning mechanism such as stating learning objectives and providing immediate feedback and avoiding certain emotional phenomena that can interfere with the educational relationship. However, they disregard the learner’s mind and learning processes and address all learners in the same way.

Contrarily, cognitivist ones underline that the learner’s mind as the key factor in learning and support more complex methods of learning such as critical thinking and problem-solving.

In contrast, constructivist ones emphasize that knowledge is constructed by learners during their interactions with the learning environment. They also believe that each learner endorses an individual learning process and thus calls for various content presentations for each topic in order to enrich the learning experience.

On the other side, socio-constructivism, faithful to the individual and social modes of construction of complex knowledge, it ensures a better fixation and transferability of learning as well as a better efficiency by taking into account interindividual differences (styles or learning strategies, of knowledge). Moreover, it promotes metacognition and autonomy.

And alternatively, connectivism advocates that learning is a process that takes place in environments composed of changing elements. Learning can be present outside of the individual (e.g. a database), and focus on connecting specialized information sets. The links allowing to learn additional information are more important than the current state of our knowledge.

1.4 COMPUTER-ASSISTED EDUCATION OVERTIME

This section historically presents the evolution of Computer-Aided Education over time, indicating the fundamental characteristics of this type of education.

1.4.1 Computer-Assisted Learning Systems (CALS)

Computer Assisted Learning was introduced in the early sixties. It can be defined as a set of techniques and methods of using computer resources as pedagogical tools integrated into the learning context, in order to optimize and facilitate the presentation of the information while reducing the financial cost and human training.

In general, these systems make it possible to introduce new possibilities concerning the individualization of teaching in which the learner can acquire concepts at his own pace. Although computer-assisted learning systems were and still are the basis of many applications, they remain limited. They can be compared to deterministic finite-state automata (presentation-question-analysis). All learners, therefore, had to follow a cyclical and identical course imposing a succession of fixed actions without the initial knowledge or the behavior of the learner taken into account. This lack of flexibility in human-machine interaction does not allow the adaptation of the educational content either to the learners or to the learning situation.

To overcome the limits linked to this rigidity and beneficiating from research carried out in artificial intelligence (AI), education, and cognitive sciences, the researchers gave birth to a new field of research in computer science, initially called intelligent computer-assisted education. This field was born around the seventies.

1.4.2 Intelligent Computer-Assisted Learning Systems (ICALS)

These systems are the result of the coupling between research conducted in artificial intelligence, educational psychology, and cognitive psychology during the 1970s. The researchers then endeavored to design and develop new intelligent pedagogical systems, the objective of which was to overcome the limits of conventional systems and promote more effective, more interactive, more flexible teaching, which better adapted to the cognitive capacities of the learner and at a lower cost.

With the progress of expert systems and human-machine interfaces, this field of research has experienced intensive development since the 1980s, intending to design environments capable of effectively imitating teaching carried out by a human tutor. The decade 80-90 was then marked by the emergence of Intelligent Tutorial Systems, which form a particular stream of computer-assisted education and which is based on personalization in training.

1.4.3 Intelligent tutorial systems (ITS)

Intelligent tutorial systems are computer education systems born in the 1990s. They offer reasoning and intervention skills during problem-solving by collecting and reusing knowledge accumulated during the interaction of the learner with the system. Thus, ITS assess the knowledge acquired by the learner, by comparing his activities and information in the field in order to offer dynamically adapted tutoring according to his specific needs and cognitive state.

The idea is to respond to the need to place the learner at the center of the learning process. These systems are characterized by studied domain modeling of expertise, and of reasoning mechanisms, which equips systems with the capacity to solve problems and answer questions not explicitly provided for; learner modeling to allow the system to adapt dynamically and individually according to the cognitive level and behavior of the learner; and teaching strategies modeling of which specifies the way of teaching and allows the system to intervene according to the pedagogical objectives or the model of the learner.

1.4.4 Interactive Computer-Assisted Learning Environments (ICALE)

The approaches presented so far have generally favored the teaching process, whose computer systems are mainly centered on knowledge transfer and led to play the role of the tutor.

Another current of thought which is based on the constructivist learning theory is carried out in parallel with ITS to give birth to Interactive Computer-Assisted Learning Environments. In these systems, the computer is used as a means for the learner to build knowledge by interacting with the environment and carrying out explorations and discoveries.

The rapid evolution of hardware and software and the development of human-machine interfaces made it possible to greatly increase and enrich the concept of interactivity, which becomes the heart of the problems targeted by this new axis of research. The idea is to design and create interactive environments to help solve problems throughout the learning process by giving control to the learner while improving the handling of these environments.

1.4.5 Computer Environments for Human Learning (CEHL)

In recent years, research in computer learning has experienced a shift towards the design, development, and evaluation of environments that take into account the different human and communicational aspects involved in learning processes. This makes it possible to promote human learning within an IT environment and to respond to the problems encountered in a classic training situation in terms of distance, assistance, adaptation, personalization, individualization, and monitoring.

This new line of research takes into account recent developments in Information and Communication Technologies (ICT) and widens the field of study to human learning in all its variations. It then highlights the Communication and Human-Machine Interaction by emphasizing both the computer side and the human side of learning.

1.4.6 Adaptive Educational Hypermedia Systems (AEHS)

The research carried out in the context of Adaptive Educational Hypermedia Systems consists of the coupling between work on hypermedia systems as well as the main guidelines on adaptive systems. These systems were born thanks to the development of computers, be it hardware or software, the democratization of the Internet, and the explosion of web technologies.

Thus, research in this disciplinary field aims to increase the functionality of hypermedia by making it more personalized and truly adaptive. In fact, AEHS use a learner's objectives, preferences and cognitive level for the adaptation of the proposed knowledge, the presentation of this knowledge as well as how it will be presented to this learner. They also allow him to offer greater flexibility during the acquisition of knowledge.

1.5 SUMMARY

Learners acquire different knowledge, skills and competencies depending on instructional approaches they are exposed to. This leads to the question as to which learning models are the most effective. Prior knowledge, learning goal, and learning tasks should be considered when selecting a specific one. It is crucial to carefully consider learners’ competence levels and the context of the task when selecting instructional strategies.

The behaviorist approach supports the mastery of content; the cognitivist one support more complex forms of learning such as problem-solving and critical thinking; the constructivist one is more suitable for dealing with fuzzy domains through information elaboration and reflection and may better support different learner needs; the socio-constructivist one promotes knowledge acquisition based on collaborative activities; the connectivist one is suitable for tackling precise knowledge that change rapidly and which require permanent updates. Nevertheless, powerful e-learning systems have been developed by designers inspired by combining features of all of these theories. In fact, an accurate learning system should incorporate aspects that are encouraged by all these perspectives such as interaction, practice, collaboration, feedback, and decision making.

Computer-Aided Education over time has known a considerable evolution during the past decades, starting from simple and rigid environments used to allow learners to study outside of school hours without teachers or mentors by providing remote access the necessary resources and services and thus trespass the limits of face-to-face teaching to adaptive environments that customize the courses to each learner apart taking advantage of the evolution of the fields of ICT an AI in order to optimize and facilitate the presentation of information.

The next chapter will be dedicated to a deeper study of AEHS which is the main subject of our research. We will give a brief definition of all its related concepts as well as the history of the hypermedia component and its generations while discussing its strengths as well as its limits. We will also coherently tackle other concepts, in particular adaptability as well as its components and techniques

Chapter 2: Adaptive Educational Hypermedia Systems

2.1 INTRODUCTION

Adaptive Educational Hypermedia Systems (AEHS) represent a continuously growing research domain, involving knowledge from several fields such as Adaptive Systems, Intelligent Tutoring Systems, Learning Management Systems, User Modeling, instructional science, pedagogy and psychology.

This chapter presents a background to the various research fields which have influenced this work. It sheds light on the field of Adaptive Hypermedia (AH) which is the primary research area of the work documented in this thesis. This chapter introduces the field and details some of the techniques and developments that have been made since its creation.

The first section presents an overview of adaptive hypermedia and introduces the different concepts related to this field. Next, background information on Adaptive Hypermedia is provided. The third section is devoted to the description of the main technical components of any AEHS. The adaptation provisioning is reviewed in following section, including a brief explanation of the kinds of adaptation provided by systems, a description of the adaptation sources as well as a summary of some methods and techniques used for adaptation. The chapter ends with some examples of Adaptive Hypermedia Metamodels to depict the working principles of AEHS.

2.2 CONCEPTS AND TERMINOLOGY

2.2.1 Multimedia

Multimedia can be defined as environments that offer access to information in a variety of formats, including text, still images, animation, video, and audio presentations. Their pedagogical validity has been supported by several primary assumptions of learning, which suggest that instruction should be designed so that learners' attention is captured as soon as possible during the learning task (Moos and Marroquin, 2010). This task can be effectively performed via inspiring multimedia presentations by offering highly captivating and relevant information that initially engages the learner (Schraw and Lehman, 2001). Therefore, various material delivery in a multimedia environment is enhanced to stimulate the individual into learning.

Moreover, the multimedia design can be persistent with the assumptions advanced by the Cognitive Load Theory. The instructional design of multimedia has been guided by this theoretical perspective based on the abstract assumption that working memory consists of two independent systems for processing verbal and written information (Baddeley, 1992). Multimedia can facilitate learning by reducing cognitive load through simultaneously presenting information to both systems (i.e. audio and text) as each one has bounded capacity to process information.

2.2.2 Hypertext

Hypertext is a document or set of documents containing information units, which is similar in a certain way to traditional reading environments as it presents text on a computer screen (Lawless and Kulikowich, 1996). These nodes of information are linked through hyperlinks and the learner can decide which hyperlink to consult during the learning process (Conklin, 1987), which allows him to determine his instructional path.

As autonomy accounts for learners' cognitive needs, hypertext environments surpass multimedia environments in terms of control features, as they allow learners to make navigational choices and control the sequencing of information which facilitates reading comprehension (Scheiter and Gerjets, 2007).

Regretfully, the nonlinear design of hypertext systems represents a double-edged sword and may create distinct challenges for learners when they are asked to make these instructional decisions. Though, this autonomy may allow learners to make instructional decisions that best meet their needs provided that learners have a requisite amount of domain knowledge to make informed decisions about which hyperlinks to access (Shapiro, 2004).

On the other hand, research pointed out a design issue that may limit learning as hypertext environments fail in including multiple information representations found in multimedia.

2.2.3 Hypermedia

A hypermedia system can be defined as an interactive system that allows users to navigate in a network of linked hypermedia objects (Kobsa, Koenenmann and Pohl, 2001).

While the design of multimedia does not offer interactivity and hypertext environments lack presentation of information in multiple formats, hypermedia has been introduced to emphasize the multimedia aspect of some hypertext applications and is considered as an augmentation of both of them (Perfetti, Rouet and Britt, 1999). It includes various representations of information as well as a nonlinear design, which means it incorporates not only text but multiple presentation supports (i.e. graphics, audio, and video) and provides non-linear access to information. A classic example of hypermedia is the world wide web. The nonlinear design allows learners to access information in a manner that best meets their needs and expectations, while the presentation of information in multiple formats can be seductive and reduce cognitive load. This wealth is used with the advantage to support and facilitate learning in educational settings and to help learners construct a useful and rich understanding of knowledge (Jacobson and Archodidou, 2000).

A hypermedia system incorporates elementary units linked to data fragments (sound, animation, etc.) called nodes, means allowing the user to move from one node to another called links and anchors. These links are the main way to arrange a document in a non-sequential way. An anchor is a position in a text semantically lower than that of the node in the case of a text and is, in general, a pointer that contains the point of departure or arrival of a link in the case of a multimedia object.

2.2.4 Hyperdocument

Hyperdocument is any informative computerized content that is organized in a non-linear manner. It doesn’t follow a previously defined structure and allows multiple reading paths (Balpe, 1990). The system will not necessarily recommend links to follow but rather make suggestions over links that go from one hyperdocument to another such as suggesting predefined paths typically designed to help novice users discover the content.

It can be defined as an interlinked set of information fragments. These fragments are modeled by nodes. And a plentiful and diverse set of structures notably relationships, sets, and composite nodes (graphs of nodes and links) have been considered to model complex and hierarchical structures of information (De Bra, Houben and Kornatzky, 1992).

The user establishes a network of links between numerous fragments of knowledge and constructs his individual knowledge while moving from one information to another, according to his personal aspirations and requirements.

2.2.5 Hyperspace

Hyperspace is structured in hyperdocuments, which means that it is composed of nodes and links (represented in the next figure by circles and arrows respectively) (see *Figure 2.1*). Nodes contain information to be presented whereas links represent paths that can be followed to reach some other nodes. Links can be intra-hyperdocument links (i.e. links between nodes of the same hyperdocument) and inter-hyperdocument links (i.e. links between nodes of different hyperdocuments).

As the hyperspace is usually enormous, the issue to avoid is that users can get easily overwhelmed by the number of paths and topics offered, and get lost in the huge amount of information losing even the benefits of linear information documents (Pérez, Gutiérrez and Lopistéguy, 1995).

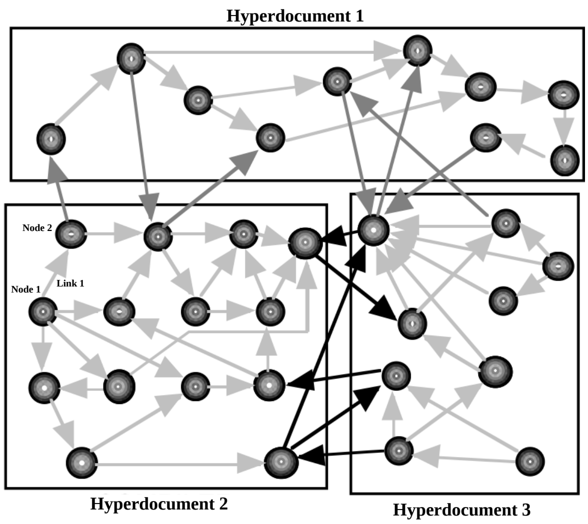

Figure 2.1: Graphical representation of the Hyperspace

2.3 RESEARCH BACKGROUND

2.3.1 Classic Hypermedia

In 1945, Vannevar Bush, a science advisor to US President Roosevelt, wrote a pioneering paper entitled 'As We May Think' (Bush, 1945) in which he describes an automated library of records indexed not sequentially but associatively by imitating the structure of the human brain. This machine, which he called the *Memex*, was designed to augment human memory, providing its user with instant access to books, film, photographs, newspapers…. As they interact with the machine, people could build up *paths* through this information space, which could be annotated and shared with others to incorporate into their own *Memex* records. The *Memex*, while futuristic and fanciful in 1945, provided researchers with a completely new design approach for navigating large-scale electronic documents.

In the following years, many different hypertext systems were developed and as different media became more accessible, hypertext systems evolved into *hypermedia* systems. The terms hypertext and hypermedia were both invented by Ted Nelson (Nelson, 1965) and are nowadays used interchangeably.

In 1994 Tim Berners-Lee's concept of a simple hypertext client-server approach took off on a global scale (Berners-Lee and Fischetti, 2001) producing what today is known as the World Wide Web. The Web, like any hypermedia system, uses the concept of *documents*, *nodes* or *pages* interrelated by a set of navigational hyperlinks. When reading a document, links are presented to the user who can choose to follow anyone and be redirected to a new document containing related information. This associative relation between information is an essential component of all hypermedia systems (Lowe, 1999). Grouping these traversed links in chronological order forms a *user path*, identical to those envisaged by Bush half a century before the Web.

The incredible growing popularity of the Web highlights the same shortcomings as those identified by hypertext researchers in the late 1980s (i.e. *Information Overload* and *Getting Lost in the Hyperspace*). The first one refers to the situation where large hypertext systems present users with more information than they can reasonably absorb in any single session. While the second points the issue of users' disorientation when browsing through many documents as the navigational structures are often poorly conceived (Conklin, 1987; Nielsen and Lyngbæk, 1990). To tackle these problems, users should be oriented through the information by pointing out documents that contain relevant and useful data. This task requires discovering the user's knowledge, goals, and interests as well as determining how much help to give him.

2.3.2 Adaptive Hypermedia

Adaptive hypermedia (AH) belong to the class of user-adaptive systems (Schneider-Hufschmidt, Malinowski and Kuhme, 1993) and represent an alternative to the traditional "one-size-fits-all" approach in the development of hypermedia systems. They collect data about the users from various sources that can include implicitly observing user interaction and explicitly requesting direct input from the user and maintain a repository of knowledge about their users, known as a user model, and use this information to adapt to the needs and goals of each particular user (Brusilovsky, 1996b).

The user model is applied to provide an adaptation effect. This adaptation can change or personalize the content of a document and provide a presentation that is adapted specifically to the user (Hothi, Hall and Sly, 2000), or guide the user through the information by providing links to other documents or information that may be of interest to the user in order to tailor the navigation between documents (Brusilovsky, Eklund and Schwarz, 1998; Kavcic, 2004). In different kinds of adaptive systems, adaptation effects could vary significantly.

The miniaturization of computing devices and the increasing use of web standards made the field of adaptive hypermedia expand to incorporate a wider range of applications that we can call adaptive web-based systems. Despite the variety of devices and applications, adaptive web-based systems still rely on exactly the same principles as developed for traditional AH.

2.3.3 Adaptive Educational Hypermedia

There are various application fields to AHS and education is an important one as users – in this case, learners - have different learning goals, knowledge and preferences and so, require different treatment. The research in Adaptive Educational Hypermedia Systems (AEHS) can be organized into 3 generations of work:

2.3.3.1 1st generation (1990, 1996)

The research in adaptive hypermedia performed and reported on up to 1996 provided a good foundation for the new generation of research. And almost all the papers published in this period describe classic pre-web hypertext and hypermedia.

Several pioneer adaptive educational hypermedia systems were developed between 1990 and 1996. These systems can be roughly divided into two research streams. The first one concerns the systems created by researchers in the area of intelligent tutoring systems (ITS), who were trying to extend traditional student modeling and adaptation approaches developed in this field to ITS with hypermedia components such as **ANATOM-TUTOR** (Beaumont, 1994) and **HyperTutor** (Pérez, Gutiérrez and Lopistéguy, 1995). While the second deals with the systems developed by researchers working on educational hypermedia in an attempt to make their systems adapt to individual students such as **InterBook** (Brusilovsky, 1996a), **ELM-ART** (Brusilovsky, Schwarz and Weber, 1996), **2L670** (De Bra, 1996) and **Hyperadapter** (Hohl, Böcker and Gunzenhäuser, 1996). These last provided "proof of existence" and influenced many more recent systems.

2.3.3.2 2nd generation (1997, 2001)

The mainstream of AEHS developed over this period were web-based systems developed for web-based education context. Despite the number of original ideas which were investigated and assessed in the early AEHS, it was not until 1996 that this research area attracted attention from a larger community of researchers. And most of the papers published in that time advanced an elaboration or an extension of previously proposed techniques.

The interest in the second-generation adaptive educational hypermedia was encouraged by the accumulation and consolidation of research experience in the field. Furthermore, the clear demand for web personalization served to boost adaptive hypermedia research and so, the imperative to address the needs of the heterogeneous audience for web-based courses individually became obvious.

The work on this generation can be subtly split into three different streams. The first one concerns systems created by web-based education researchers who focused on creating adaptive web-based educational systems with adaptive hypermedia components aimed to produce systems that shall be exploited in teaching, and disregarded developing new technologies. Consequently, the works of this stream mostly reused ongoing technologies and explored diverse disciplines and approaches. The second involves systems created by ITS or adaptive hypermedia researchers who focused on creating novel techniques for adaptive hypermedia such as the initial **AHA!**

project which explored several approaches to link removal (De Bra and Calvi, 1998), **MetaLinks** which explored advanced approaches to hyperspace structuring (Murray *et al.*, 2000), **INSPIRE** explored the use of learning styles (Papanikolaou *et al.*, 2003) and **MANIC** (Stern and Woolf, 2000) which explored innovative approaches for user modeling and adaptive presentation. Fortunately, the choice of the web as a development platform expanded the life of many earliest systems such as the first web-based adaptive educational hypermedia systems developed before 1996 (e.g. **ELM-ART** (Weber and Brusilovsky, 2001) and **InterBook** (Brusilovsky, Eklund and Schwarz, 1998) that are still utilized. They have been considerably upgraded to incorporate novel techniques and were used for several experimental studies that oriented the development of the field. The third deals with systems created by researchers who focused on developing frameworks and authoring tools for producing adaptive hypermedia systems. These works led to frameworks for adaptive web-based education such as **KBS-Hyperbook** (Henze and Nejdl, 1999), **Multibook** (Steinacker *et al.*, 1999), **ACE** (Specht and Oppermann, 1998), **CAMELEON** (Laroussi and Ben Ahmed, 1998), **MediBook** (Steinacker *et al.*, 2001), and **ECSAIWeb** (Sanrach and Grandbastien, 2000). Even when a framework doesn't result in an end-user authoring tool, it's still useful as it typically introduces a generic reusable architecture and approach that could be used to produce a range of adaptive systems with a low operating cost. Several notably experienced teams working on AEHS projects for multiple years provided practical authoring systems that could be utilized to develop adaptive hypermedia systems and courses such as **InterBook** (Brusilovsky, Eklund and Schwarz, 1998), **ART-Web**/**NetCoach** (Weber, 1999; Weber, Kuhl and Weibelzahl, 2002), **AHA!** (De Bra and Calvi, 1998) and **MetaLinks** (Murray *et al.*, 2000).

Altogether, the systems of the second-generation adaptive educational hypermedia demonstrated a variety of ways to integrate adaptation technologies into web-based education systems as well as the value of these technologies. However, they failed to influence practical web-based education.

Some other examples of hypermedia developed in this period: **AST** (Specht *et al.*, 1997), **Medtech** (Eliot III, Neiman and LaMar, 1997), **PT** (Kay and Kummerfeld, 1997), **AHM** (da Silva *et al.*, 1998), **CHEOPS** (Negro, Scarano and Simari, 1998), **HysM** (Kayama and Okamoto, 1998), **RATH** (Hockemeyer, Held and Albert, 1998),

SKILL (Neumann and Zirvas, 1998), **German Tutor** (Heift and Nicholson, 2001), **ActiveMath** (Melis *et al.*, 2001).

2.3.3.3 3rd generation (2002, -)

Nearly 10 years after the advent of the first AEHS, just a minority are used for teaching real courses, usually for classes headed by one of the authors of the adaptive system. Instead, the predominantly web-enhanced courses rely on learning management systems (LMS) or massive open online courses (MOOCs), even if, for every function that a typical LMS or MOOC performs, we can find an AEHS that can significantly outperform the LMS.

On the one hand, LMS are strong holistic systems that support several needs of both teachers and students. Teachers can use an LMS to establish web-based course notes and quizzes, to communicate with students and to track their advancement. Students can use it for communication and collaboration. On the other hand, the MOOC definition derives from the combination of various concepts such as e-learning, massive communication, knowledge sharing, and openness. It allows teachers to lecture more students on one course than in a lifetime of teaching. Its concept expresses a way of knowledge sharing, using digital channels of the internet and can be developed into two other concepts: connective MOOC (cMOOC) and extended MOOC (xMOOC). While the cMOOC concept comprehends a connected and sharing digital context, which follows a philosophy of connectivism, the xMOOC one is based on a behaviorist pedagogical approach and is focused on content prepared by universities.

The weakness of modern AEHS is not the quality of their performance, but rather their inability to satisfy the requirements of functional web-enhanced education. The current third generation of adaptive educational hypermedia research has been defined by the defy of integrating AEHS technologies into the typical educational process.

Different research groups follow diverse research paths as they highlight different reasons for the domination of LMS and MOOCs. On the one hand, researchers, who focused on the flexibility of LMS/MOOCs, attempted to provide in one system as many teacher and learner support features as provided by a modern LMS/MOOC (e.g. content authoring, calendar, quizzes, forums, chat, and wiki) while still incorporating the ability to adapt to the user such as an intelligent LMS with an agent that learns from log data (Ueno, 2005) and a SCORM compliant adaptive LMS (Morimoto *et al.*, 2007; Kazanidis and Satratzemi, 2009). On the other hand, other researchers tackled a great characteristic of an LMS/MOOC, which is the aptitude to incorporate open corpus web content. They investigated numerous approaches to include open corpus content in an AEHS and at the same time ensure adaptive guidance for this content such as adaptive navigation support for open corpus content (Brusilovsky, Chavan and Farzan, 2004; Brusilovsky, 2007). A great number of researchers chose to investigate the integration of learning styles and cognitive features in AEHS (Papanikolaou *et al.*, 2003; Zapalska and Brozik, 2006; Mahnane and Laskri, Mohamed Tayeb Trigano, 2013) A different stream chose to focus on adaptive features of web-based educational systems which are based on system interoperability and reusability of content. While some of them are attempting now to integrate existing adaptive hypermedia technologies with the concepts of standard-based reusability, even if other teams argue that the current generation of standards is not able to support the needs of adaptive learning (Dagger, Wade and Conlan, 2002). The others attempt to explore the ideas of the Semantic Web for content representation and resource discovery, capitalizing on standards such as Resource Description Framework (RDF) and Topic Maps (Ounnas *et al.*, 2006; Dolog and Nejdl, 2007; Snae and Brückner, 2007; Yarandi, Tawil and Jahankhani, 2011; Hsieh *et al.*, 2012). The others try to combine the features of both standards and ontologies in developing their platforms (Zine, Derouich and Talbi, 2019). And another stream chose to dig and integrate the concept of competencies in their systems (Karampiperis and Sampson, 2006; Sitthisak, Gilbert and Davis, 2007; Magdaleno-Palencia *et al.*, 2011).

Some other examples of hypermedia developed in this period: **WebCOBALT** (Mitsuhara *et al.*, 2002), **INSPIRE** (Papanikolaou *et al.*, 2003), **MLTutor** (Smith and Blandford, 2003), **SIETTE** (Conejo *et al.*, 2004), **QuizGuide** (Hsiao, Sosnovsky and Brusilovsky, 2010).

2.4 SYSTEM ARCHITECTURE

"Adaptive hypermedia is hypertext and hypermedia system that reflects certain characteristics of the user in the user model and applies it to adapt visible and varied aspects of the system to the user" (Brusilovsky, 2001).

Adaptive educational hypermedia systems (AEHS) provide considerable help in the learning process as it defines an order in the learning of concepts, and use the available rich and diversified educational resources to offer personalized and tailored courses. They can better meet the needs of learners, identify their gaps and adapt the courses to their working methods, rhythm and speed of assimilation.

Even if there is a huge diversity concerning the existing AEHS, almost all of them are founded on the same set of design concepts (*see Figure 2.2*). The cornerstone of adaptivity in these systems is the existence of a learner model that contains all learner's information crucial for the system to identify learner's characteristics, strengths, weaknesses, preferences, emotional and cognitive states, and metacognitive skills. Another key feature to adaptivity in these systems is the presence of a domain model made of topics, concepts, rules and other knowledge elements that goes beyond the traditional hyperspace formed by interconnected pages. It intends to identify the relevant concepts and their relationships and provides an overall structure of the studied field.

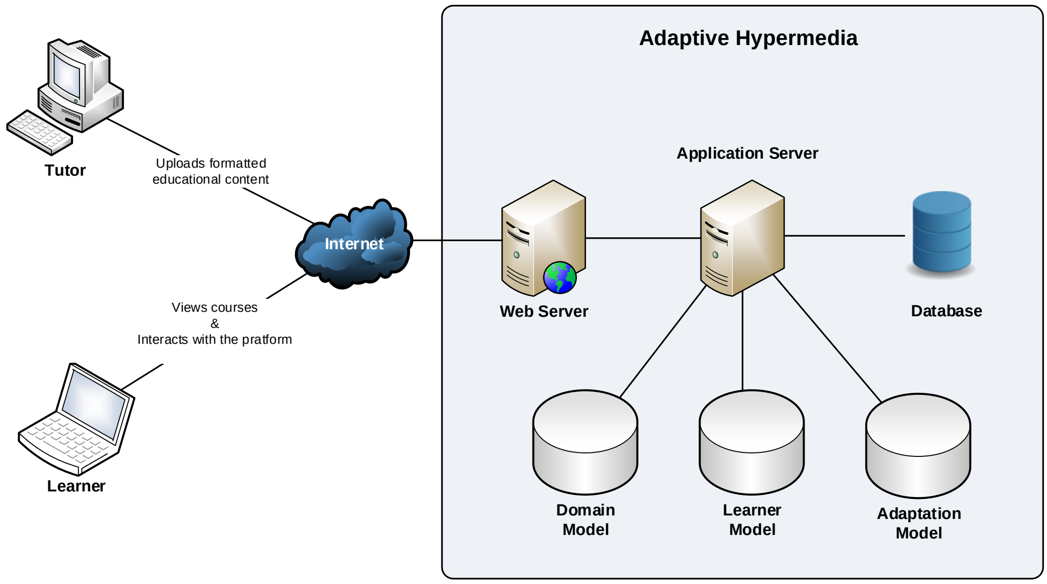

Figure 2.2: Adaptive educational system main components

2.4.1 Domain model

On the one hand, the domain model, also known as the knowledge space, is used to describe the content of information pages in AEHS. On the other hand, it structures the information about individual user knowledge and goals (i.e., the learner model). Consequently, the domain model enables to bridge the gap between user knowledge and goals on one side and the information content on the other side by using specific

AH technologies such as adaptive sequencing or adaptive link annotation, which allows the learner to receive the most appropriate educational content.

The structured domain model derives from the field of ITS, where it is used by systems incorporating functions such as task and/or curriculum sequencing, and instructional planning (Brusilovsky, 1992; Alshammari, Anane and Hendley, 2014). It is composed of a set of small domain knowledge objects (KO). Each KO represents an elementary fragment of knowledge for the given domain. KO can be named differently in different systems (e.g. concept, knowledge item, topic, knowledge element, learning object). Depending on the domain, the application area, and the choice of the designer, KO can represent bigger or smaller pieces of domain knowledge. A set of KO forms a domain model, and KO are related to each other to form a network that represents the structure of the domain covered by a definite AEHS. This kind of model turned out to be relatively simple and powerful and was later acknowledged as the d standard by almost all educational and many non-educational adaptive hypermedia systems.

The general principles of knowledge structuring are shared by the majority of AEHS. However, practical systems differ in their complexity and supported adaptation techniques. For instance, regarding information indexing (i.e., connecting information pages with knowledge elements), basic systems use only one concept to designate an information fragment. More complex systems relate many pages to the same concept and require more precise multi-concept indexing to make pages more distinct from the system's point of view, which enables them to provide a wider range of adaptation techniques.

While some systems developed for teaching practical university courses employed only the simplest vector domain model (Brusilovsky and Anderson, 1998; De Bra, 1998), many modern AEHS use sophisticated ontology-based networked models with several kinds of links that represent different kinds of relationships between the KO (*see Figure 2.**3***).

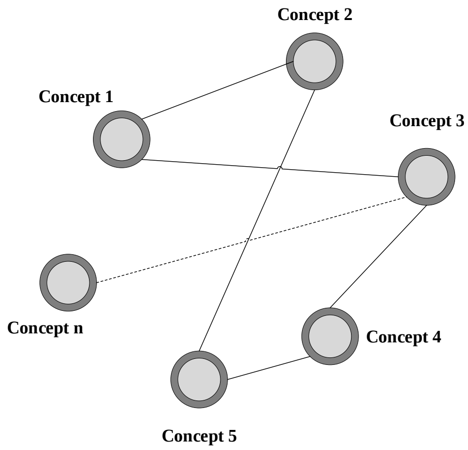

Figure 2.3: Network domain model example

The most commonly used kinds of links in AEHS are prerequisite links between the KO. This kind of links represents the fact that one of KO must be learned before another (Henze and Nejdl, 2001; Davidovic, Warren and Trichina, 2003; Papanikolaou *et al.*, 2003). However, the classic semantic links "is-a" and "part-of" links are gaining popularity due to the increasing use of more formal ontologies rather than typical domain models (Steinacker *et al.*, 2001; De Bra, Aerts and Rousseau, 2002).

2.4.2 Learner model

“A user model is a source of knowledge containing explicit suppositions about all aspects of users that might be relevant in a system’s dialogue” (Guangbing Yang, Kinshuk and Graf, 2010). In other words, the learner model is a structure that represents knowledge of system about a learner.

The purpose of learner modeling is to have a full description of all aspects of learner’s profile and behavior in order to dynamically provide appropriate educational content, and customized support and feedback, and improve the learning motivation. This means that adaptation accuracy is tightly depending on the strength of learner’s model. And so, any intelligent educational system should store the learner model, update it, and adapt its behavior to the content of this model.

Different adaptive systems store different information about users depending on the purpose of adaptation. In the case of AEHS the user is a learner and the learner model must represent all learner characteristics that should be taken into consideration

2.4.3 Adaptation model

The adaptation model represents the mechanism responsible to adapt content, links, representation and structure. It describes the set of adaptation rules responsible for the construction and presentation of the content to be delivered to the learner.

This model relies on condition-action rules that supplies adaptation as well as user model update. They can trigger each other, and consequently often need to be controlled to ensure termination and convergence.

2.5 ADAPTATION PROVISIONING

2.5.1 Adaptation supported systems

Regarding adaptation, three different types of hypermedia systems can be identified (*see Figure 2.4*) (Edmonds, 1982): adapted, adaptable, and adaptive systems.

2.5.1.1 Adapted systems

Adapted systems refers to systems in which the adaptation is the work of the designer himself and are implemented after a test phase. The user does not intervene to adapt the system but rather identifies himself through a previously defined user profile or group of users. In such systems, adaptation is not perceived since it cannot be specific to each individual.

2.5.1.2 Adaptable systems

Adaptable system are systems that can be modified at the explicit request of the user. He enters his preferences via a dedicated interface, saves them in a model and restores them at his request.

2.5.1.3 Adaptive systems

Adaptive systems implement behavioral monitoring mechanisms that leverage domain knowledge, learner knowledge and knowledge about learning processes, interpret them using specific models, infer user needs and preferences, exploit user and domain knowledge and manage learning paths to dynamically to deliver personalized pedagogical approaches and content adapted to each user. The updating of the user model is carried out by the system itself, by observing the interaction of the user with the system.

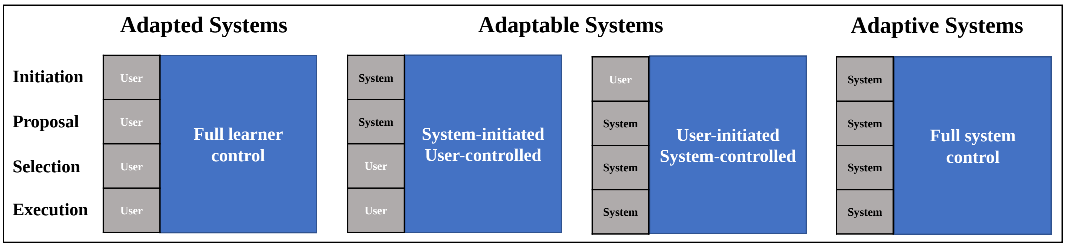

Figure 2.4: Different types of adaptation

2.5.2 Adaptation sources

In order to achieve adaptation, an AEHS relies on several criteria and aspects of the learner that will be detailed in the next chapter. Brusilovsky identified four criteria (Brusilovsky, 1996b) which are: the objectives to be reached by the learner, his knowledge concerning the concept or concepts of a given domain, his previous experiences and competencies acquired outside the current system and his preferences relating to the presentation of documents.

2.5.2.1 Learner objectives

For any learning system, determining the objective is vital as it represents a characteristic of the learner which is linked to the context of the teaching field. This parameter is variable since it changes from one learning session to another and can even change during the same session.

2.5.2.2 Learner knowledge

The learner's domain dependent knowledge is the most important criterion for existing AEHS. In fact, most of the adaptive presentation techniques used are based on the knowledge of the learner as the main source of adaptation. The learner's knowledge is also inconstant since it changes as the learner progresses in his teaching. That said, the system must follow the variation in learner knowledge and update the corresponding learner model.

2.5.2.3 Experience & competences

These two criteria correspond, at first sight, to that of knowledge. However, the difference comes from the fact that they relate to the learner’s domain independent knowledge acquired during previous experiences outside the learning system. A learner's experience and competences include learner's profession, work experience in areas related to the learning area as well as their perspectives.

2.5.2.4 Learner' preferences

Each learner has specific preferences and choices that manifest themselves through the choice of certain links rather than others or content over others. Preferences cannot be deduced by the AEHS, it is up to the learner to formulate them either directly to the AEHS or indirectly.

2.5.3 Adaptation provisioning techniques and methods

Adaptive techniques are computer science-based or mathematical techniques that allow systems to adapt themselves to users' requirements, goals and preferences and customize their learning paths. The next section describes the adaptive technologies and methods as well as their application scopes.

2.5.3.1 Adaptive technologies

Adaptive components generally provide the adaptation capability to e-learning systems. In particular, adaptive technologies can be classified into five different categories:

- Soft computing

Soft computing techniques are methodologies and techniques that exploit the tolerance for uncertainty and approximate reasoning models to reach flexible, robust and cost-effective solutions that mirror human-like decision making with the aim to best cope with complex and real-world problems (Chaturvedi, 2008). Techniques such as machine learning, fuzzy logic, evolutionary algorithms have been employed considerably in adaptive e-learning systems to deal with issues like learning style detection (Castro *et al.*, 2007), users' experiences warehousing and assessment (Chrysafiadi and Virvou, 2012; Romero *et al.*, 2013), learning objects presentation (Baylari and Montazer, 2009), learners' achievements evaluation and improvement (Hwang, Hung and Chen, 2014), and optimal learning paths construction (Idris *et al.*, 2009; Muhammad *et al.*, 2016).

- Machine learning

Perceived as a subcategory of artificial intelligence and closely linked to computational statistics, machine learning refers to the scientific study of statistical models and algorithms that could rely on patterns inferred from experience gained from previous tasks to perform the following ones (i.e. make predictions or decisions) without using explicit instructions and thus automatically improve their performance, efficiency and usefulness (Michie, 1968; Mitchell, 1997; Witten, Frank and Hall, 2011).

While machine learning algorithms vary in their approach, the type of input and output data, and the category of tasks that they are intended to perform, the most common types of machine learning techniques are supervised, unsupervised and reinforcement learning.

Supervised learning models such as decision tree, association rule mining, artificial neural and Bayesian network have been used to reach adaptivity objectives such as course recommendation systems, biometric verification, learning object personalization (Baylari and Montazer, 2009) and learning style detection (Özpolat and Gözde B. Akar, 2009).

- Ontologies

Ontological modeling provides a standard way of modeling a knowledge domain in a semantic way using representative primitives like classes or sets and expressing complex relationships between these concepts to guarantee easy transmission, interpretation, and reuse (Borst, 1999). By specifying the meaning of concepts, it enables the construction of formal and machine-understandable instruction in e-learning environments (Gruber, 1995; Jia *et al.*, 2011).

In adaptive e-learning systems ontologies can be used, on the one hand, to build domain models and conceptualize the learning contents (Dichev, Dicheva and Aroyo, 2004). In the other, they can be used to structure users' characteristics that are relevant to provide adaptivity including his knowledge and preferences (Sosnovsky and Dicheva, 2010; Zine, Derouich and Talbi, 2019) and provide adaptive navigational support (Karampiperis and Sampson, 2004).

- Application software

Application software refers to mass-produced and ready-to-use systems which are available for sale to the general public. They have been commonly used in adaptive e-learning systems in order to provide less expensive components. These prefabricated software components help to provide a large and diverse set of applications and can be classified into two web applications and non-web applications.

- Biometrics

Biometric techniques use distinct measurable physiological and behavioral characteristics to describe humans. While physiological characteristics such as fingerprint, face and iris recognition are related to the shape of the body, behavioral ones such as typing rhythm and voice are related to the pattern of behavior of a person (Jain, Ross and Nandakumar, 2011).

Currently, Biometrics is being mainly used to authenticate users during e-learning exam taking (Ramim and Levy, 2007). However, these techniques can be used for detecting user's problems such as boredom and apprehension and measuring learner's confidence and motivation by inspecting emotional behaviors.

- Hybrid techniques

In some cases, some artificial intelligence techniques such as fuzzy logic are not efficient when working alone. Consequently, it would be more reasonable to combine them with others to improve their efficiency. In this sense, hybrid techniques refer to the integration of two or more techniques that could be used to improve and enhance the performance or the proposed systems. For example, some researchers used a fuzzy ontological approach to represent user profiles (Ferreira-Satler *et al.*, 2010; Sani and Aris, 2014).

2.5.3.2 Application fields in adaptive hypermedia

There are various application fields of the aforementioned adaptive technologies. The most important ones are described below.

- Adaptive presentation

Adaptive presentation originates from research on intelligent systems (Boyle and Encarnacion, 1998) and can be defined as a set of techniques for altering the content of information to the requirements of an individual, or group of users. This means that when the learner reaches a particular page, the system displays its content appropriately.

The main issue with adaptive presentation systems is that they necessitate an extensive amount of knowledge about explicit relationships between concepts to change their presentation. Consequently, systems employing adaptive presentation techniques seek to achieve domain independence whenever possible using content abstraction.

Various techniques have been proposed regarding the adaptive presentation. On the one hand, most of work in this area has been categorized by Brusilovsky (*see Figure 2.5*) (Brusilovsky, 2001) as canned text adaptation which includes fragment processing techniques like *fragment altering*, *inclusion*, *removal*, *sorting* and *dimming* as well as *Stretchtext* (i.e. hiding and showing embedded fragments at the request of the user) (Hohl, Böcker and Gunzenhäuser, 1996; De Bra and Calvi, 1998; Hothi, Hall and Sly, 2000). On the other, some researchers tried to incorporate advanced techniques such as (Yang and Wu, 2009) who suggested an attributes-based ant colony system to help learners find an adaptive learning object more effectively. And (Cabada, Barrón Estrada and Reyes García, 2011) who proposed a system that adapts the content according to the learner's corresponding learning style (Felder-Silverman model) using self-organizing maps.

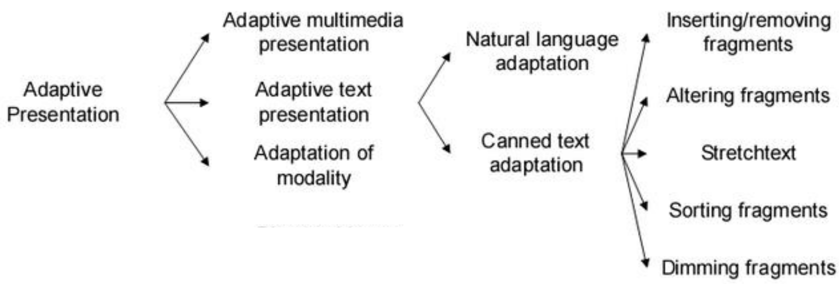

Figure 2.5: Taxonomy of adaptive presentation according to Brusilovsky

- Adaptive navigation

Adaptive navigational support comes from the early adaptive hypermedia systems (de La Passardiere and Dufresne, 1992; Kaplan, Fenwick and Chen, 1993) and concerns information access based on browsing. This means that when the learner navigates from one item to another, the system tailors the learning path (Carchiolo, Longheu and Malgeri, 2010; Nabizadeh et al., 2020) and modifies or augments the existing set of hyperlinks to provide him with relevant information. Unlike adaptive presentation that changes the instructive content of a single document, navigational support alters the structure of the relationships between documents.

Adaptive navigational support includes diverse techniques which can be used individually or combined to provide adaptation (*see Figure 2.6*). For instance, *adaptive link sorting* that reorders and ranks the hyperlinks with the topmost items being the most relevant to the learner based on the content of the learner model (Hohl, Böcker and Gunzenhäuser, 1996; Weber and Specht, 1997; Brusilovsky, Eklund and Schwarz, 1998), *adaptive link annotation* that changes a link's text, style, and appearance (De Bra and Calvi, 1998), *link hiding* that hides, but keeps active, links whose target content is inadequate with the level of knowledge or objectives of the learner (e.g. rendering the link in the same style as the surrounding text), *direct guidance* that can indicates a link's importance or usefulness to the learner (e.g. displaying the link with attractive color and font or with an additional icon), and *Link Augmentation* that insert additional relevant links to other existing pages (Maglio and Farrell, 2000; Bailey, El-Beltagy and Hall, 2002).

On the one hand, link sorting and annotation ca be destructive of the original document structure as they alter the document's existing navigational hyperlinks. On the other, link augmentation can cause a navigational overload, as the page could appear to have a greater number of links on it. To deal with these issues, several techniques such as soft computing have been utilized (Carchiolo, Longheu and Malgeri, 2010; Wang and Fischer, 2012) and hybrid techniques (Chen and Duh, 2008).

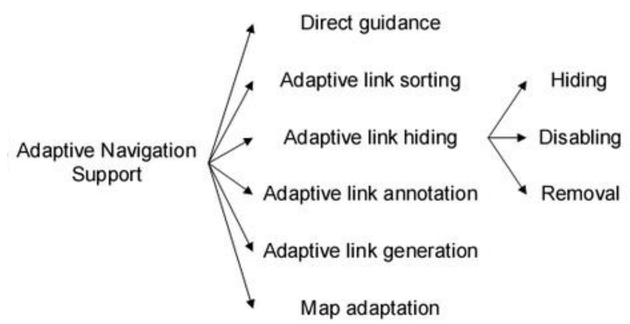

Figure 2.6: Taxonomy of adaptive navigation according to Brusilovsky

- Concept maps construction

Concept maps are graphical representation which is utilized to characterize and systematize relationships between concepts. These concepts are represented hierarchically (i.e. the most general concepts are placed in the top of the map while the most specific ones are placed in the bottom-level).

While a composite concept contains one or more sub-concepts, atomic concepts do not contain anyone. Each and every concept contains concept attributes that represent fragments of information regarding the concept they belong to (Cristea and De Mooij, 2003). Two concepts can be related to each other through a relation characterized by a label and a weight. These relations enable to check the pertinence of concepts to other knowledge domains via cross-links (Novak and Cañas, 2006), but don't have any independent semantic meaning.

Concept maps have been successfully employed in the adaptive e-learning context to reinforce guidance and orientation (da Silva et al., 1998), evaluate learning achievement (Nesbit and Adesope, 2013) and enhance student's attention (Cline, Brewster and Fell, 2010). Generally constructed by learning experts, researchers have attempted to automatize their construction and the evaluation of the relevance degree between concepts by mean of ontologies and/or fuzzy logic (Carr et al., 2001; Bai and Chen, 2008) to decrease their developing costs.

- Learning style automatic detection

Learning styles can be defined as the individual differences in acquiring and processing information. They enable adaptive e-learning systems to adjust the content presentation to each learner's needs and interests more effectively.

Several approaches to the automatic detection of learning styles have been proposed relying on the investigation of behavioral data gathered from students' interaction with the system (e.g. undertaken actions and their duration) (Karagiannis and Satratzemi, 2019). For instance, machine learning techniques are widely used for detecting and classifying learner's learning style namely *NBTree* (Özpolat and Gözde B Akar, 2009), *neural networks* (Lo and Shu, 2005; Zatarain-Cabada et al., 2010) , *Bayesian networks* (García et al., 2007; Alkhuraiji, Cheetham and Bamasak, 2011), *decision tree* (Ortigosa, Paredes and Rodriguez, 2010) and *genetic algorithms* (Yannibelli, Godoy and Amandi, 2006).

- Learner's issues detection and alleviation

During learning sessions, learners may feel bored, disoriented or exhausted, which can reduce significantly the learning outcome. In order to detect and alleviate these issues, adaptive technologies can be used. For example, as aforementioned, biometric techniques can be used for detecting such problems by monitoring learners' gaze patterns. Then, the adaptive e-learning system can try to reorient his focusing patterns towards learning material that could increase his motivation and engagement (D'Mello et al., 2012). Another example considered in this category is the evaluation of the learner during the learning process to determine its effectiveness where semantic-based techniques proved to be useful (Biletska et al., 2010).

2.6 ADAPTIVE HYPERMEDIA METAMODELS

Since the start of research in adaptive hypermedia, a wide range of systems in many varied fields has been produced. Though, very few reference models were developed. These models abstractly specify the components and mechanisms that can be used for building adaptive hypermedia systems.

The goal of each of these models is to define the context of use and the domain application areas of hypermedia systems, formulate the main objectives and requirements of designing hypermedia systems, and introduce the design concepts of this kind of systems, taking into account their main components (e.g. domain model, user model,) as well as the different adaptive methods and techniques that can be implemented to provide personalization.

This section highlights some of the adaptive hypermedia reference models in order to understand the aforementioned description.

2.6.1 Dexter Hypertext Reference Model

The Dexter Hypertext Reference Model was introduced in 1990 to capture the important abstractions found in a wide range of hypertext systems and introduce a common language for the people involved in hypermedia development (Halasz and Schwartz, 1994). It only provides the realization of a set of interfaces and does not attempt to cover all the details of the user interaction with the hypertext.

The reference model addresses not only adaptive hypermedia but hypertext systems in general and uses the word “hypertext” to refer to both text-only and multimedia systems. Moreover, the model has been proven to be useful and has since then influenced the design of many interactive web-based systems. It can be used as a basis for discussing and reinforcing hypermedia systems as well as for promoting interoperability and content sharing.

The Dexter Model is formally specified in the Z specification language (Spivey and Abrial, 1992), incorporates three layers (i.e. the Run-Time Layer that deals with the mechanisms for user interaction with the hypertext, the Storage Layer that describes how the nodes and links are connected and stored and the Within-Component Layer that describes the content and structures of nodes within a hypertext network) and includes the interfaces between these layers (i.e. Presentation Specification and Anchoring) (see *Figure 2.7*).

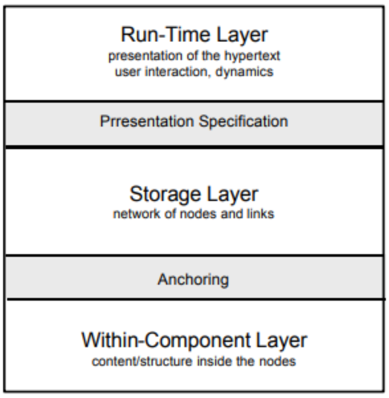

Figure 2.7: Dexter hypertext reference model

2.6.2 Adaptive Hypermedia Application Model (AHAM)

Developed as an extension of the Dexter model to support adaptivity, Adaptive Hypermedia Application Model (AHAM) is one of the initial and most popular formal models for adaptive hypermedia that describes AH from the authors' point of view (De Bra, Houben and Wu, 1999).

AHAM describes adaptive applications as consisting of three interconnected main layers (*see Figure 2.**8***): The Storage Layer which is composed of a set of nodes and links, the Within-Component Layer which specifies the content and structure of the nodes, and the Run-time Layer.

AHAM expanded the Storage Layer of the Dexter model by adding three sub-models (Knutov, De Bra and Pechenizkiy, 2009): the Domain Model (DM) that describes concepts in a hierarchical structure and defines abstract and special domain concept relationships; the User Model (UM) that also describes concepts, but with user-specific attributes, given that each concept in a DM has a corresponding concept in the UM; the Adaptation Model (AM) or the Teaching Model (TM) that defines how user actions are transformed into UM updates and consequently into the generation of presentation specifications, based on generic and specific adaptation rules (i.e. the adaptation mechanism and behavior).

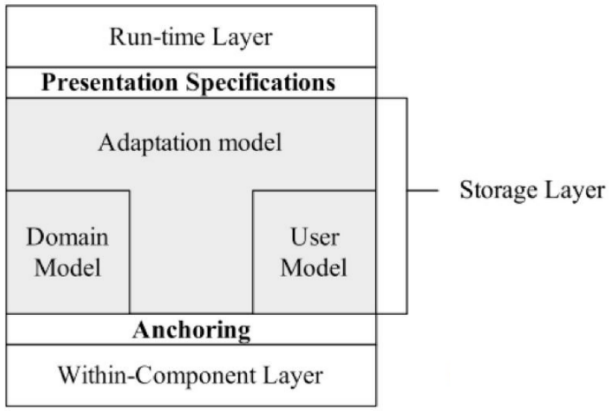

Figure 2.8: AHAM Reference model

2.6.3 Munich Reference Model

The Munich Adaptive Hypermedia Reference Model is another model that extends the Dexter Hypertext Reference Model by incorporating a user model and adaptation model (Koch and Wirsing, 2002). It aims at using general terminology independently of the application field.

Very similar to AHAM that specifies the adaptation rule language, it differs in using the Unified Modelling Language (UML) as a formal foundation and the Object Constraint Language (OCL) as a formal specification (Wirsing *et al.*, 2006). UML augments the intuitive comprehension of the model through visual representation and the OCL allows a meticulous description of the metamodel through invariants for model elements.

The layered architecture proposed by the Dexter Model has been substituted by UML package diagrams (*see Figure 2.9*) and description of the user model, domain and adaptation was illustrated by UML class diagrams (see. These diagrams are also used to describe the various features that are offered by the three models.

The Munich Model extends the run-time layer, responsible for the user interaction, with the acquisition of user behavior and management of the sessions needed in AH systems. However, it doesn’t detail the content and structure defined by the within-component layer as they depend on the application. It divides the Storage layer into three sub-models, the Domain sub-model that handles the fundamental structure and content of the hypermedia system as a set of nodes, operated as data containers, links, and navigation mechanisms, the User sub-model that manages sets of users’ attributes selected for adaptation purposes, the Adaptation sub-model made-up of a set of adaptation rules that achieve the personalization in accordance the information in the User sub-model.

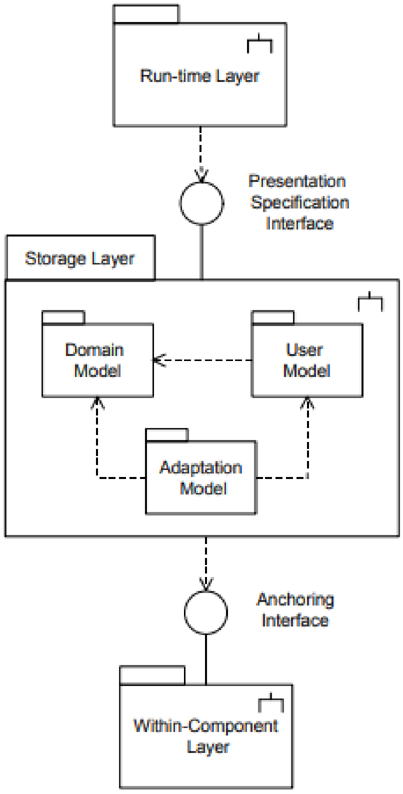

Figure 2.9: Munich Reference Model

2.7 SUMMARY

AEHS originates and beneficiated from studies on several fields such as hypertext systems and intelligent tutoring systems. They bring a new perspective in the educational area as they can improve the user interaction with computer systems and represent an alternative to one-size-fits-all approach since they allow different students to use the same form of environment adapted to their profile. This research area is expanding and it presents various trends such as standardization and data mining.

In this chapter, we outlined several notions and background information regarding AEHS, identified the major component incorporated in these systems (i.e. domain model, learner model, and adaptation model), exposed some techniques and methods used to provide adaptation and some of the main characteristics of students considered for such adaptation. We concluded this chapter by a brief description of several AH

Metamodels that were developed in order to provide researchers with abstract specifications that can be used for building powerful and standards compliant AEHS.

Moreover, AEHS are able to adjust their performance and functioning in accordance with the users' profile, behavior and context and facilitate a learning process centered on the user, by incorporating a learner model that records various information about user characteristics (e.g. knowledge, competencies, goals, and preferences). This model is used to adapt the contents of the hypermedia according to the learners' needs and preferences.

Finally, this chapter dealt mainly with the general aspects and concepts of AEHS, while the learner model – the main component for providing adaptivity - is tackled in the next chapter.

Chapter 3: Learner Characteristics, Learner Model and Learner Modeling

3.1 INTRODUCTION

It is claimed that hypermedia systems meet the objective of adaptation and are a suitable and effective option for providing personalized learning paths and appropriate intervention in selecting and displaying each learning object or activity in line with the learners' individual differences. This adaptation is essentially based on a meticulous design of the learner model, which is the core component of any adaptive learning system. It incorporates all the learner's pedagogical and psychological characteristics that are necessary for the system to identify the learner (knowledge, learning styles, psychological states, etc.), which guarantees an accurate and proper performance.

Recent developments in the semantic web have captivated researcher on using these technologies for developing adaptive e-learning systems (i.e., learner modeling, domain knowledge representing, etc.). The building blocks of the Semantic Web are ontologies. They provide a suitable mean for representing knowledge due to their flexibility and extensibility in designing concepts and their relationships. They were defined as "formal and explicit specifications of a shared conceptualizations" (Gruber, 1995)(Guarino, Oberle and Staab, 2009), which means that ontologies capture and share consensual knowledge and should be defined declaratively, structured and machine-interpretable and assessable.

In this chapter, the proposed work intents to improve learner's model representation to meet the requirements and needs of adaptation. We took IMS-LIP, IMS- ACCLIP and IMS-RDCEO standards into consideration and incorporated their characteristics to our proposed learner model so that it conforms to international standards. Moreover, the suggested learner model takes advantage of the semantic web technologies that offer a better data organization, indexing and management and ensures the reusability, the interoperability and the extensibility of this model.

The first section discusses some works that used ontologies to describe the user model. Next, a taxonomy of the features and characteristics that can describe a learner based on existing learner models is provided. Then, basic concepts related to learner modeling are presented. The international standards that attempted to model the learner data in a formal way that promotes reuse and interoperability are outlined in the fourth section. The chapter ends with our proposal concerning an IMS compliant ontological learner model.

3.2 RELATED WORKS

We can find in the literature that using ontologies to model the user profile has already been proposed in various applications like web search (Lawrence, 2000), personal information management (Katifori *et al.*, 2005), human resource management (Arena *et al.*, 2017) and healthcare (Ongenae *et al.*, 2013). Several attempts have been made to implement ontological learner models in the adaptive educational systems. (Yago *et al.*, 2018) present an ontology network-based student model the structuring and representation of a student model called ON-SMMILE. It combines the student model ontology with student independent ontologies and organizes the information obtained from the student model in accordance with standard specification. (Rani, Srivastava and Vyas, 2016) propose a system to improve knowledge management and representation of associated data based on an ontological learner model that uses the VARK learning model to align learner to proper paths of learning. (Muñoz *et al.*, 2015) suggest an ontology model called OntoSakai to represent LMS users' context. (Bajenaru and Smeureanu, 2015) present an ontological learner modeling to organize the educational information in Healthcare Human Resource Management in Romania. (Sani and Aris, 2014) used fuzzy logic and Ontology techniques to model the student's learning behavior to enhance the system's adaptability. (Panagiotopoulos *et al.*, 2012) outline an ontology-based student model for distance learning students. That can be used as an integral ITS module and can be easily accessed from a web-based application. (Yarandi *et al.*, 2012) describe learners' model ontology for creating personalized e-Learning systems based on learner's abilities, learning styles, prior knowledge and preferences. (Ounnas *et al.*, 2006) introduce a semantic learner model based on the FOAF ontology to support automation of the process of grouping students and preserve at the same time each learner's personal needs and interests.

3.3 LEARNER'S FEATURES TAXONOMY

Numerous researches claimed that an accurate definition the learner's characteristics influences and increases considerably the capability and efficiency of learning activities (Truong, 2016) (Santos and Boticario, 2015) (Kurilovas *et al.*, 2014).

In the following, we outline a taxonomy of the potential features and characteristics that can describe a learner based on the investigation of existing learner model structures and the analysis of the needs.

Different adaptive systems store different data about users according to the objective of the adaptation. In our case, the user is a learner, so the system should be able to answer questions such as: What is the name of a learner? What is her/his educational level? What is her/his motivational status? What's her/his learning style? What type of media does she/he use for interaction? Or how well does she/he master a certain topic?

As there is an exhaustive choice of the learners' characteristics that can be incorporated in the student model, the selection of the appropriate ones is required. Consequently, we have to select only the necessary and relevant ones in the context of the higher education system *(see Figure 3.**1**)*. We can cite:

Personal profile: deals with basic personal information about the learner such as name, first name, age, email, username and password, affiliation, educational level, and deficiencies.

Knowledge: includes learner's background and acquired skills and knowledge level that are specific to a domain. This information can be evaluated via tests and questionnaires during the learning session. Moreover, it includes domain-independent knowledge such as computer mastery, mastered languages and other official certificates.

Errors: are mistakes that can be defined as non-recurring bad answers, that learners can easily fix by themselves.

Misconceptions: refer to the correct execution of an incorrect procedure and erroneous conceptions or mistaken notions that are symptomatic of a faulty line of thought.

Goals: important to determine the learning strategies are the learning goals of the learner defined in terms of knowledge and/or skills to acquire either at the end of the course or during the learning session.

Assessment: learner's taken tests and evaluations, the obtained scores, the acquired knowledge, and level of mastery.

Preferences: different preferences regarding the different aspects of the learning environment such as the coloring scheme, the fonts and the size of the text.

Learning styles: designate the learning choices and learning differences that affect how a learner collects and deals with the learning objects (Özyurt and Özyurt, 2015).

Motivational states: the adaptive learning environment should interpret the motivation level of the learner and adapt its behavior to their state and assign suitable tasks in response to these emotions. Motivation is measured using parameters such as effort, interest, boredom, distraction, and persistence, etc. (Harandi, 2015).

Cognitive abilities: refer to intellectual skills or the mental process to acquire knowledge such as attention, knowledge, memory, perception, concentration, collaboration skills, decision making, reasoning, and critical thinking.

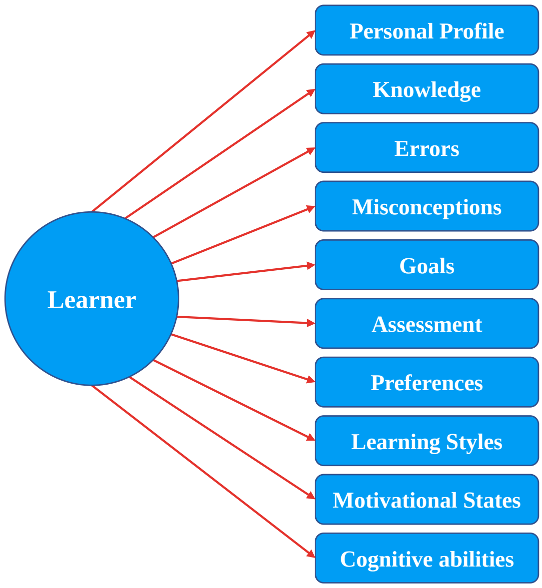

Figure 3.1 : Learner's characteristics

3.4 BASIC CONCEPTS

3.4.1 Learner model

The learner model is a data structure used to describe, record, track, retrieve and update learner's characteristics which may be relevant for adaptive learning. It is the key item in any adaptive E-Learning system. It aims to provide educational resources in a way that meets the needs and expectations of each learner (Hlioui, Alioui and Gargouri, 2016). More specifically, this model provides the necessary information about each learner to the environment to facilitate the learning process and the acquisition of knowledge, the learning path and interface adaption and suitable feedback and support providing (Buche *et al.*, 2006).

Unlike the learner profile, which is a collection of personal information about the learner recorded without any description or interpretation, the learner model consists of a higher level of abstraction and modeling of this stored information. Researchers claim that in order to provide customization in an e-learning system, it is crucial to store not only the learner's elementary characteristics (e.g. personal information, abilities, prior and current knowledge, goals) in the learner model, but rather catch, as faithfully as possible, the student's psychological state, preferences and reasoning process (Gauch *et al.*, 2007) (Murray and Pérez, 2015).

3.4.2 Learner model representation

While adaptation requires knowledge about learners, the learner model contains explicitly modeled assumptions that represent the learner's characteristics which are pertinent to the system. The constituents of a learner model are arranged differently in accordance with the design of the environment. There are several techniques for modeling the learner and refining this model. An overview of some of them is presented in the following.

The *scalar model* estimates the level of knowledge of the learners by means of a mark on a given scale, whether quantitative (for example a number going from 0 to 10) or qualitative (for example beginner, intermediate, advanced). Despite their simplicity, scalar models have been widely used to support adaptation (*see Figure 3.2*).

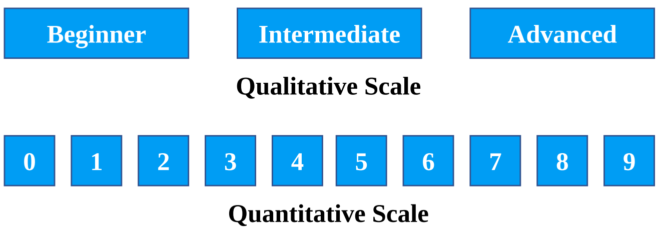

Figure 3.2 : Scalar model example

One widely adopted approach for learner modeling is the *social model or Stereotypes.* It allows the classification of all distinct learners of an adaptive system in several predefined groups based on shared characteristics *(see Figure 3.3).* Then the system will adopt the same behavior with all the learners belonging to the same group (Kay, 2000).

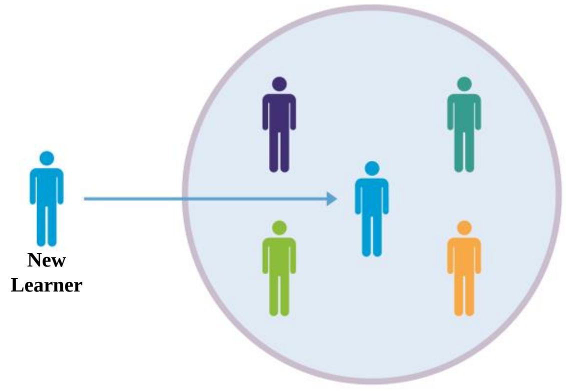

Figure 3.3 : Stereotype example

The most common representation of a learner model is the *overlay* model (Aitdaoud, 2017). It represents a learner's knowledge as a subset of the domain knowledge that represents individual subjects and concepts *(see Figure 3.**4**)*. While the *differential model* (Zine, Derouich and Talbi, 2016), a variant of the overlay model, sheds light on the gaps between the concepts covered by learner current knowledge and the concepts that should be mastered at the end of the course *(see Figure 3.**5**)*. Therefore, for both cases, the system will provide the learner with educational material until it covers the needed concepts to reach a certain learning objective (expert's knowledge). These models are inadequate for modeling advanced systems due to their inability to represent the erroneous knowledge that the learner can acquire. In contrast to overlay and differential models, *error (see Figure 3.**6**)*, *buggy*, and *perturbation* learner models represent incorrect beliefs that learners may hold and incorporate information about possible misconceptions or bugs and take into account all incorrect knowledge of the learner to provide suitable advice to correct his mistakes (Anouar Tadlaoui *et al.*, 2016). Yet those models are more powerful but are much harder to develop.

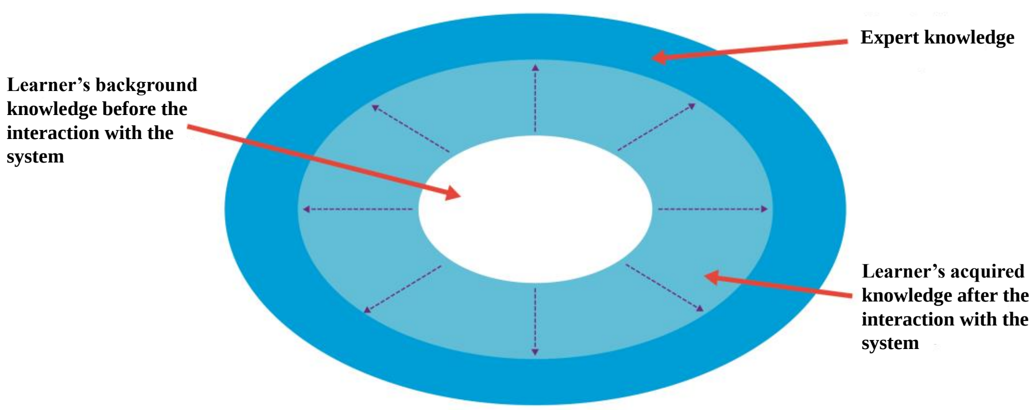

Figure 3.4 : Overlay model

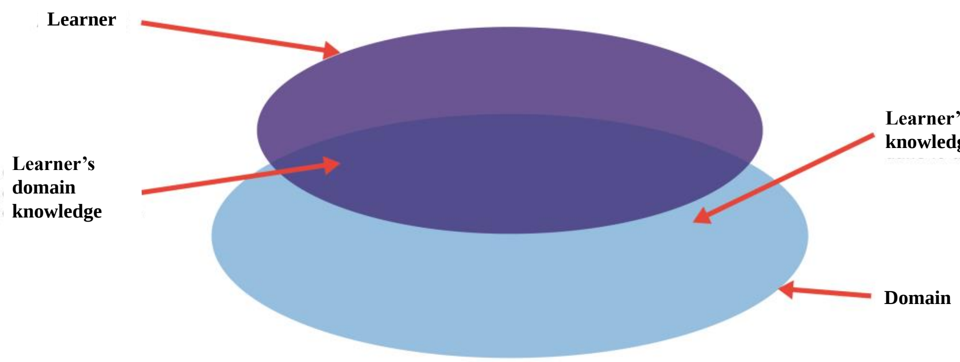

Figure 3.5 : Differential model

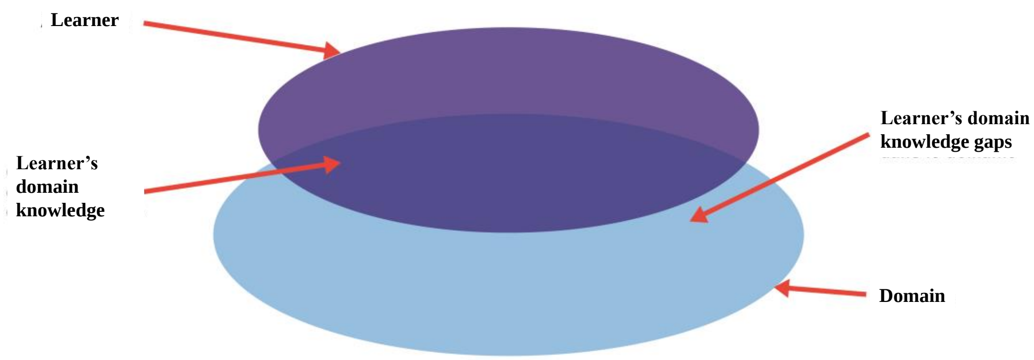

Figure 3.6 : Error model

Other widely used approaches are the probabilistic models: *Fuzzy logic* (Chrysafiadi and Virvou, 2012) *(see Figure 3.7)* and *Bayesian networks* (Millán, Loboda and Pérez-de-la-Cruz, 2010) *(see Figure 3.8)* differ from classical set models as they allow representing uncertainty. They improve the accuracy and efficiency of the process of observation and analysis of action sequences. And since there is no direct interaction between the teacher and the student, the presence of uncertainty in the diagnosis of the learner is increased, so, due to their ability to easily represent human concepts, the integration of one of these in the learner model to anticipate the learner's future behavior and performance, improves the adaptability of the system.

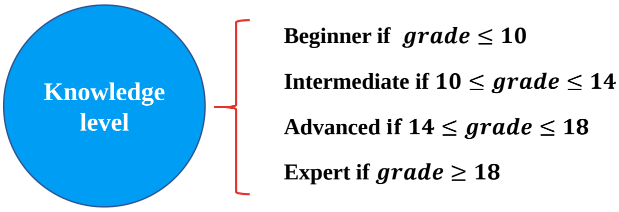

Figure 3.7 : Fuzzy logic example

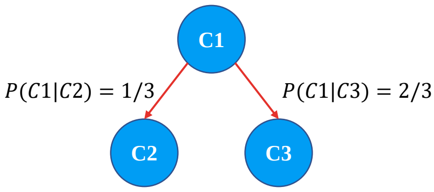

Figure 3.8 : Basic Bayesian Network example

And last but not least, ontologies are becoming the typical approach of knowledge representation and have a lot of benefits in this area (Al-Yahya, George and Alfaries, 2015). They have been proven to be an effective means, in the knowledge management field, for describing data within a specific domain in a semantic way (Snae and Brückner, 2007).

Unlike traditional data structures that only provide a structure for data instances storage, ontologies can express extremely complex relationships between the concepts they represent. They store content in a machine-readable format so as to be perceptible to the human and the machine, which enhance the parsing capabilities *(see Figure 3.**9**)*. On one hand, owing to their reasoning and inference abilities, they allow new knowledge extraction. On the other hand, they allow the formal representation of abstract concepts and properties to ensure reusability, extensibility, and interoperability of content over the web.

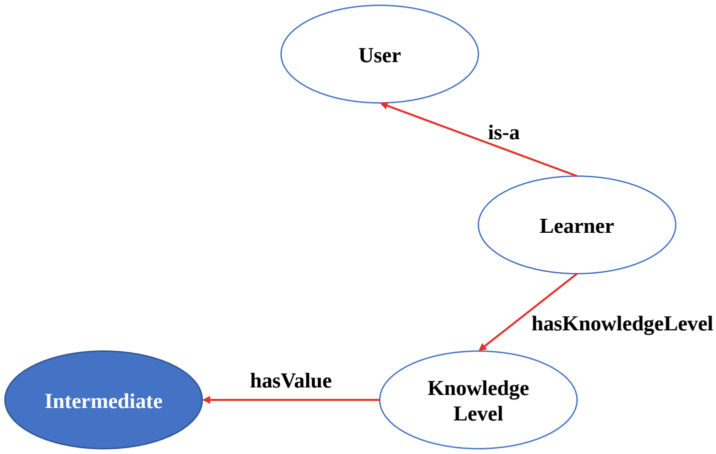

Figure 3.9 : Basic Ontology example

3.4.3 Learner model elicitation

In order to derive learner model information, adaptive learning systems usually solicit the user directly via forms, quizzes, and menus (static acquisition), as the communication flow between the learner and the system requires direct feedback from the learner. Another way to gather this information is through inferring data based on the user's interactions with the system during the learning sessions (dynamic acquisition). The system can mine information from the actions logs by applying machine learning techniques (Almohammadi *et al.*, 2017). There are also systems that use a hybrid approach that combines these two approaches (static initialization and dynamic update).

3.5 LEARNER MODEL STANDARDS

Standardization doesn't address only the learning objects, but also the learner information and so, learner characteristics should be well defined to ease their use in different platforms of e-learning and to grant a more accurate personalization.

Moreover, standards allow reducing variability in data models used to maintain learner profile records. Within this context, researchers in the educational field have deeply investigated those characteristics and attempted to model the learner data in a formal way that promotes reuse and interoperability.

Several standardization institutions such as the *IEEE Learning Technology Standards Committee* and *IMS Global Learning Consortium* have developed norms to meet that purpose, we review below the most important and most prominent ones.

3.5.1 *IEEE PAPI Learner* (Public and Private Information for Learners):

Developed by the *IEE LTSC* (Learning Technology Standards Committee) is one of the first proposals of a standard framework for constructing and classifying learner's data (LTSC, 2002),. It's a format which specifies the syntax and semantics of learner records and incorporates the Dublin Core metadata element set.

This specification provides a minimal amount of learner information and aims at supporting the representation, retrieval, and interchange of learner models among different educational systems. And it supplies researchers or developers intending to build a learner model with a foundation for the development of learner models and a standardized and growing source of data.

PAPI logically splits the learner information into six distinct and expandable subsets *(see Figure 3.**10**)*: (1) *Learner Personal* presents the personal information about the learner such as his name, address and email; (2) *Learner Relations* describes the relationships with the other users of the platform such as learners and tutors; (3) *Learner Security* holds the user's security details and access rights such as passwords, public and private keys…; (4) *Learner Preference* indicates information targeted to improve the human-computer interactions and provide the optimum learning experience such as learning styles, preferred language or disabilities; (5) *Learner Performance* refers to the record of the learner's history and measured performance such as grades, progress and goals that is created and used to offer the most advantageous and appropriate learning path; (6) *Learner Portfolio* aims at presenting and evidencing learner' achievements and skills by providing a collection of a learner's accomplishments and experience.

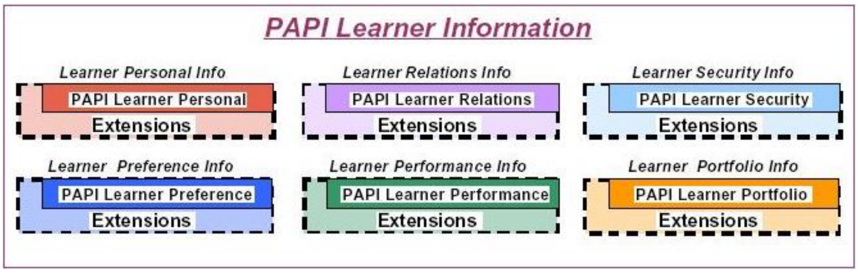

Figure 3.10 : IEEE PAPI learner information (LTSC, 2002)

3.5.2 IMS Global Learning Consortium specifications:

The IMS Global Learning Consortium developed various specifications and guidelines relevant to learner modeling and content and interfaces adaptation to meet the needs of individuals such as:

3.5.2.1 LIP (Learner Information Package):

The Learner Information Package (*LIP*) specification defines an *XML* structure that describes the essential characteristics of a learner and comprises information comparable to that covered by a learner's CV for recording and management purposes (Beidler *et al.*, 2001)(Smythe, Tansey and Robson, 2001).

Aiming at exploring learning opportunities for learners, it promotes the interoperability and cooperation between software applications, that use and might need to exchange and share a part of the collection of learner information (both data and metadata), (e.g. learning management systems, knowledge management systems, resume repositories, or any other e-learning environment) by defining a set of packages that can be used to import and export data from an *IMS* compliant system.

LIP structures the data into eleven segments that represent the primary data structures that are mandatory to support the learner information *(see Figure 3.**11**)*. These segments are: (1) *Identification*: describes the personal data on the learner, (name, age, address, email, etc.); (2) *Goal*: provides information about the purpose of the learning task, the intended career and other objectives such as personal goals and aspiration; (3) *QCL* (Qualifications, Certifications & Licenses): lists all of the learner's qualifications, certifications and licenses obtained from recognized authorities; (4) *Activity*: contains a description of the learning related activities in any state of completion (training, work experience, etc.); (5) *Transcript*: presents an institutionally-based summary of academic results and achievements; (6) *Interest*: describes the learner's hobbies and recreational activities; (7) *Competency*: describes the skills, experience and knowledge acquired, etc.; (8) *Accessibility*: describes general accessibility such as language abilities and preferences, disabilities, eligibility and learning preferences; (9) *SecurityKey*: holds security data of a person, such as passwords, access rights and security keys assigned to a learner; (10) *Affiliation*: represents information records about the professional associations and the organizations where the learner has a membership (work groups…); (11)

Relationships: describes the relationships between core data elements used to store the learner information used in this model.

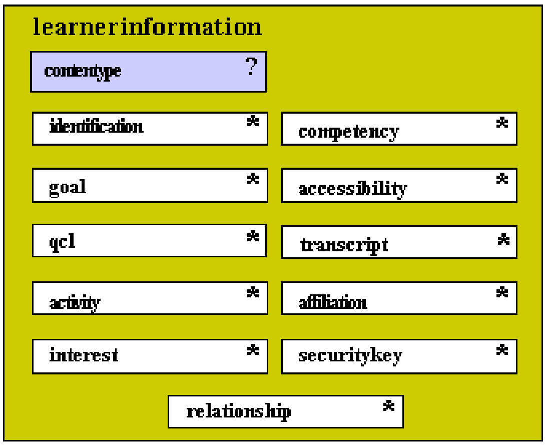

Figure 3.11 : IMS LIP learner information (Beidler *et al.*, 2001)

3.5.2.2 ACCLIP (ACCessibility for Learning Information Package):

IMS ACCLIP is one of the first initiatives of the *IMS* Accessibility Working Group to extend the *LIP* specification to address accessibility issues and allow learner accessibility preferences to be defined *(see Figure 3.**12**)*. It adjusts the <accessibility> element in *IMS-LIP*, trough discarding the <disability> element and including the <AccessForAll> one (Specification, 2003) (IMS Global Learning Consortium, no date).

The *ACCLIP* specification is about individualization and customization and is not disability-centric, which means it can be used for both the standard system and the assistive ones. And so, it improves accessibility not only for people with disabilities but also for non-disabled learners by assuming that any learner will have different access preferences depending on any number of factors or constraints like low-bandwidth or small screens. It allows the system to adapt the selection of learning content, its display, and controls to match the learner's individual needs and preferences by enabling the learner to specify his accessibility preferences for the manner of displaying the resource, the way of controlling it and the form of the delivered content (Harrison and Treviranus, 2003).

Accessibility preferences are sorted into three classes: the ones related to the content, those relevant to the content display and those in touch with the control of the content. Content preferences describe alternative or equivalent types of content that the learner might choose such as the audio descriptions instead of the visual content which can be relevant for the visually impaired or text instead of audio content for those that might not have speakers on hand while learning. Display preferences describe how the learner wants to have the interface and content displayed. Control preferences define alternative ways of handling the device and describe how the learner prefers to control it (standard keyboard/virtual keyboards…).

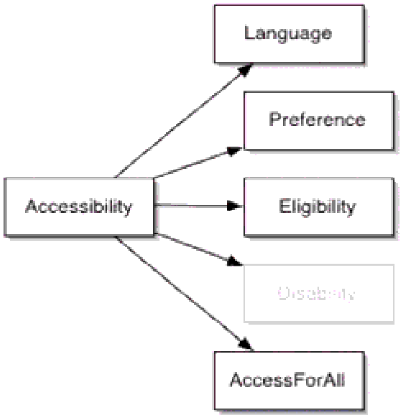

Figure 3.12 : IMS AccLIP information model

3.5.2.3 RDCEO (Reusable Definition of Competency or Educational Objective):

IMS RDCEO provides a common specification of learner's competencies, using unstructured textual definitions, and disregarding the usage context. It defines a minimalist but extensible information model that can be used to describe, reference and exchange definitions of competencies, mainly in the context of e-learning (IMS Global Learning Consortium, 2002).

This specification supports the representation of competency main characteristics in a formal way (competency includes skills, knowledge, learning outcomes, etc.). Competences can be those of a career plan or those of a learning plan (e.g. prerequisites representation or learning outcomes definition) and can be associated to a globally unique reference, which grants interoperability between knowledge management systems (e.g. learning systems, human resource systems, skills repositories, etc.).

However, it does not define how competences would be used as part of a learning process, assessed and certified.

The *RDCEO* Information Model defines four categories to characterize a competency: (1) *Identifier*: the unique, permanent and sufficient label to reference the competency in any other system; (2) *Title*: a short textual description of the competency and is human readable and recognizable; (3) *Definition*: a structured and optional description that provides a definition of the competency; (4) *Description*: an optional text-area, interpretable only by a human and which gives a more complete definition of the competency.

identifier and *title* are the only mandatory ones.

3.5.3 FOAF (Friend Of A Friend):

Founded by Dan BRICKLEY and Libby MILLER in the mid-2000, *FOAF* is an open-source and community-lead project with the goal of linking people and information using the Web (Brickley and Miller, 2014). It consists of a Linked Data system expressed using the Resource Description Framework (*RDF*) and the Ontology Web Language (*OWL*), in order to define a machine-readable ontology characterizing people, their interests and activities, documents, organizations, and relationships between them. This specification incorporates useful classes and properties for describing people online and can be easily coupled with other vocabularies, which grants the capture of a valuable collection of metadata (Panagiotopoulos *et al.*, 2012).

FOAF vocabulary is not a standard in the sense of *ISO* or *W3C* Process Standardization, but it is managed by following the style of the *W3C*'s standards work (*XML*, *RDF*, and *OWL*), which makes all *FOAF* documents well-formed *OWL/RDF/XML* documents.

FOAF incorporates five basic categories to represent a profile: (1) *Person* includes basic description of the leaner such as name, age, address, email, etc.; (2) *Document and Image* holds information about a document or an image related to the learner; (3) *Organization* points to the social institutions the learner is a member of; (4) *Online Account* stores information related to learners' accounts; (5) *Projects and Groups* store information about the groups or projects the learner participates in.

3.5.4 EduPerson:

Defined jointly by *INTERNET2* and *EDUCAUSE*, *eduPerson* standard is an attribute schema that intends to standardize research and higher educational user and organizational characteristics by providing a practical common list of attributes and definitions for inter-institutional data exchange.

It deals with information similar to the one found in an employee information system (e.g. data about the person and the organization to which he belongs) and incorporates bindings to an LDAP object class designed to facilitate communication between universities, notably to exchange data about people amongst US ones.

And considering that its aims at exchanging data, *eduPerson* provides very detailed descriptions comparing to other standards and allows only authorized users and services to access information and that is done disregarding the location or the manner of storage of the original information.

The learner's information which is addressed by this standard is classified in the two categories: (1) General attributes, which holds learner's general information about the learner, such as address, name, security settings, and information about the organization the learner belongs to, e.g. name, location, etc.; (2) Attributes is created to facilitate collaboration and communication between institutions and include learner's affiliation, learner's ID, affiliation, etc.

3.5.5 Comparison of the standards:

The table below (*see Table 3.***1**) summarizes the differences between all learner models described above based on their proposed taxonomies and supported features

The presentation of the main characteristics of the aforementioned standards confirmed the common belief which states that *PAPI* and *IMS-LIP* are the most used and important ones due to the completeness of the plethora of characteristics they offer and features they support. Nevertheless, both standards have some shortcomings. *PAPI* categories do not allow a detailed description of all the previously stated learner information. While *PAPI* is a standard that considers the performance information as the most important information about a learner, it neither takes into account learning data (e.g. learning activities) nor covers the goal and competencies categories that can be used for recommendation and filtering techniques. *IMS-LIP* was able to overcome *PAPI* imperfections and allows online learning systems to be better adapted to the needs of the learner by proposing a better categorization and adopting a CV alike description. Although relations to other people don't figure explicitly in *IMS-LIP*, they can be represented by relationships between different records using the identification category.

The other *IMS* specifications (e.g. *IMS-ACCLIP* and *IMS-RDCEO*) were developed to serve specific purposes (resp. accessibility and competencies) and propose a better representation of other information that was not raised by *IMS-LIP*.

EduPerson is the most detailed and suitable for collecting data and transferring it between institutions, but it's only used to point to documents. *FOAF* is the only model that explicitly outlines learner's relations with others and points directly to other learner profiles. But none of them hold any description of performance or preferences which shows that they were not developed to support personalization.

Some of these standards share a set of common learner characteristics. It is a usual practice to produce a learner model combining different learner standards and profiting from their unique benefits and overcome their shortcomings.

Supported features/aspects	Reference Model					
	PAPI	*IMS*			*FOAF*	*eduPerson*
		LIP	*ACCLIP*	*RDCEO*		
Personal data	+	+		-	+	+
Educational path						
Competencies	-	+/-		+		
Interest						
Affiliation		+			+	+
Accessibility			+			
Info portability	+	+			+	+
Personalization	+	+			+	
Recording Achievements	+	+				
Relations and Community building	+/-				+	+/-
Learning Styles	+	+				
Academic performance	+	+		-		
Preference	+/-	+/-		-		
Motivation						
Security	+	+			x	+
Goal		+				
Disability		+	+		x	+/-
Certification	+	+				
Portfolio	+	+				
Activity						
Learning objective	+	-		-		

Table 3.1 : Comparison between standards for learner information

3.6 LEARNER MODEL ONTOLOGY:

Ontologies construction is expected to incorporate methods and techniques used in software engineering. In the development process of our ontology, we followed the (Noy and McGuinness, 2001) method that consists of seven phases as shown in the figure below (*see Figure 3.13*). These phases aren't strictly sequential but follow an iterative process.

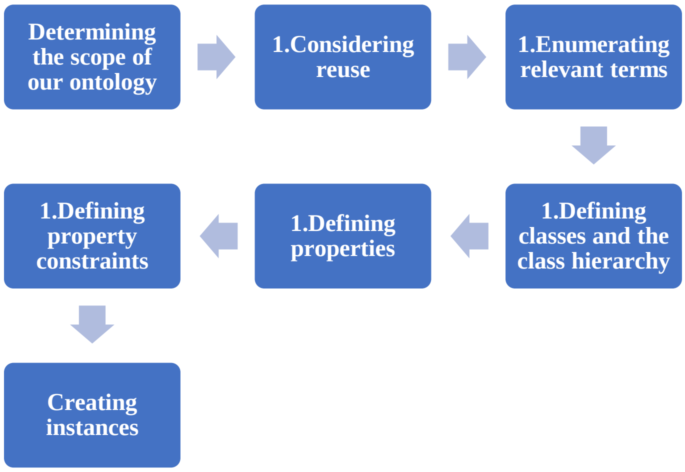

Figure 3.13 : Development process of the proposal

3.6.1 Development process

3.6.1.1 Determining the scope of our ontology:

In this step, we tried to define the purpose and the coverage of our ontology as It's very important to define from the beginning what the ontology is going to answer. And we aim to have a simplistic representation and avoid to make the schema overcomplex and unusable and hard to maintain.

We have defined the questions for which the information included in our ontology should provide answers (competency questions) *(see Table 3.2)* and we used this set of questions as templates we keep in mind before starting the ontology engineering steps.

Q1	Which learner's characteristics should be considered when addressing a learner?
Q2	What's the knowledge level of leaner A in domain B?
Q3	What are the cognitive abilities of learner C?

Table 3.2 : Excerpt of competency questions

3.6.1.2 Considering reuse:

We investigated the learner modeling standards mentioned in section 5 as well as upper, domain-specific, reference ontologies and ontologies that have been validated through use in other applications. We've taken into consideration reuse in the ontology development in order to save effort and ensure that there will be interoperability between our ontology and other ontologies since that our ontology might have to interact with systems that use other ones. And so, terms that we defined in our ontology can be reused, for example, in job seeking system to define someone's competencies.

3.6.1.3 Enumerating relevant terms:

Basically, we started by enumerating all the important terms in the learner modeling field that we'll use to build our ontology. We went through articles and standards to dig specific terms, their properties and constraints on these properties. These terms are a starting point to create classes of our ontology *(see Table 3.**3**)*.

Learner	Learner style	Disability
Novice	Reflexive	Motivation
Competency	Name	Certificate

Table 3.3 : Excerpt the listed terms

3.6.1.4 Defining classes and the class hierarchy:

We categorized elements with similar properties to create classes and define the class inheritance. We used a combination of the top-down and bottom-up modes of development: We started with the most pertinent concepts, then specialized the most general ones and organized the specific information that we collected about the individuals in more general classes to create a taxonomic hierarchy of our classes.

3.6.1.5 Defining properties:

We defined attributes of instances of each class and their relation to other instances (slots) as well as the relationships that link the classes of characteristics of each class.

To provide the relationships amongst two individuals from given classes, we specify the mutual OWL object properties that are in multiple forms (e.g. *hasAffectiveState* and its inverse property *isAffectiveStateOf*) *and w*e specified datatype properties that are used to link objects to datatypes (e.g. *hasBirthDate*, *hasName*…).

3.6.1.6 Defining property constraints:

After defining classes and properties on these classes we defined constraints on these properties. Constraints are used to limit the set of possible values for a property.

We determined the domain and range of each property as well as its cardinality, value type, minimum, maximum, and default values.

3.6.1.7 Creating instances:

We created instances of classes as well as the corresponding slot values in order to specialize classes and populate specific individuals.

3.6.2 Our proposal

The figures below depict the graphical representation of the developed learner ontology, which is a detailed version of the concept hierarchy. It represents a well-structured and shared vocabulary that tends to capture all the concepts presented in section 3 for describing learner profiles and aims at answering queries about learners' static and dynamic characteristics. Our ontology is compliant with the *IMS* standards (*LIP*, *AccLIP*, *RDCEO*).

We decided, in our modeling approach, to arrange learner model characteristics into facets. The *Learner* class *(see Figure 3.**14**)* is the key concept of our hierarchy as it includes all specific details regarding learners. It's associated with the corresponding sub-classes through *hasProfile*, *hasEducation* and *hasPersonality*, object properties.

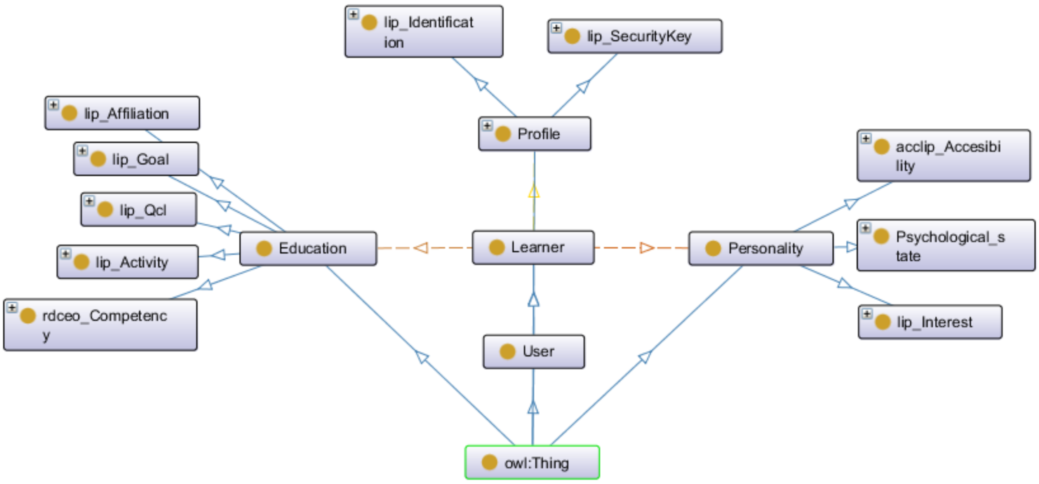

Figure 3.14 : Learner model ontology

Profile: is composed of the *Identification* class *(see Figure 3.15)* and the *SecurityKey* one. It represents each user's individual static information that will persist and won't evolve during sessions such as user's name, gender, email, etc. which allows the system to identify and address every user. It contains security data of users too; in our case it holds passwords.

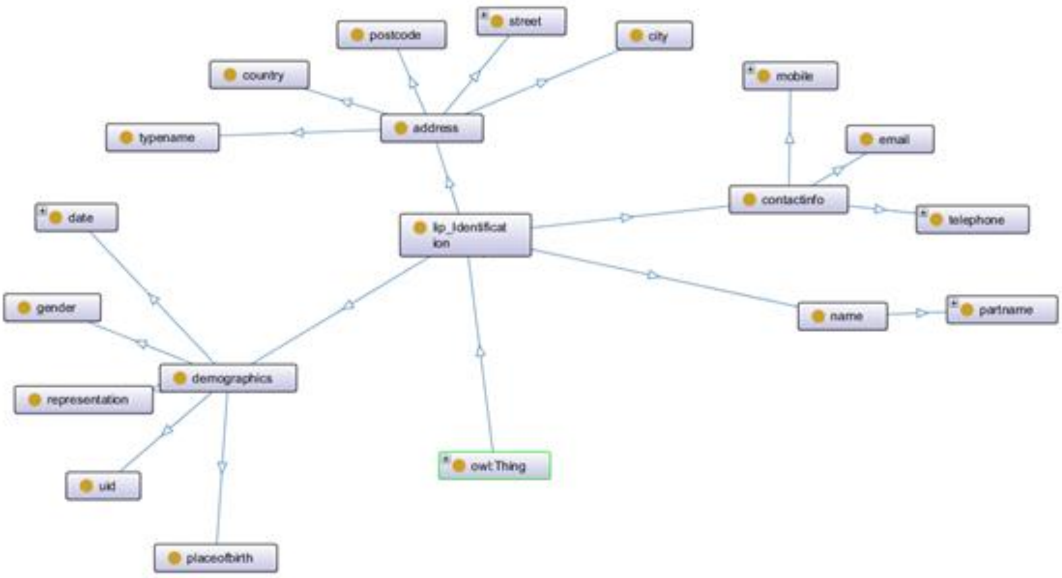

Figure 3.15 : Identification class

Education: contain asserted and inferred data about learner education and is composed of four sub-classes:

- The *Affiliation* class represents data about the associations and organizations where the learner has a membership (workgroups…) such as information about the organization, the membership number and the undertaken role of the learner.
- The *QCL* class is based on the learner's previous education and experience and lists all of the learner's qualifications, certifications, and licenses obtained from recognized authorities. These last have a specific registration number and might have a validation period.
- The *Goal* class provides information about the personal aspiration, the expected job or career, the aim of the undertaken learning tasks and other objectives.
- The *Activity* class contains a description of the learning activities and tasks such as a description of the activity, the state of completion and evaluation details.
- The *Competency* class *(see Figure 3.16)* was created according to the *IMS-RDCEO* standard and contains descriptions and references of competences. It provides a flexible schema for describing, expressing and exchanging subtle details of competencies, offers different means to assess diverse learner's aspects such as skills, knowledge, abilities, outcomes, and objectives described in learning or professional fields. Each competence might have quantitative and/or qualitative assessment.

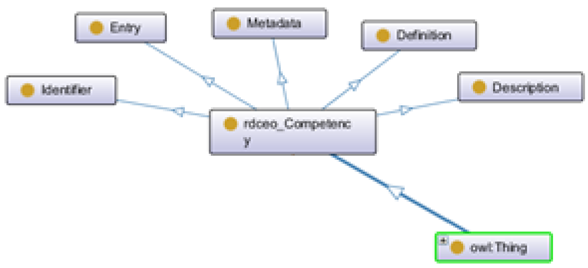

Figure 3.16 : Competency class

Personality: represents learner's accessibility preferences as well as his psychological state and interests.

- The *Accessibility* class *(see Figure 3.17)* deals with accessibility issues regarding language, eligibility and learning cognitive preferences concerning material display, system control, and the desired content transformations or enhancements.

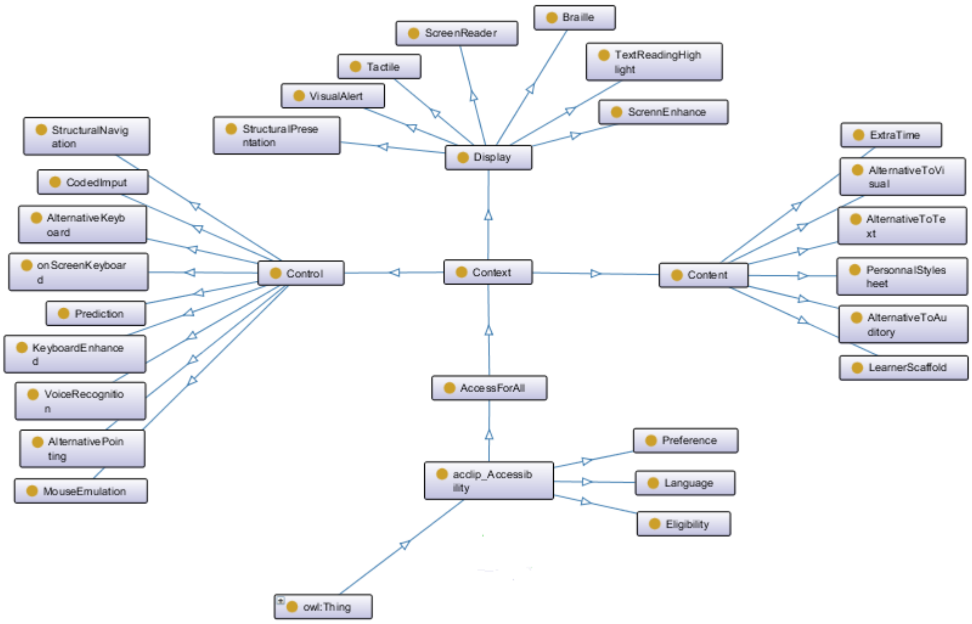

Figure 3.17 : Accessibility class

- The *PsychologicalState* class (see *Figure 3.18*) holds relevant information about learner's affective states, learning styles and cognitive and metacognitive factors. The system will observe how a learner reacts to these different types of stimuli and use this information to select suitable instructional content and strategies and provide a tailored learning experience. This class, its respective sub-classes and their way of representation have been the subject of a profound study and will be detailed in another paper.

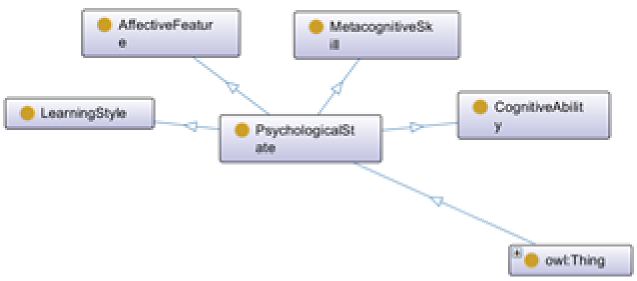

Figure 3.18 : PsychologicalState class

- The *Interest* class holds information about learner’s hobbies or recreational activities.

3.6.3 Evaluation and validation of the proposed ontology

We used the reasoner *Hermit 1.3.8.413* to evaluate and verify our ontology. A reasoner is a tool used to infer information that is not explicitly contained within the ontology and interpret the semantics of the objects included in an ontology model and to extract information from it. It allows consistency, subsumption, equivalence, instantiation checking of the proposed ontology. The reasoning may be done at different levels. While from the learner’s answer to a question, the learner’s correct or buggy knowledge can be inferred, from learner’s result in assessment, the system can obtain the acquired competency and the degree of mastery and from the assessment’s type learner’s abilities might be deduced (memory, learning speed…).

Hermit is an *OWL-DL* reasoner that offers a set of functionalities to inspect *OWL* documents such as identifying conflicting axioms by mean of the consistency function and grants datatypes verification, model evaluation, anomalies identification, and correction.

The evaluation verifies the syntax and semantics of the refined ontology by considering the scenario and the end-users so to have the learner model apt to be incorporated in the adaptive e-learning system.

The result of the reasoner indicates that there is no contradiction between axioms. Which means that the implemented model is in accordance with *OWL2QL* specifications which are a good compromise between computational weight and expressiveness.

3.7 SUMMARY

In this chapter, we present an ontology-based approach to model learners enrolled in distance learning. We started from a detailed statement and collection of the academic learner’s characteristics which are considered relevant for adaptation and reviewed the main modeling approaches available in the literature. Then, we studied the current learner modeling standards in educational systems. After that, we described the development process, the scenario and the validation of our proposal.

One of the key benefits of this approach is the integration of semantic rules which once combined with inference mechanisms provide additional knowledge about the learners. The most challenging part has been the selection of the most appropriate characteristics to be included in the ontology that would be, at the same time, compliant with the current learner modeling standards (the IMS standard in our case).

We choose to use ontologies because of their knowledge representation, reuse, sharing and modeling abilities. In an e-learning context, ontologies allow the semantic annotation of data (e.g. learner profiles, educational content) which offers a better data organization, indexing, and management in order to deliver to the learner relevant educational materials according to her/his ontology-based profile. Also, the use of interoperable representation of learner models allows adaptive e-learning systems to build, maintain and update their learner models with data from all of the different systems that the learner uses.

In the development of our proposal, we defined several questions that it should be able to answer. Then, we categorized the characteristics and organized them into a hierarchy. We realized the learner model ontology by means of the ontology editor *Protégé 5.2.0* We validated it by means of the reasoner *Hermit 1.3.8.413* to demonstrate its completeness, expressiveness, and consistency.

We can exploit the semantics contained in the metadata of the learner model and apply semantic indexing and clustering to group learners that share similar characteristics. This would lead to more accurate resources and learning activities recommendation to learners belonging to the same group and help us to deal with the cold start limitations.

We can take advantage of these semantics to create complemental and supportive pairs or groups when dealing with collaborative learning activities (e.g. having at least a person with a competency that is indispensable to the completion of a project or requests automatically learners that pursue the same learning goal to join the same forums and discussions.).

The next chapter will deal with learning styles that represent an important facet of the learner that allows a more accurate tailoring of the learning material presentation.

Chapter 4: Learning Styles in AEHS

4.1 INTRODUCTION

As demonstrated in the literature, the learner plays a central role in the complex learning process. And as noticed by teachers, learners aim at different goals, have diverse necessities, distinct backgrounds, skills and other significant characteristics (Graf et al., 2009). They vary extremely in the speed and manner with which they collect new information and ideas, and in the confidence with which they process and use them. For example, some studies have highlighted that adult learners learn differently from younger ones (adult learners and young ones don't learn the same way) (Ausburn, 2002). This makes each learner's requirements and preferences unique. The approach to instruction in which a single teaching scenario is used for all learners, better known in the literature as the 'one-size-fits-all' approach, is often unsuitable (Šimko, Barla and Bieliková, 2010).

Learner's individual differences have remarkable potential that should be exploited to provide more accurate guidelines and learning support. This last lead to a better understanding of the subject, to the enhancement of learner's performance and motivation and consequently the optimization of the learning outcomes.

On the one hand, cognitivist and constructivist theories of learning revealed that several learning strategies should be integrated to accommodate individual differences and learning style (Cassidy, 2004). On the other hand, researchers claimed that if a learner has a strong preference for a particular learning style, the strategies and even the learning resources should match that style to improve the learning experience (Felder and Silverman, 1988).

Learner diversity that exists in the classroom plays a role in influencing the teaching and learning process in the classroom. While all types of learners still need to be addressed, variety in instructional approaches can be used to address this diversity (Mei Ph'ng, 2018). In addition, the various learning styles as a great deal of ongoing research indicate that learners have different strengths and preferences in the way they absorb and process information (James and Gardner, 1995). Studies in psychology point out that people show noteworthy individual differences in problem-solving and decision-making activities. For instance, students with a solid inclination for a particular learning style may experience problems in learning if the teaching style does not coordinate with their learning style.

Even if researchers still argue on the usefulness of considering students' learning styles in adult education, the use of learning styles measures continues to be popular. And despite the absence of rigorous research findings to support this practice, there is no evidence for its ineffectiveness.

Some researchers claim that learning styles don't match the way the brain stores and reason about information. Others mention that there might be an optimal way to explain a particular subject, but the same style can't always be the best for a specific learner. And rather than focusing on one's best learning style, it is more interesting to on the worst, and try to improve learner's ability to learn in every style.

Even if the idea of learning styles hasn't reached maturity and hasn't proven a total success, there are still many strong reasons which show that employing learning styles can be beneficial to learners. One of the major reasons to use learning styles is because it encourages variety (i.e. as long as a learner feels at ease in the process of learning, no matter what his learning style is, he will learn better). Another reason and as involvement matters, a multimodal classroom is more engaging (i.e. if a learner prefers learning through activities, reading and listening to lectures will make him feel bored and discourage him). Even if learning styles turn out to be nothing more than a personal preference, it still a creative and smart way to engage learners and enhance their motivation. Moreover, learning styles remind us that each learner is different, and while it is nearly impossible to satisfy all learners, success opportunities can be given to everyone by varying the teaching way at least.

This chapter starts by critically examining the most influential learning style models according to the literature and presents a comparative summary of these learning style models (emphasizing their implication on teaching highlighting their strengths and weaknesses). Afterward, it shows how to measure the chosen learning style. Thereafter, it shed light on the impact of learning styles on learners preferred multimedia type. Next, it exposes the instructional design for learning path identification using the Felder-Silverman learning styles model. And finally, it presents a statistical study conducted to identify higher education learners default learning style.

4.2 LEARNING STYLE MODELS CLASSIFICATION

On the one hand, cognitivist and constructivist theories of learning revealed that several learning strategies should be integrated to accommodate individual differences and learning style (Cassidy, 2004). On the other hand, researchers claimed that if a learner has a strong preference for a particular learning style, the strategies and even the learning resources should match this style to improve the learning experience (Felder and Silverman, 1988).

The appellations ‘learning style’ and ‘cognitive style’ are commonly used interchangeably, even if cognitive style may denote a specific facet of learning style (Cassidy, 2004). Moreover, learning styles are commonly associated with terms as “learning preferences”, “learning skills”, “learning strategies” and “learning approaches” (Coffield *et al.*, 2004). This diversity of interpretations and terminologies led to the development of many learning style models.

Given the variety related to learning style, and the existence of a large number of learning models (Coffield *et al.*, 2004), a categorization of these models helps to identify their key features.

The model of Curry’s onion can be used to group learning theories into three primary layers according to the degree of stability over time of the preferences represented by each one (Curry, 1983, 2000) *(see Figure 4.1).*

- **Instructional preference styles** (the outer layer of the onion): The least persistent over time, they deal with various modes of information delivery, may often change and therefore are less important in learning.
- **Information processing styles** (the middle layer): More stable over time than the instructional preference ones, they cope with the information processing way that influences the way learners memorize, infer and interpret information.
- **Cognitive personality styles** (the inner layer): The most unalterable over time, they are based on personality traits that have a more significative influence on learner’s interaction with the learning environment.

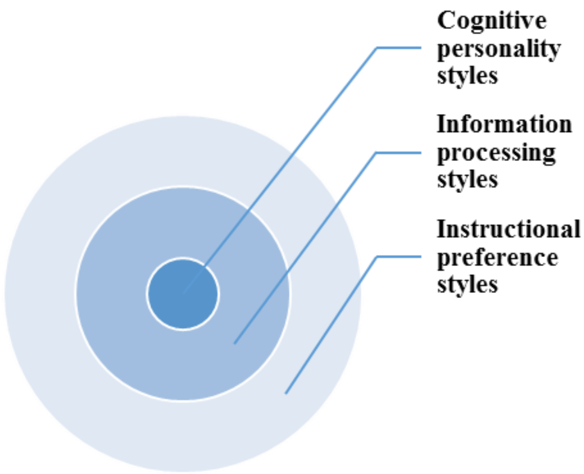

Figure 4.1: Curry's Onion learning styles model

(Coffield *et al.*, 2004) claimed that Curry's onion model relies on theoretical assumptions and lacks experiential evidence to determine learning style stability. And so, they suggested "The families of learning styles" to classify learning style models with reference to several learning style overviews and on quantitative evidence. This spectrum was inspired from the onion model as well as analyses and overviews by key figures in the learning styles field (Curry, 1991; Riding and Cheema, 1991; Bokoros, Goldstein and Sweeney, 1992; Chevrier *et al.*, 2000; Entwistle, McCune and Walker, 2001).

The "families of learning styles" categorizes over seventy learning style models into the following *(see Table 4.1)*:

- **Constitutionally based learning styles and preferences**: Supposed to be fixed and very difficult to change, they are open to relatively easy environmental modification. These styles are mostly innate personality traits and represent the dominance of specific perceptual and sensory channels including the four sensory modalities: visual, auditory, kinesthetic and tactile.
- **Cognitive structure**: Presumed to be general habits of thought, they reflect intuitive and structural characteristics of the cognitive system and focus on the interactions of cognitive controls and cognitive processes (Riding and Rayner, 2013).
- **Stable personality types**: Believed to be mostly stable but can change over time, they are viewed as embedded characteristics within the personality traits

which are assumed to shape all aspects of an individual's interaction with the environment.

- **Flexibly stable learning preferences**: Assumed to have some long-term stability even if they can change slightly from one situation to another, they are viewed as crucial preferences rather than fixed characteristics. This family of learning styles classifies learners in accordance with a measure that mirrors the way they receive and process information.
- **Learning approaches and strategies**: Frequently changing depending on the situation, they came out from the drop of the learning styles for a holistic and active view of learning approaches and study strategies. They describe how learners prefer to tackle learning tasks generally according to their perceptions of a task and the adopted cognitive strategies (Entwistle, McCune and Walker, 2001).

Constitutionally-based learning styles and preferences	Cognitive structure	Stable personality types	Flexibly stable learning preferences	Learning approaches and strategies
• Dunn and Dunn • Gregorc • Bartlett • Betts • Gordon • Marks • Paivio • Richardson Sheehan • Torrance	• Riding • Broverman • Cooper • Gardner et al. • Guilford • Holzman and Klein Hudson • Hunt • Kagan • Kogan • Messick • Pettigrew • Witkin	• Apter • Jackson • Myers-Briggs • Epstein and Meier • Harrison-Branson • Miller	• Allinson and Hayes • Herrmann • Honey and Mumford • Kolb • Felder and Silverman • Hermanussen, Wierstra, de Jong and Thijssen • Kaufmann • Kirton • McCarthy	• Entwistle • Sternberg • Vermunt • Biggs • Conti and Kolody • Grasha-Riechmann • Hill • Marton and Säljö • McKenney and Keen • Pask • Pintrich, Smith, Garcia, and McCeachie • Schmeck • Weinstein, Zimmerman and Palmer Whetton and Cameron

Table 4.1: Coffield's Families of learning styles

4.3 LEARNING STYLE MODELS

In adaptive e-learning environments, various learning styles theories have been used. In this section, we focused on the most influential learning style models. Since they are the most suitable for the implementation of an adaptive e-learning environment, we are particularly interested in the flexibly-stable learning preferences. However, we decided to take one model from each other family into consideration for reviewing purposes.

4.3.1 Gregorc's Mind Styles Model

LS family: Constitutionally-based learning styles and preferences

Anthony Gregorc defines learning styles as stable, cognitive, affective, and physiological traits that serve as indicators of how learners perceive and deal with information and react during learning sessions. Furthermore, he argues the teaching strategies, the personality of individuals, and the media are highly correlated.

He claims that minds interact with any context through channels and that there are two dimensions of learners' innate abilities of perception and ordering, and distinguishes between four observable channels: abstract, concrete, random, and sequential tendencies. A combination of these tendencies is indicative of the individual style. And so, four learning styles are identified within Gregorc's model *(see Table 4.**2** and Figure 4.**2**).*

Dimension	Pole	Learning style
Perception	Concrete (C)	1. AS 2. AR 3. CS 4. CR
	Abstract (A)	
Ordering	Sequential (S)	
	Random (R)	

Table 4.2: Gregorc's Mind Styles Model

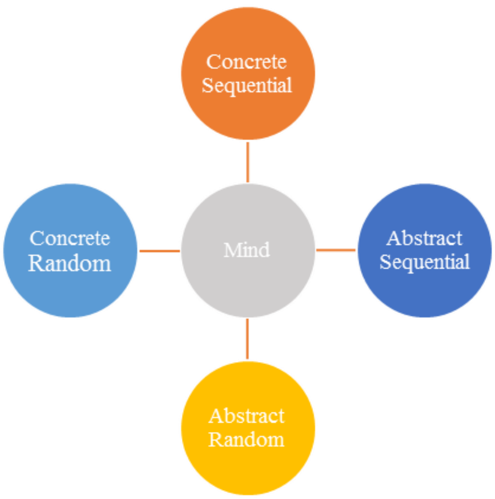

Figure 4.2: Gregorc's four channels model

In order to determine learner's learning style, the Style Delineator has been developed, which is a 40-item self-report inventory involving the rank ordering of sets of words.

4.3.2 Riding Cognitive Style

LS family: Cognitive structure

Riding Cognitive Style model is mainly focused on how cognitive skills develop (Riding and Cheema, 1991). Its authors state that the cognitive style is the individual's way of thinking and at the same time the individual's favorite and habitual approaches of organizing and representing information. Furthermore, they define a learning strategy as the processes used by the learner to comply with a learning activity requirement. Besides, they claim that while strategies may be learned and developed over a period of time, styles are static and are relatively innate characteristics of any individual and state that their model is oriented essentially to the cognitive skills developing approaches, and so, it influences the study orientation, the instructional inclination, the hands-on learning, the social attitude, and managerial skills.

(Riding and Cheema, 1991) reviewed the descriptions, correlations, methods of assessment, and effect on the behavior of over 30 models, and concluded that they could be grouped into two uncorrelated dimensions: one concerning to cognitive organization (holist-analytic); and one involving mental representation (verbal-imagery) *(see Table 4.3 and Figure 4.3)*. And Riding states that the first dimension originates from Witkin research on field dependence and field independence (Witkin *et al.*, 1962), while the second is based on the dual coding theory of Paivio (Paivio, 2013).

Dimension	Pole	Learning style
Cognitive organization	Holist (H)	1. HV 2. HI 3. AV 4. AI
	Analytic (A)	
Mental representation	Verbal (V)	
	Imager (I)	

Table 4.3: Riding Cognitive Style

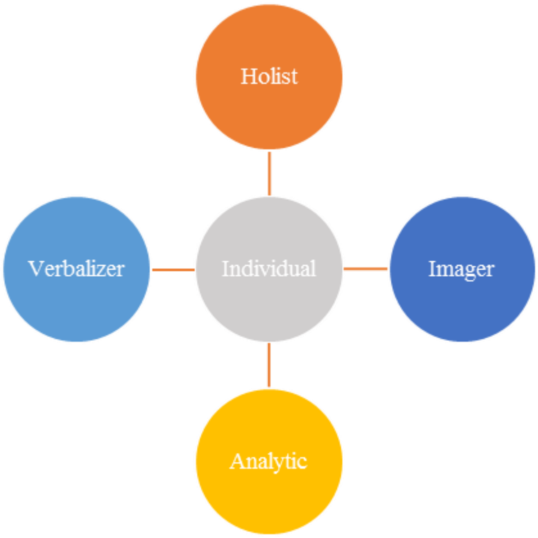

Figure 4.3: Riding Cognitive Style uncorrelated dimensions

In order to retrieve learner's cognitive style, Riding has developed an assessment method named the Cognitive Styles Analysis (CSA) (Sadler-Smith and Riding, 1999). The cognitive representation dimension test items are entirely visual and the score is relying on a response speed comparison on a matching task and on embedded figures task analytic preference. And the items for the verbal-imagery dimension are all verbal and are in accordance with the relative speed of categorizing items as being similar through their conceptual similarity or color.

4.3.3 Myer-Briggs Type Indicator Theory

LS family: Stable personality types

Developed by Isabel Briggs Myers and her mother, Katharine Cook Briggs, MBTI is a model based on the theory of psychological types of Carl Jung. It aims at helping each person to understand his unique personality. This model is based on the belief that the variances in behavior from one person to another can be expressed in terms of preferences between polarities and each person has a natural preference (Myers, McCaulley and Most, 1985). Accordingly, when someone uses his favorite pole, he/she generally succeeds better and feels more skilled.

Furthermore, MBTI's dimensions define the four main dichotomies of psychic life and represent humans' personality core functions (Girelli and Stake, 1993). Each dimension has two uncorrelated poles, and each person is predisposed to one pole in each dimension *(see Table 4.4)*. So, this model allows the generating of sixteen unique personality types.

<table>
<tr><th>Dimension</th><th>Pole</th><th>Learning style</th></tr>
<tr><td rowspan="2">Attitude</td><td>Introvert (I)</td><td rowspan="8">1. ISTJ
2. ISFJ
3. INFJ
4. INTJ
5. ISTP
6. ISFP
7. INFP
8. INTP
9. ESTP
10. ESFP
11. ENFP
12. ENTP
13. ESTJ
14. ESFJ
15. ENFJ
16. ENTJ</td></tr>
<tr><td>Extravert (E)</td></tr>
<tr><td rowspan="2">Information processing</td><td>Sensing (S)</td></tr>
<tr><td>iNtuitive (N)</td></tr>
<tr><td rowspan="2">Decisions making</td><td>Thinking (T)</td></tr>
<tr><td>Feeling (F)</td></tr>
<tr><td rowspan="2">Environment evaluation</td><td>Judging (J)</td></tr>
<tr><td>Perceiving (P)</td></tr>
</table>

Table 4.4: MBTI learning style

In order to detect learning styles, three forms of the Myers-Briggs Type Indicator instrument were developed (a standard 93-item version, an extended 126-item version, and an abbreviated 50-item version). And in all instances, scores are given to generate one of the sixteen unique personality types (Capraro and Capraro, 2002).

4.3.4 Felder-Silverman Learning Style Model

LS family: Flexibly stable learning preferences

The Felder-Silverman learning style model (FSLSM) (Felder and Silverman, 1988) is, another model based on the work of Carl Gustav Jung, a widely used in adaptive educational systems focusing on learning styles. It describes the learning styles of engineering learners in a detailed way. It distinguishes between preferences on four measurements (dimensions) which are linked to the four dimensions of information: information processing (How does the learner prefer to process information), information perception (What type of information does the learner prefer in order to perceive), information input (Through which sensory channel is external information most effectively perceived), and information understanding (How does the learner progress towards understanding) and therefore enables adaptive learning systems to provide a better-tailored learning material (Graf *et al.*, 2009).

Moreover, FSLSM enables the learning style model to considers exceptional behavior which means that learners with a high preference for a certain behavior can act sometimes differently. This model rates the learner's learning style in a scale of four dimensions to define sixteen distinct learning styles *(see Table 4.5)*.

<table>
<tr><th>Dimension</th><th>Pole</th><th>Learning style</th></tr>
<tr><td rowspan="2">Perception</td><td>Intuitive (I)</td><td rowspan="8">1. IAVQ
2. IAVG
3. IAEQ
4. IAEG
5. IRVQ
6. IRVG
7. IREQ
8. IREG
9. SAVQ
10. SAVG
11. SAEQ
12. SAEG
13. SRVQ
14. SRVG
15. SREQ
16. SREG</td></tr>
<tr><td>Sensing (S)</td></tr>
<tr><td rowspan="2">Processing</td><td>Active (A)</td></tr>
<tr><td>Reflective (R)</td></tr>
<tr><td rowspan="2">Input</td><td>Visual (V)</td></tr>
<tr><td>vErbal (E)</td></tr>
<tr><td rowspan="2">Understanding</td><td>seQuential (Q)</td></tr>
<tr><td>Global (G)</td></tr>
</table>

Table 4.5: Felder-Silverman Learning Style Model

In order to detect learning styles, Felder and Soloman elaborated a 44-item questionnaire, named the Index of Learning Styles (A Soloman and Felder, 1999), where 11 questions are asked for each dimension (Lakkah, Alimam and Seghiouer, 2017).

4.3.5 Kolb's Experiential Learning Theory

LS family: Flexibly stable learning preferences

Inspired by the works of John Dewey and Jean Piaget, the American psychologist Kolb developed a four-stages learning style model named "The Experiential Learning Theory" in the early 70s. According to Kolb, the experience is the key element of any learning process, and knowledge comes from the blending of grasping experience and transforming it (Kolb and Kolb, 2005).

He defined a learning model composed of these two orthogonal dimensions *(see Table 4.6)*. The Grasping dimension poles are Concrete Experience (when the learner is confronted to a new situation or a remake of similar previous experience) and Abstract Conceptualization (when the learner's reflections initiate a new understanding or the expansion of the current knowledge). Likewise, the Transforming poles are Reflective Observation (when the learner observes the new experience and positions in accordance with his/her prior knowledge) and Active Experimentation (when the learner puts his or her newly acquired or expanded knowledge into practice).

<table>
<tr><th>Dimension</th><th>Pole</th><th>Learning style</th></tr>
<tr><td rowspan="2">Grasping / Prehension</td><td>Concrete Experience (CE)</td><td rowspan="4">Diverging (CE/RO)
Assimilating (AC/RO)
Converging (AC/AE)
Accommodating (AC/AE)</td></tr>
<tr><td>Abstract Conceptualization (AC)</td></tr>
<tr><td rowspan="2">Transforming / Processing</td><td>Reflective Observation (RO)</td></tr>
<tr><td>Active Experimentation (AE)</td></tr>
</table>

Table 4.6: Kolb Learning Style Model

Kolb proposed a four-stage hypothetical learning cycle and claimed that these four stages are interrelated, with each one leading to the following. He assumed that we can enter the learning cycle at any stage and learners will show a preference for some phases more than others. A learner can start with direct experience and makes it specific or of an abstract experience (AC/CE). Then these experiences (concrete or abstract) are transformed into knowledge when we reflect and think about them or when we experiment an active form of the received information (RO/AE).

For instance, student A goes through a concrete situation and accumulates experience (CE), this leads him to make some observations and reflections about the situation (RO), later on he will build abstract concepts and theories to explain these observations (AC), which he can actively experiment and validate to make decisions or resolve problems (AE). Once the circle is complete the learning outcome leads to the construction of new experiences which triggers the cycle of learning all over again *(see Figure 4.**4**)*.

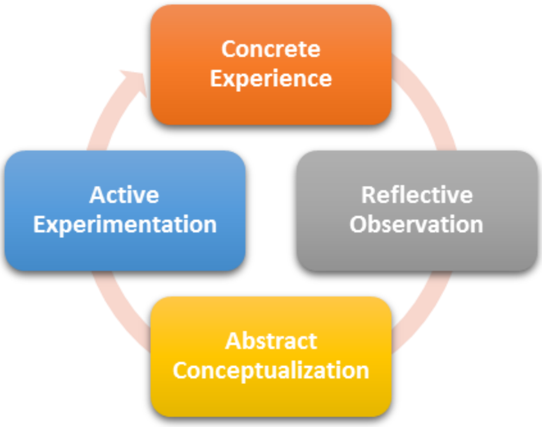

Figure 4.4: The Experimental Learning Theory learning cycle

In order to assess an individual's preferred modes of learning, Kolb elaborated a forced-choice ranking questionnaire that the subject has to complete, named the Kolb's Learning Style Inventory. It evaluates the individual's abilities throughout two spectrums: concrete experience to abstract conceptualization, and active experimentation to reflective observation. The first version of the LSI appeared in 1976, and it was revised several times (1985, 1999, and 2011) (Kolb and Kolb, 2013).

4.3.6 Honey and Mumford's Model

LS family: Flexibly stable learning preferences

Grounded in Kolb's theory, Honey and Mumford learning style model describes learning styles as behaviors and attitudes that determine individual learning preferences (Knight, 1983; Honey and Mumford, 2000). They claim that people learn in the same way as experimental scientists conduct research and that learners' learning styles differ according to the phases of the learning process which they are best at. Despite the fact that their theory also relies on the steps of the experiment process, it doesn't assume the establishment of bipolar dimensions, as is the case with Kolb.

The authors refer to the learning styles with four stages and considers that learners should become proficient in all of them *(see Figure 4.5)*: Activists (i.e. individuals who approve experiencing); Reflectors (i.e. individuals who rather reviewing experiences or pondering over facts); Theorists (i.e. individuals who favor reasoning); and pragmatists (i.e. individuals who prefer planning the next steps).

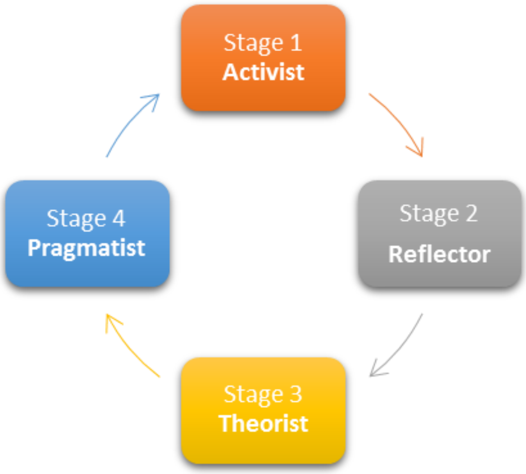

Figure 4.5: Honey & Mumford learning cycle

In order to assess an individual's learning style, Honey and Mumford Learning Style Questionnaire was developed. It consists of 80 items with true/false answers, that probe preferences for four learning styles, with 20 items for each style.

4.3.7 Entwistle's Approaches to Learning and Studying Inventory

LS family: Learning approaches and strategies

Noel Entwistle, a researcher in the field of educational psychology, and his colleagues developed a "teaching-learning process" experimental model in order to guide institutions to undertake a process of critical reflection on their adopted methods with the intention of reforming the whole learning environment to enhance the student learning quality (N. Entwistle 1990). This model intends to encompass the problematic influence structure that links motivation, academic performance and learning approaches with the indirect effects of teaching and assessment methods. Furthermore, it aims to identify the students' tendencies to adopt deep, surface and strategic approaches to learning and studying.

Entwistle defined a strategy as the manner a learner chooses to confront a specific learning assignment in accordance with its observed requirements and a style as an extensive description of a learner's favored approach of dealing with learning tasks generally (Entwistle, Hanley and Hounsell, 1979). Moreover, he distinguishes three separate learners' personality types in higher education courses in conformity with studies on the effects of personality on learning: non-committers, hustlers and plungers. While the first category of learners tends to be thoughtful, anxious and riskaverse, the second one is composed of competitive, dynamic but insensitive students, and the third gathers sensitive, thoughtless and self-reliant ones.

The Approaches to Learning and Studying Inventory (ALSI) have been developed to evaluate learners' approaches to learning and their perceptions about the course organization and the teaching impact (N. J. Entwistle, McCune, and Tait 1997). It was derived from evaluations of other measures, namely, the Approaches to Studying Inventory (ASI-1981); the Course Perception Questionnaire (CPQ-1981); the Revised Approaches to Studying Inventory (RASI-1995) (N. Entwistle and McCune 2004); and the Approaches and Study Skills Inventory for Students (ASSIST-1997).

The complete version of the ALSI questionnaire uses a Likert technique to determine students' attitudes by rating a series of related items that deal with the aspects of a specific construct (deep, surface and strategic) on a five-point scale. It incorporates three parts: The first one is concerned with students' perceptions of learning; The second relates to their study practices; The third involves students' preferences for different kinds of teaching (N. Entwistle and Tait 2013).

4.4 DISCUSSION

This section defines the comparative summary of the selected most influential learning style models. The following table (see *Table 4.7*) summarizes this discussion and shows the learning style's model name, family, instrument, strengths, and weaknesses.

The ***Gregorc's Mind Styles Model*** relies on individuals' instinctive abilities of 'perception' and 'ordering'. While Gregorc states that his model has high levels of internal consistency and test-retest reliability, no evidence for his theoretical claim is provided and significant uncertainties were expressed about its psychometric properties in the literature. Concerning validity, moderate correlations are reported for criterion-related validity, but there is no empirical evidence for construct validity. Some of the words used in the instrument are unclear or may be unfamiliar to the end-users which makes it irrelevant for the assessment of individuals.

Even if the ***Riding Cognitive Style Model*** is known for its simplicity, it lacks empirical evidence and suffers from unresolved conceptual problems and serious difficulties with its instrument. Within this model, only cognitive aspects of thinking and learning are dealt with without taking into account the affective and conative ones. Moreover, learning styles are assumed to be fixed, and metacognitive training which might lead to learning styles alteration is not considered. The author hasn't provided any evidence about its reliability, while other studies have revealed that internal consistency and test-retest reliability are very poor. And finally, its pedagogical impact is questionable.

The ***Myer-Briggs Type Indicator Model*** was specifically designed as a tool to classify an individual's personality type in general, and their approaches to relationships with others. Some researchers in the learning styles field choose to exclude the MBTI on the grounds that its scope as a personality measure outweigh cognitive regulations and behavior specifically related to learning. Furthermore, victim of its own massive commercial success of the MBTI as style measurement instrument, some of the critical and experiential examinations done with it are superficial and neglectful. That's why the research evidence to advocate it as an effective style evaluation and pedagogical support is still unconvincing. On the one hand, there has been considerable debate about the construct validity of the MBTI and the irrelevant forced-choice format of the instrument. On the other hand, the stability of the MBTI types allocations is open to question in part because the middle scores are prone to misinterpretation due to small numerical differences. Finally, the practical application of MBTI in pedagogy is still ambiguous as there is no evident perception of how type dynamics impact on education.

The ***Felder-Silverman Learning Styles Model*** beneficiates from a considerable amount of available literature and has been frequently used by educators in different disciplines for providing adaptivity regarding learning styles in e-learning environments as it provides a detailed description of the different dimensions of the learner's style and taking into account inclinations on four measurements. Moreover, its instrument, the ILS, has undergone multiple studies according to the literature and has proved to be user-friendly and effective for instruction and assessment design in accordance with the learners' learning styles because the results are easy to interpret, and because the number of dimensions is controlled and can, in fact, be implemented. Even if there is no full consensus on studies results, they have shown satisfactory convergent and discriminant validity, scarce reliability, and satisfactory consistency.

The ***Kolb's Experiential Learning Theory*** is one of the first learning style models, based on an explicit theory, that engaged a tremendous international literature dedicated to its examination. However, Kolb disrecommends the use of its instrument, the LSI, for individual selection purposes as it cannot measure individuals with thorough precision. Moreover, the psychometric properties of the LSI have been the subject of criticism, and there is no unequivocal evidence in the literature that shows that it enhances academic performance. Although the LSI beneficiated from the critique to improve the reliability of the instrument, the test-retest reliability suggests that the LSI is rather volatile and the reliability coefficients for the four basic scales are not (enough) satisfactory.

While ***Honey and Mumford's Model*** can be used for personal development by drawing proposals to help individuals to fortify underexploited styles, studies prove it uselessness for individuals' selection on the basis of their learning styles as it exposes no enough distinctive scale scores to allow them to be categorized. Moreover, it labels individuals while most people show more than one strong style. And even if it has been extensively used in the professional field, it requires to be reformed to transcend shortcomings critics showed when evaluated by researchers and more proofs of its validity are essential in order to adopt it with confidence.

Entwistle' ***Approaches to Learning and Studying Inventory*** is an important aid for the discussion and diagnosis of the effective and ineffective strategies for learning in accordance with learners' actual approaches as a basis for redesigning instruction and assessment. However, the use of the instrument for adapting the pedagogic environment turned out to be difficult for non-specialists who lack an in-depth understanding of its underlying implications. The model has undergone extensive evaluation and the result showed satisfactory reliability and internal consistency but contested construct and predictive validity. Moreover, the external analysis confirmed the validity of the deep, surface and strategic approaches. All in all, this model needs to be redesigned, tested and revalidated for pedagogical interventions.

Model	Family	Instrument	Instrument mechanism	Strengths	Weaknesses
Gregorc	Constitutionally based learning styles and preferences	Gregorc Style Delineator (GSD)	Rank a set of items	✓ Considerable internal consistency ✓ High test-retest reliability ✓ Moderate criterion-related validity	× Poor psychometric properties. × Static learning styles × Undemonstrated construct validity × Theoretical evidence of the pedagogical impact × Irrelevant for the individuals' assessment
Riding	Cognitive structure	Cognitive Styles Analysis (CSA) (1991)	Select only one answer from two alternatives	✓ Simplicity ✓ Acceptable face validity	× Debatable conceptual issues × Weak internal consistency × Very low test-retest reliability × Questionable evidence of pedagogical impact × Unreliable instrument
MBTI	Stable personality types	Myers-Briggs Types Indicator (MBTI) (1962)	Likert scale question	✓ Provides a view of the whole personality ✓ High-reliability coefficients ✓ Approved face validity	× Not learning specific × Complicated relationships between elements and scales × Weak stability of the learning styles × Contestable construct validity × No proof of any beneficial outcomes concerning the pedagogical impact.
FSLSM	Flexibly stable learning preferences	Index of Learning Styles (ILS) (1996)	Select only one answer from two alternatives	✓ Learning specific ✓ Flexible and stable learning styles ✓ Detailed description of the	× Low predictive validity

				learning style of a learner ✓ Widespread use ✓ Satisfactory convergent and discriminant validity ✓ Scarce reliability ✓ Convenient for instruction individualization	
Kolb	Flexibly stable learning preferences	Learning Style Inventory (LSI) (1976) Revised Inventory (R-LSI) (1985) Learning Style Inventory-v3 (1999)	Rank a set of items	✓ Flexible and stable learning styles ✓ Reliable instrument ✓ Convenient for instruction individualization	× Unsuitable for individual selection × Deficient notion of a learning cycle × Doubtful psychometric properties × Controversial reliability × Disputed construct validity × Low predictive validity × Theoretically-based the pedagogical impact
H&M	Flexibly stable learning preferences	LS Questionnaire (LSQ) (1982)	Mark a set of items	✓ Learning specific ✓ Helpful for individuals to fortify an under-used style ✓ Instrument translated into dozens of languages	× Individuals labeling × Useless for assessment/selection × Very criticized model design × Moderate internal consistency × Speculative validity × No empirical evidence of pedagogical impact
Entwistle	Learning approaches and strategies	Approaches to Studying Inventory ***(1981)***	Rank a set of items	✓ Learning orientations assessment ✓ Course organization and	× Complex model × Instrument with limited accessibility

		Course Perception Questionnaire (1981) Revised Approaches to Studying Inventory (1995) Approaches and Study Skills Inventory for Students (1997) Approaches to Learning and Studying Inventory (2007)		instruction preferences evaluation ✓ Satisfactory reliability and internal consistency ✓ Confirmed validity of deep, surface and strategic approaches ✓ A basis for discussing the effective and ineffective strategies for learning ✓ A basis for redesigning instruction and assessment	× Requires in-depth understanding × Test-retest reliability is not demonstrated. × Contested construct and predictive validity × Difficulties to transform the learning environment in accordance with the instrument results × No empirical evidence for the pedagogical impact

Table 4.7: Learning styles models comparison

All the aforementioned things considered; the Felder-Silverman Learning style model reveals itself to be the most appropriate model for providing adaptivity and accurate instruction and assessment design in accordance with the learners' learning styles in e-learning environments.

Moreover, and according to the literature, Felder Silverman model turned out to be the most preferred model of learner style used in the learning theories and has been successfully implemented in many previous works when individually adapting the learning material. (Özyurt and Özyurt, 2015) within the scope of adaptive education systems, inspected 69 studied published from 2005 to 2014. The results revealed that the Felder-Silverman learning style model was the most preferred model (42%), followed by the Kolb model (14.5 %). In another work, (Truong, 2016) examined integrating learning styles in adaptive e-learning systems by reviewing 51 studies published from (2004 to 2014). The results of this study show that the Felder-Silverman learning style model was the most preferred model (70.6%), and then the VARK model (9.8%). In a more recent study, (Kumar, Amit; Ahuja, Neelu Jyothi;

Singh, 2018) investigated the researches on learning styles used in e-learning environments published between the years 2001 to 2016. y When these studies were classified by considering the used learning style, it has been observed that Felder Silverman model was the most preferred model of learner style used in the learning theories (n= 33; 46.67%), followed by Kolb model (n=14; 19.71).

4.5 SUMMARY

Through the review of learning style research, we found several models and assessment instruments that can be applied to university's education. Many of these have been adapted as online tests. The review shows that the Felder Silverman model is the most suitable for adaptive e-learning for the aforementioned and discussed reasons.

Future research and empirical studies will be done specifically to investigate the efficiency of these learning styles for optimal learning and teaching experience that leads to better learning outcomes. Moreover, all of the existing learning style instruments were built using only the textual form of information, which is considered more suitable for verbal learners than others. Consequently, and in order to increase the efficiency of the ILS instrument, we are thinking of constructing another form of the standard questionnaire that will be more convenient for a larger panel of users using the different forms of information. Furthermore, a future paper will be dedicated to how can we ideally detect learners' learning style in a hybrid manner by combining the use of the revised form of the questionnaire to initialize the model and automatic detection techniques to update it after each learning session.

All the aforementioned concepts are brought together in the next chapter in order to outline the design and implementation of our proposal of an AEHS that presents the course material in a customized way to each learner, based on his or her knowledge level, preferences and learning style.

Chapter 5: Design and Implementation of the Proposed AEHS

5.1 INTRODUCTION

Throughout the previous chapters, we have conducted an in-depth study on the different aspects and elements of the educational field and analyzed the different models of our system in order to the design and implementation of an improved dynamic adaptive hypermedia system.

The design of our proposal of an AEHS relies on the incorporation of components that answer three main questions (*see Figure 5.**1***): What do we adapt? To whom do we adapt? And how can we adapt?

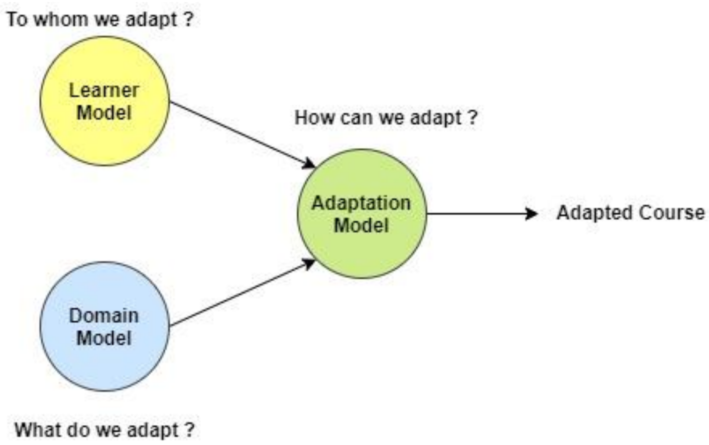

Figure 5.1: An abstract architectural representation of AEHS

The objective of this chapter is to bring together all the aforementioned concepts with the aim of providing a system which presents the course material in a customized way to each learner, based on his or her knowledge level, preferences and learning style. Moreover, this chapter deals with the realization of the system, by presenting the prototype produced which consists of the implementation of some components of the AEHS.

In the following, the methodological choices, the analysis and the proposed design based on the UML language for the development of our environment are presented. Then, the technological choices are explained and defended. Finally, the implementation of the different modules is depicted.

5.2 METHODOLOGY

We analyzed and designed the e-learning system taking into consideration all theoretical foundations aforementioned. First, we started by describing the different roles of the actors involved in the learning process. In a second step, we conceptually fixed the functionalities specified according to the models of our architecture defined above. We have started an in-depth description of the learner model, which is the main component of our environment. Then, we detailed our proposal for the domain model.

Finally, we tried to implement the architecture obtained, and we created a module, for each topic:

- Evaluating the learner's learning style and retrieving his presentation preferences.
- Creating a course with specific structure and teaching material (i.e. learning objects, evaluation objects, etc.).
- Matching the course content with the corresponding learner profile.

The system implemented use dynamic objects to allow presenting the content of a course according to the preferences of the person who uses it.

5.3 MODELING AND ANALYSIS REQUIREMENTS

Case modeling can show how the system works. A number of diagrams are presented showing how actors interact with the system, as well as the use cases which are explained in more detail, illustrating how they communicate with each other use cases.

This part also gives a global description of the different class diagrams, as well as the attributes and methods that make it up. Also shown is an activity diagram that help to understand how the classes interact with each other when a user performs an action on the system.

5.3.1 System actors

The descriptions of the actors are exposed in the following (*see Figure 5.2*):

- **Authenticated user**

When a user logs in, he is automatically assigned the role of authenticated user. A user will have additional roles as well as the authenticated user role according to the authorizations granted to his profile. By default, authenticated users have permission to edit their own profile, send messages.

- **Learner**

When learners first join the system, they see all available courses so he can select one or more to enroll in. Once he has subscribed or been enrolled into a course, a user with the learner role can participate in the related activities and view resources but he is not allowed to alter them. He can view his own marks if the teacher has allowed this. A learner's view and navigation in the system will be different from the course teacher's or from the other learners. Teachers determine how a student enrolls, and what they can do or see in the platform.

- **Non-editing teacher**

A non-editing teacher is able within a course to view, track and grade learner' work, but may not alter or delete any of the activities or resources. This role allows teachers who required support from a course creator to validate the realized course.

- **Course creator**

A user assigned the role of course creator can create a course, add activities and manage learning and evaluation objects. The role of course creator could typically be assigned to a technician that would assist the non-editing teacher when creating the course.

- **Teacher**

Teachers can do almost anything within a course, including adding or changing the activities and tracking and grading students. They have a combination of non-editing teacher and course creator privileges.

- **Administrator**

The administrator has authorizations to do anything. He has the technical skills for managing the system (setting up the system, updating accounts, etc.). The primary administrator cannot be removed from the site administrator role.

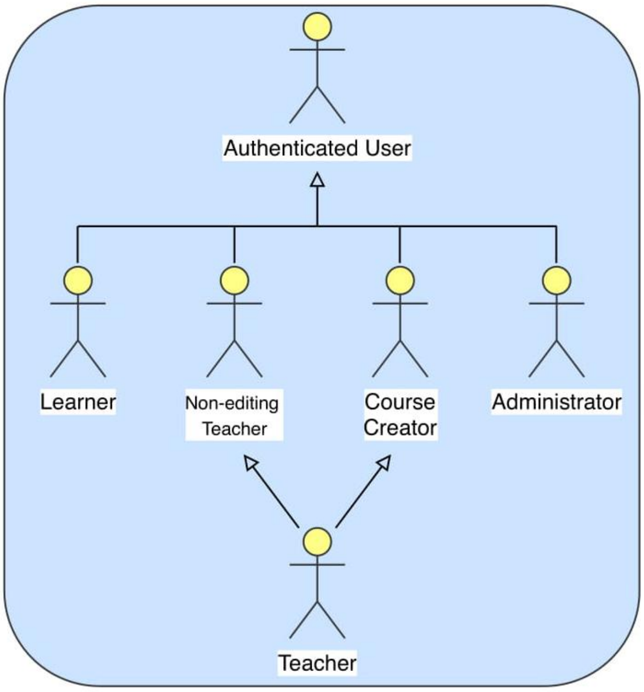

Figure 5.2: System actors

5.3.2 Use cases models

A use case is a way to use the system and is represented by an ellipse. An actor represents a role performed by a real person and is represented by the figure of a person. The lines show how to relate the different use cases and actors.

The description of the user's use cases (*see Figure 5.***3**) is shown below:

- *Subscribe:* Allow a user to register by filling a registration form.
- *Choose a role:* the authenticated user choses a role between learner, teacher, non-editing teacher and course creator. This role is subject to validation.

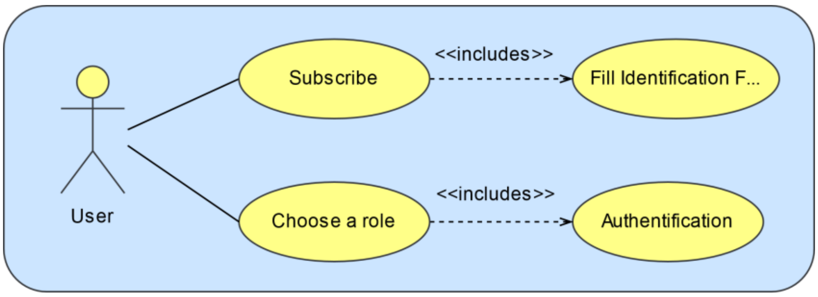

Figure 5.3:User's use case diagram

The description of the learner's use cases (*see Figure 5.4*) is shown below:

- *Fill LS Questionnaire:* Allow the user to take a test Felder learning styles to identify and save the different dimensions of his learning style.
- *Set Presentation Preferences:* Provide learners with several options to allow them to customize their interfaces.
- *Choose a Course:* Allow a learner to enroll in an available course.
- *Start Learning Session:* Allow the learner to start a learning session in a chosen course and access the corresponding learning objects.
- *Sit for a Test:* Allow the learner to sit for a test. It can be a pretest that any learner must take in beginning of a course to instantiate his knowledge level, an exam to assess the outcome at the end of the course, or simply a posttest that he must validate at the end of a chapter before getting into the next one.
- *Access Collaboration Tools:* Provide a variety of tools to learners already registered to ask for help or to interact and cooperate with other learners.

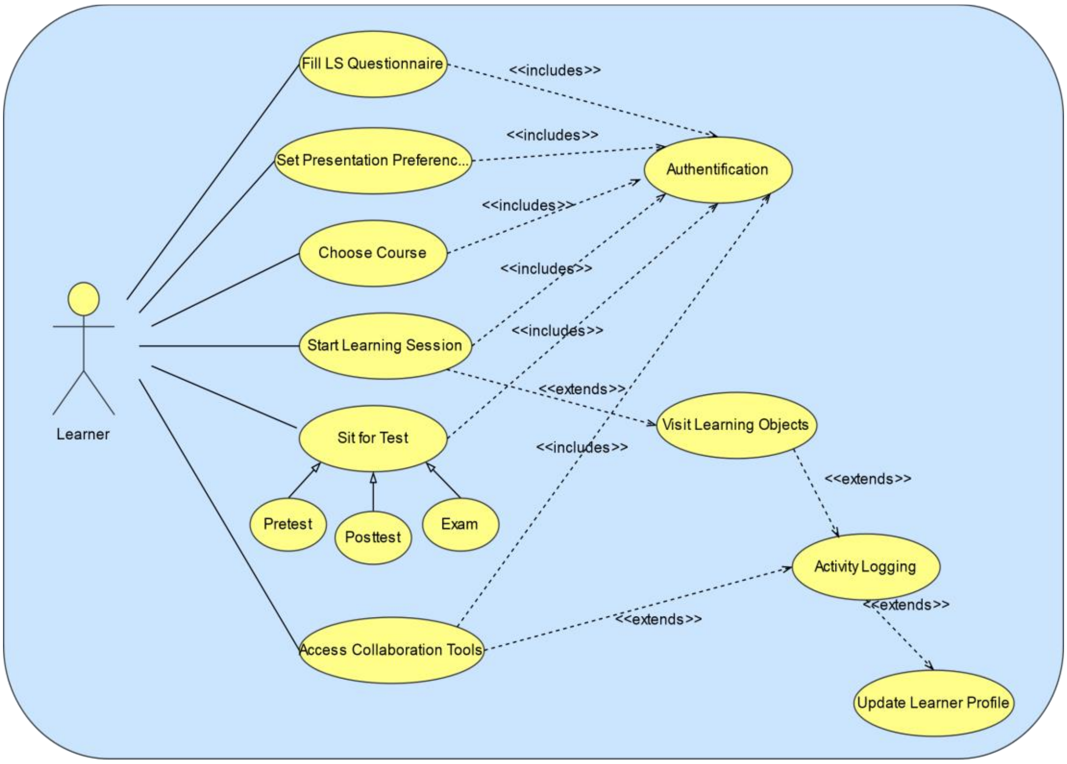

Figure 5.4: Learner's use case diagram

The description of the course creator's use cases (*see Figure 5.5*)is shown below:

- *Create Course:* Create a course and assign it a unique identifier, title and description.
- *Create Learning Object:* Provide a variety of options to students already registered to use the system of individualized instruction.
- *Create Evaluation Object:* Create evaluation object such as single-choice or multiple-choice question.
- *Create/Manage Media:* Allow the association of media resources which are in text or multimedia form, previously stored in the resource database, with the corresponding learning/evaluation object.
- *Define Course Structure:* Define the relations between all the learning objects and evaluation object of a course.
- *Define Pedagogical Rules:* Define the guidelines describing the method to achieve a specific objective, taking into account the cognitive level of the learner for each concept.

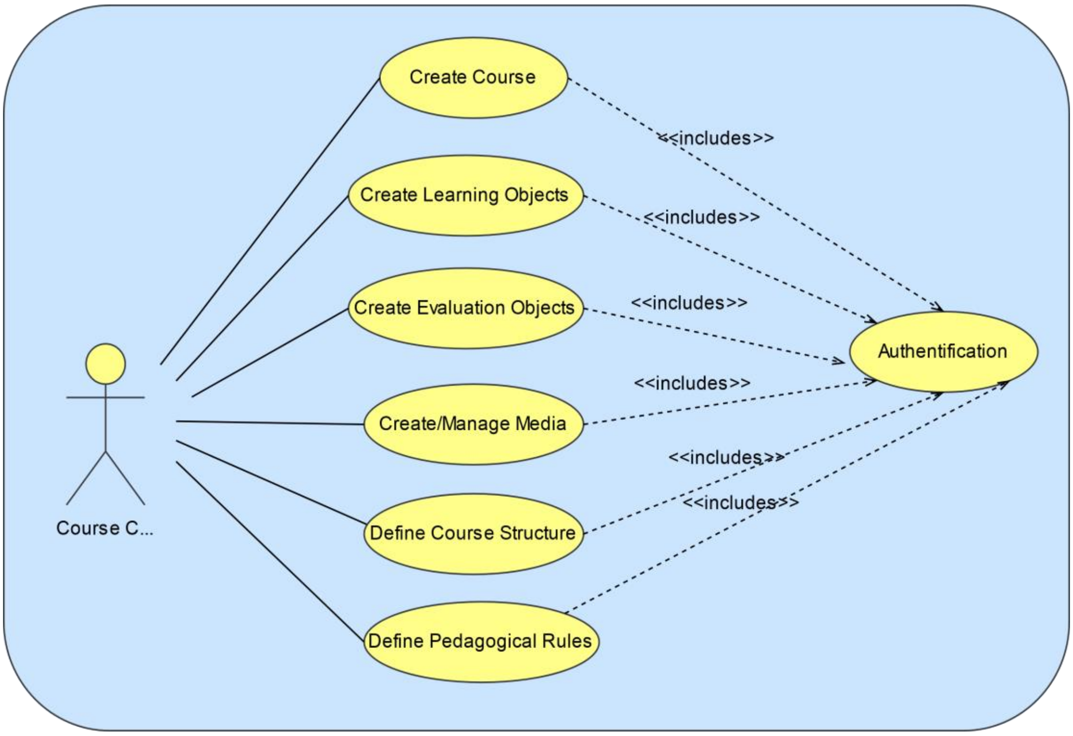

Figure 5.5:Couse creator's use case diagram

The description of the non-editing teacher's use cases (*see Figure 5.6*) is shown below:

- *Validate Learner:* Validate the enrollment of a learner in the course.

- *Validate Course, Validate Learning Object, Validate Evaluation Object, Validate Media, Validate Course Structure, Validate Pedagogical Rules:* Allow the evaluation of the produced content via a sequence of test and validation operations, during which he can validate the version or suggest changes to all the design phases in order to ensure its proper functioning.
- *Track Learners Progress:* Allow to ensure educational activities monitoring of a learner or group of learners such as, giving answers to learners' questions, analyzing progress, developing personalized advice, etc.
- *Use Collaboration Tool:* Allow the teacher to communicate with the learners in order to provide them with further explanations or instructions.
- *Enroll Students:* Allow enrolling a learner or a group of learners in the course.

Figure 5.6: Non-editing Teacher use case diagram

The teacher’s use cases are not described as the role of the teacher is a combination of the non-editing teacher and course creator roles.

5.3.3 Class diagrams

Following the design ideas discussed in the previous sections, we developed the different models using the UML2 class diagrams.

5.3.3.1 Learner model class diagram

After the studies that we carried out and detailed previously, we developed our design of the learner model which integrates the seven facets using the class diagram UML2. In this diagram we have used different colors to facilitate the distinction between the different facets of our model (*see Figure 5.7*).

First of all, our learner is user, which means that he inherits all his attributes and properties. These attributes (i.e. first name, username, email, address, etc.) will be used in order to instantiate the learning independent characteristics of the learner.

A learner can hold many qualifications or certifications that we referred to in our model with the class "QCL" and can be affiliated many organization ("Affiliation class"). Furthermore, he can have or acquire many competencies. Moreover, a learner has one or many learning goals that which achievement will be the purpose of the learning sessions. He can subscribe in several courses and, consequently, can engage in learning activities; learning activities data will be used to update his knowledge level in a definite domain.

A Learner can have accessibility preferences and psychological features that will be described in the following.

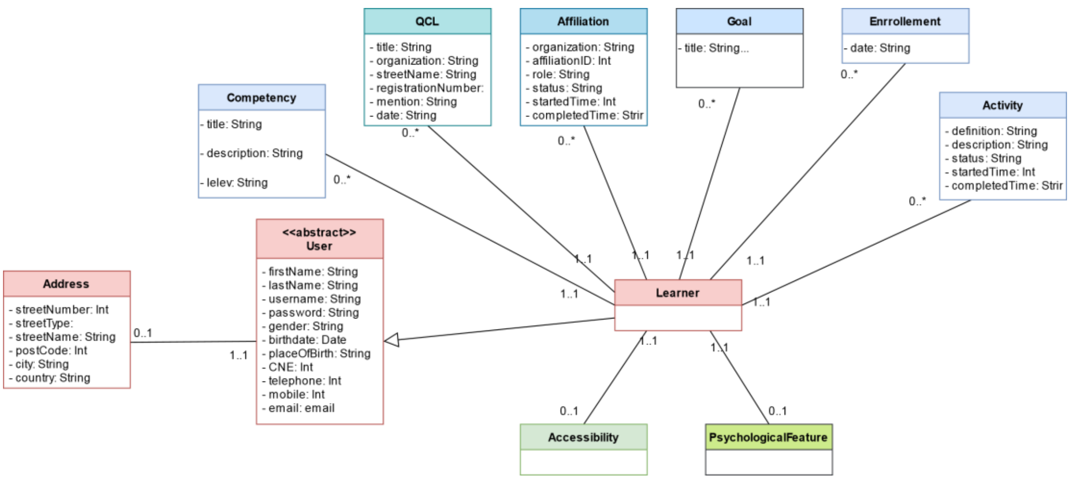

Figure 5.7: Learner Model class diagram

- Accessibility facet (*see Figure 5.**8***):

A learner can master one or more languages. Thus, the system will allow him to view the course material in his preferred one. Moreover, he can customize his interface by configuring one or more themes and consequently the system will automatically display the course pages depending on many factors such as the chosen theme, the daytime, the connection speed and the equipment with which he connects to the platform.

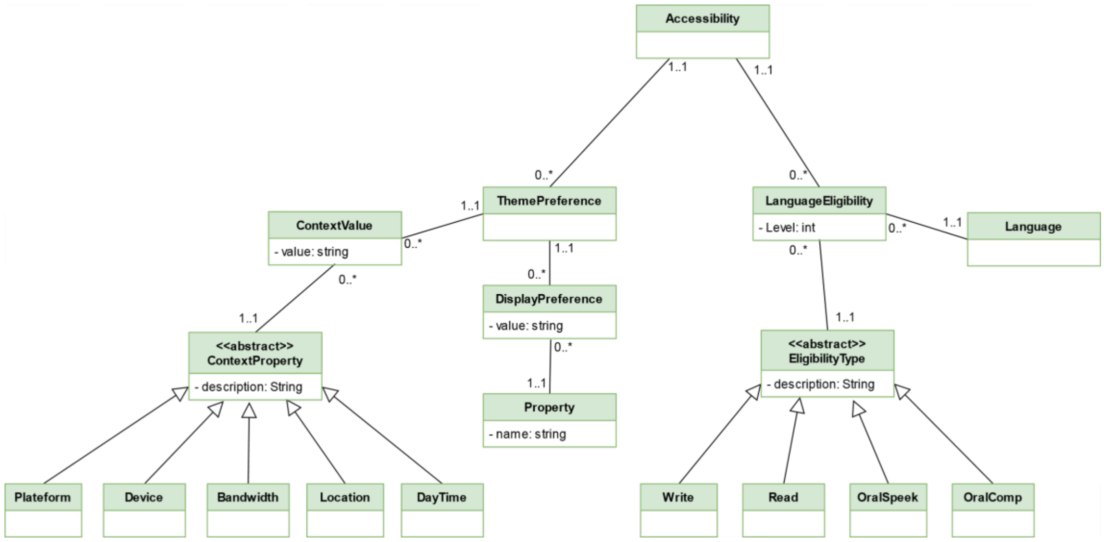

Figure 5.8: Detailed accessibility facet

- Psychological Feature facet (see *Figure 5.**9***):

Another important facet of the learner is the one dealing with the psychological features. A learner will be assigned a learning style according to the Felder-Silverman Learning Style Model, as well as an affective state, cognitive abilities and metacognitive skills. These psychological features will serve as a solid background to accurately adapt the presentation of activities' learning material.

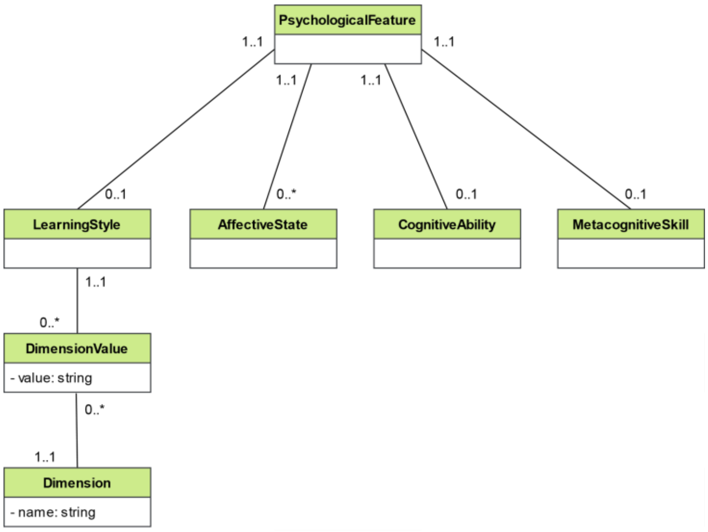

Figure 5.9: Detailed Psychological Feature facet

5.3.3.2 Domain Model class diagram

The domain model contains and represents learning material in a way that facilitates the process of recommendation and adaptation when using the system. The figure (*see Figure 5.***10**) depicts the domain model that is represented as a class diagram.

The class HyperDoc represents the course which is the root of the domain model structure. In this context, a course is made up of a series of chapters, each of which deals exclusively with one particular division of the course. Respectively every chapter is composed of one or more sections, each of which deals with a specific subject of the course (i.e. definition, exercise, etc.).

Each section contains a set of knowledge objects (KOs) that classified primarily as basic, intermediate or advanced, with each category determining its appropriateness for learners according to knowledge levels. These KOs incorporate metadata and references that allow to describe the main characteristics and can be either a learning object (LO) or an evaluation object (EO).

Each LO is a small fragment of content that can designate a practical work (PW) or an explanation of a concept in different formats (i.e. text, audio, video, etc.). It can be can be of different levels of difficulty and can have mandatory and optional prerequisite LOs. While EOs refer to questions such as single-choice, multi-choice or cloze question and are part of an evaluation of the course that can be a pretest, an exercise or exam.

A learner can enroll in several courses and can start a learning activity which consists in visiting one or more KOs during a period of time that would be recorded for adaptation purposes.

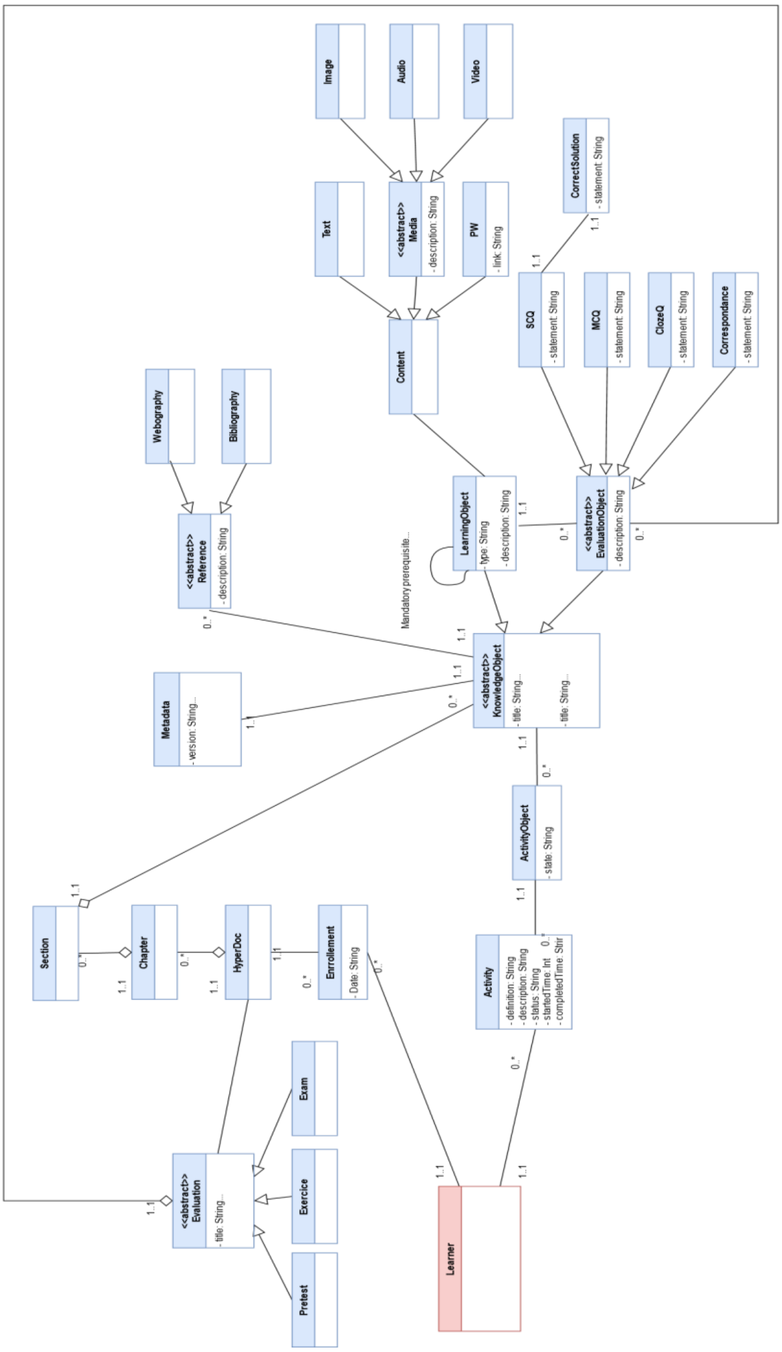

Figure 5.10: Domain Model class diagram

5.3.4 Activity Diagram

The following activity diagram (*see Figure 5.11*) presents course operation and operating tasks.

Once a course project initiated, the course creator will create the course (i.e. title, description, etc.). Then, he will construct the learning objects and the evaluation objects. Next, he will upload the created corresponding media and define the course structure and the pedagogical rules. Afterwards, his work will be subject of validation by the non-editing teacher before the publication of the course. These tasks might be done by only one user if he has the teacher role.

As soon as the course is created and validated, the course will be published on the platform. The next task will be learners' enrollment or the validation of learners subscribed before they can start learning.

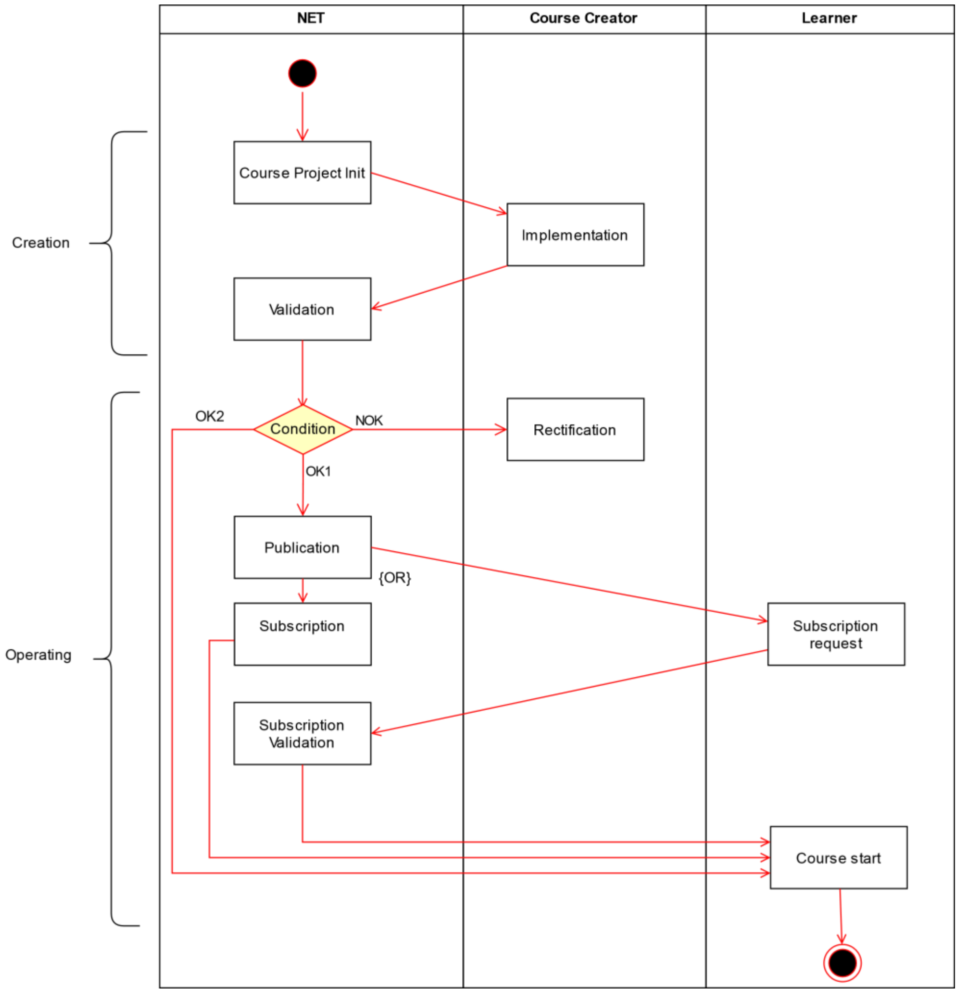

Figure 5.11: Course creation and operating activity diagram

5.3.5 Scenario

The use scenario describes the actions and reactions between the system and the learner (see *Figure 5.**12***).

When a first-time user accesses the platform, he is asked to register and fill a form about the personal information (name, demographics, contact info…), password, qualifications, and interests. Then he is invited to respond to a set of psychologically-oriented questions in order to determine his psychological features such as his learning style and cognitive abilities and adjust his preferences settings via a menu of options to customize the presentation.

Once done, and whether the learner has just completed registration or already has an account and has just logged in, he is requested to define his learning goal and sets for placement pretest to evaluate his knowledge on the field before accessing the course. The system initializes the learner’s knowledge about this field and assigns him a level according to the result of this pretest.

Relying on the previously cited collected information, the system goes on gathering the appropriate course via selecting and combining relevant learning concepts as well as presenting them in a customized way to build the learning activity.

Hence, the learner starts the adapted learning activity that might contain sub-activities and evaluation tasks. Finally, when the course learning activities are completed and all the sub-goals are achieved, the goal is reached and the competency is mastered.

During learning sessions, the system infers data from learner interactions and assessments and updates learner’s information.

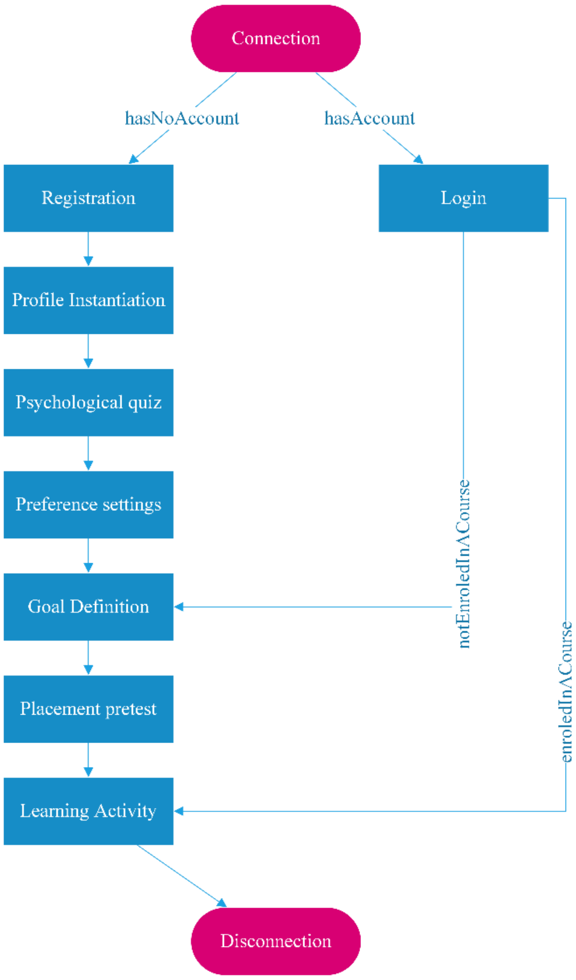

Figure 5.12 : First connection to the platform scenario

5.4 REALIZATION OF THE PLATFORM

5.4.1 Study of needs and technological choices

Developers of dynamic web applications have been using the LAMP open-source tool stack (consisting of the Linux Operating System, the Apache Web Server, MySQL as a database and PHP as the scripting language) for some time. However, a new tool stack for web-application development has emerged over the last few years — known as the MEAN Stack.

MEAN takes its names from the four tools that together provide both client & server-side components for interactive web applications: MongoDB which provides the object-database; Express.js which provides a framework for web routing; Angular.js for web applications; and Node.js — the JavaScript engine, and web server component.

All four of these tools are based around the JavaScript language — which although initially developed for client-side web programming has entered into common usage for server-side programming, thanks in large part to environments such as Node.js.

5.4.1.1 Node.js

Although canonically listed last when referring to MEAN, Node.js (or just Node) is the most important tool of the stack. Built around Google's V8 JavaScript engine, and implemented in C++; Node provides a high-performance, asynchronous event-based server. Node can be used to build a lightweight and high-performance web server environment, ideal for constructing web-service APIs.

5.4.1.2 Express.js

Express.js builds on the underlying capability of Node, by providing a web application server framework. This framework provides a wrapper around a lower-level Node interface: giving the developer, a convenient means to handle routing and HTTP operations (such as GET and POST). Express.js facilitates a simplified and more elegant solution than implementing these services directly using Node.

5.4.1.3 MongoDB

The majority of web-services will require some sort of storage: often in the form of a database management system. Whilst traditionally that might have been provided using an SQL-based Relational Database Management System (such as MySQL or SQLServer) there is a growing trend to use a NoSQL type of database. NoSQL databases can be used to provide a more flexible "document-oriented database" with a dynamic schema.

MongoDB is a high-performance NoSQL database built around the JSON data format and as such is ideally suited to server-side JavaScript environments such as those provided by Node.

5.4.1.4 Angular

The last part of the MEAN stack is Angular. Angular is an open-source web application framework, maintained by Google, which provides a client-side framework for MVC (Model-View-Controller) single page web applications.

To gain the maximum benefit from Angular, it was combined with Bootstrap. Bootstrap is a popular Open-Source CSS framework, which is described as "...the most popular HTML, CSS, and JS framework for developing responsive, mobile first projects on the web". Bootstrap provides elegantly designed CSS elements, making it easy to design web content with a clean, modern look. Together, the combination of these tools with the under-lying logic implemented with Angular, make it very easy to create a powerful and richly designed web application, which can consume the web-services provided by the other tools in the stack.

5.4.2 Implementation

Most AEHS today have been implemented as prototypes. Their development is generally carried out on an ad hoc basis and improved in successive stages.

AEHS are complex systems and therefore require an appropriate software engineering process. As far as we know, there is currently no systematic engineering process that describes how an AEHS should be implemented.

AEHS are complex systems characterized by the presence of a very rich multimedia material, the creation of the structure of the navigation links and an aesthetic graphic design. These constraints require a great effort involving different activities related in particular to obtaining learning and evaluation objects with all the problems related to copyright, etc. We can mention as examples the scanning of text, images and videos, recording of audio, adjustment of the quality of the parts obtained, etc.

To all this, we must add the efforts linked to the adaptability of the content, presentation and navigation. In addition, as we saw in the previous chapters, adaptability and individualization depend closely on the modeling of the learner, that is to say the construction, maintenance and use of this model to offer adjusted and customized courses.

We have chosen the module of electrical engineering, taught at the higher school of technology in Fez, as a learning area. This choice is not arbitrary. Thus, as specified above, our research work also consists in the implementation of a remote laboratory platform aimed at providing distant access to the laboratory equipments. For some years the electrical engineering department has faced a problem mainly due to the mass of students compared to the available equipment. Hence a strong need was expressed for a remote solution that would support hands-on practical work (PW).

We have chosen to implement our platform in terms of independent software modules. The first module deals with the learner model and aims at creating learners' profile by evaluating the learner's learning style and retrieving his presentation preferences. The second tackles the issue of creating courses with specific structure and teaching material (i.e. learning objects, evaluation objects, etc.) (*see Figure 5.**13** and Figure 5.**14***). And the third, copes with adaptation issues by matching the course content with the corresponding learner profile (*see Figure 5.**15**, Figure 5.**16** and Figure 5.**17***).

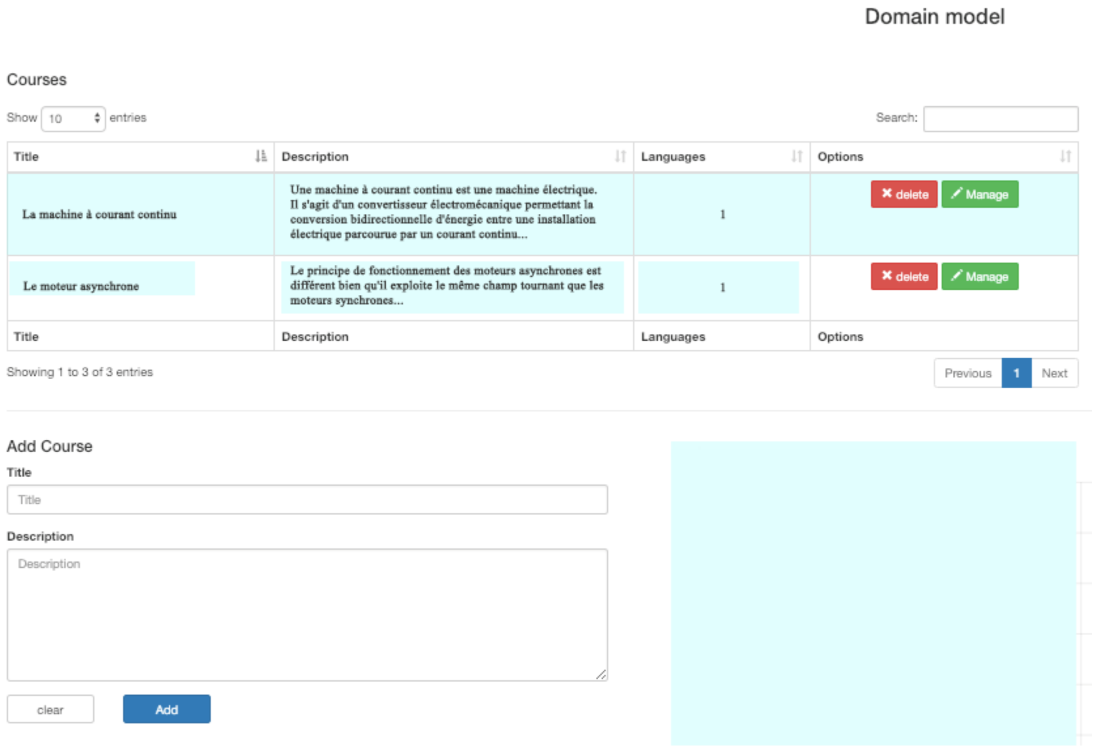

Figure 5.13: Course creator module screenshot (course creation)

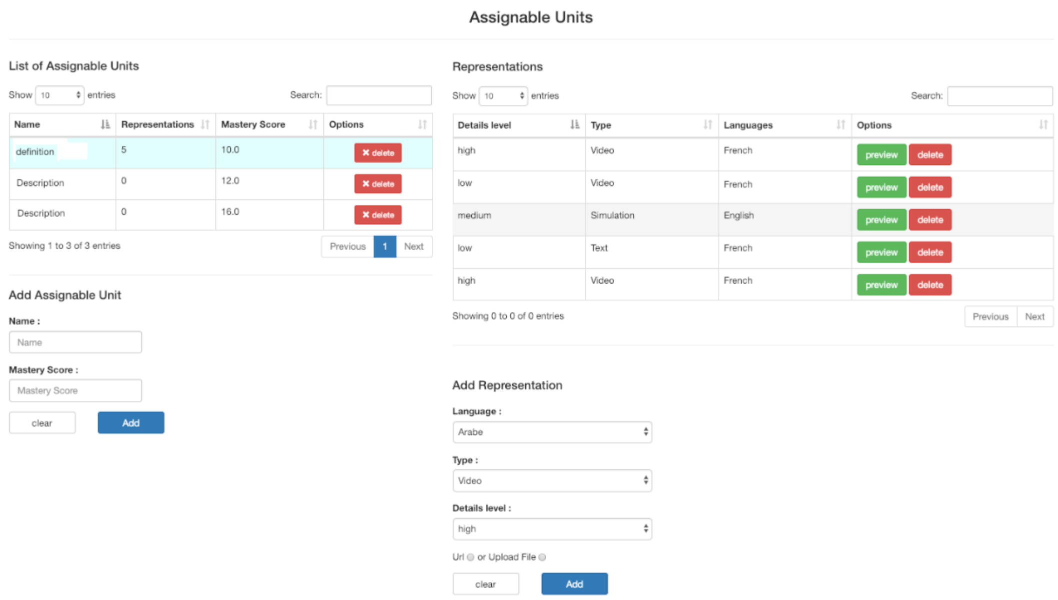

Figure 5.14: Course Creator screenshot (LOs creation)

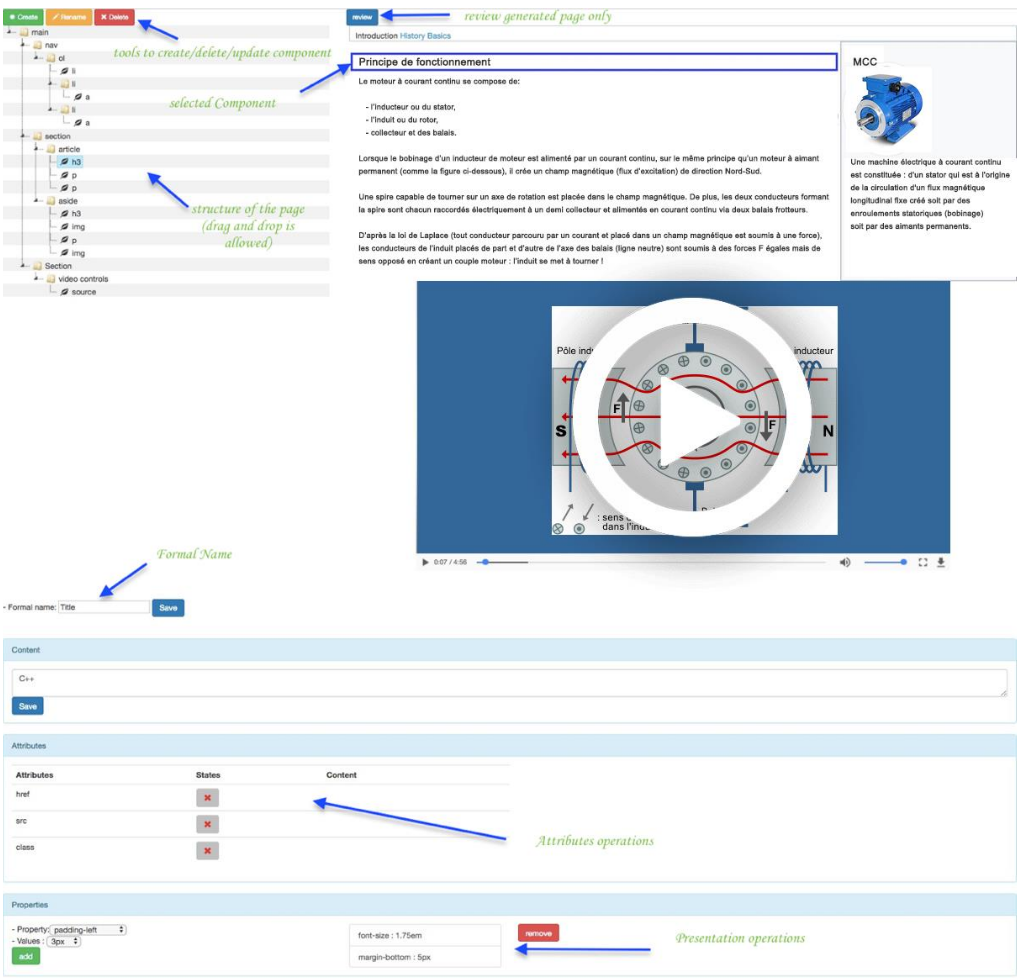

Figure 5.15:An example of a course page before adaptation

Figure 5.16: The same course page presented to a learner prefering text

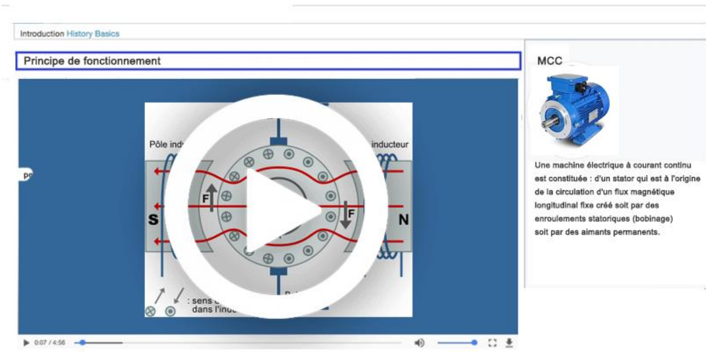

Figure 5.17: The same course page presented to a learner preferring video

Finally, and as aforementioned, our proposed learner model has a facet called Activity where we record and track all types of learning activities. We have chosen to implement the logging with the experience API (xAPI), which is a new specification for online training software capable of recording and tracking all types of learning experiences.

We have used the "xAPI reporting data model" which is the main part of this specification. It describes the structure and properties of the 'Statement' (log) for all types of learner experiences and events. The xAPI data model takes the form: "Actor + Verb + Activity + Additional properties" (*see Figure 5.**18***).

That grants better semantics and allows interoperability with other systems. In other words, if we decide to upgrade or to change our learner model or if a learner start to learn in another platform, the stored and logged historical data still could be used.

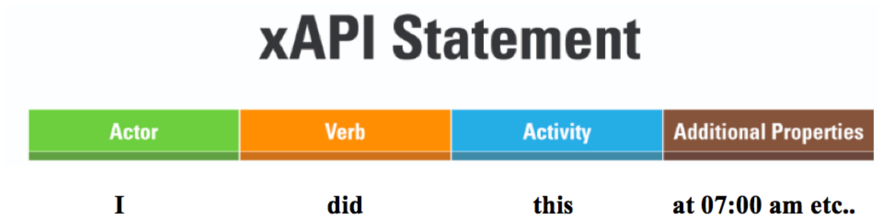

Figure 5.18: XAPI data structure

5.5 SUMMARY

In this chapter, we presented our proposed design and outlined the implementation of some modules of the AEHS. Subsequently, we carried out a global analysis of our system, in which we presented the architecture of our system as well as the actors and the different use cases.

We then started designing the different modules that make up our system, namely the learner model and the domain model. For the learner model, we have chosen to design a model open to modification and visualization. This model, as we have seen, is structured in seven facets covering the static and dynamic characteristics of a learner. Each of these facts covers a specific aspect of the learner. The design of the domain model is flexible enough to accommodate material related to any application domain or course. The structure of the domain model has four levels: course, chapter, section, and KOs that can be LOs for learning tasks and EOs for evaluation purposes. The adaptation model is not a major part of this research, and no significant contribution is claimed in this regard. It is acknowledged that the representation of the adaptation model is similar to the many adaptive e-learning systems.

We implemented 3 modules, each one dedicated to an already definite task. The first one deals with the learner model and thus, is used to retrieve learners' different characteristics and presentation preferences. The second can be used to create a course, define its structure and add the various corresponding knowledge objects. The third one retrieves learners' presentation preferences to accurately adapt each page of the course. Moreover, we implemented the logging with the experience API (xAPI), that grants better semantics and allows interoperability with other systems.

Finally, we choose electrical engineering as the learning domain. In the following, we will present our proposal for a practical platform for remote work that has been named SEITI RMLab.

Chapter 6: Design and Implementation of a Remote Measurement laboratory in electrical engineering

6.1 INTRODUCTION

Practical work remains a considerable handicap in engineering courses as these last insist upon dealing with real instruments. Unfortunately, these instruments are only available on a restricted schedule and might be unaffordable for institutions with a humble budget. Moreover, the unavailability of didactic online laboratories in engineering education delays the setting up of e-classes. So, the need is obvious for interactive platforms to enhance the availability of the laboratories and regulate the workload for each student.

Remote labs are educational materials that go further than virtual labs, based only on simulations, and grant distance access to laboratory equipments through the Internet, and allowing their configuration, supervision and measurement retrieval (Rodriguez-Andina, Gomes and Bogosyan, 2010).

This chapter presents a platform for an efficient and cost-effective remote measurement laboratory in electrical engineering with an ergonomic and practical interface to ensure better dissemination and integration of educational content and to reproduce, as closely as possible, the system that should be handled. It aims to present all the necessary steps for the modeling of a remote laboratory (expression of needs, formulation of objectives, definition of pedagogical contents and environments) and tools.

The first section reviews the objectives and scope of different RLs available in the literature. Then, a comparison of the different types of laboratories is provided. The following section outlines the motive behind the creation of RLs in electrical engineering. Next, a detailed review of the first version of the RL of our remote laboratory that we named after our research team (Team SEITI) is presented. Thereafter, the improvements that we intended to bring to the project are listed thoroughly and the realization of the improved version of the RL is presented in details. The last section presents the results obtained after the assessment of the outcome of the platform.

6.2 RELATED WORKS

Nowadays, a lot of institutions are developing and using their own solutions of online laboratories. Many initiatives emerge in the literature to provide shareable experiences. While some of them are remote laboratories, the others stand for repositories or indexation systems with functionalities like advanced searching tools, booking systems, recommendation system and multiple parameters filtering mechanisms.

In the following, review the objectives and scope of some representative projects.

6.2.1 Online Laboratories

- *ISILab* (Internet Shared Instrumentation Laboratory): Developed at the University of Genoa and based on a modular system named ISIBoard, it authorizes real experiments execution and manages concurrency among users who remotely drive instruments and carry out experiments of scalable complexity that deal with basic electronic measurements via the Web, but only allows users to conduct practical work with predefined experiments (Chirico, Scapolla and Bagnasco, 2005).
- *RwmLab* (Remote Wiring and Measurement Laboratory): developed by The Western Michigan University, is an easily replicable, fully reusable, and highly flexible remote lab for teaching electronics to undergraduate students that addresses real-time remote wiring of electrical and electronic circuits. It allows students to remotely connect instruments, change their settings, and retrieve real measurement over the Internet instead of using simulated data. RwmLab behaves as a local multi-circuit board on a common distributed panel, allowing to "physically" wire an electronic circuit in the laboratory over the Internet. The measures obtained remotely match the ones collected in the conventional, which allows students to achieve, check, or complement their practical work assignments at home (Asumadu *et al.*, 2005).
- *NetLab*: developed at the University of South Australia, is an online remote laboratory project that uses a circuit builder to allow remote electronic circuits wiring and measurement. It is used by teachers and tutors for demonstrations during lectures, and offers to students a mean for conducting their experiments remotely on real laboratory equipment. It gives the user the impression of conducting hands-on experiments through its realistic graphical user interface

that incorporates buttons and knobs behaving like they would on real equipments (Nedic and Machotka, 2007).

- *iLAB* is a multidisciplinary lab, developed by The Massachusetts Institute of Technology in collaboration with Microsoft Research, that implement a highly extensible environment that could serve a potentially infinite number of users and online laboratories. It provides a framework that can support access to experiments that can be rigorously defined before execution starts, or in which the student can customize the procedure of the experiment in real time (Harward *et al.*, 2008).
- *iSES* (the Internet School Experimental System): led by the Charles University in Prague, is an open remote laboratory system that allows the simple construction of remote experiments via paste and copy approach of pre-built typical blocks. It uses a basic ISES hardware and ISESWIN and ISES WEB Control kit as software for control and data transfer and supports real-time remote data acquisition, data processing and control of experiments (Schauer *et al.*, 2008).
- *PEMCWebLab*: led by the Brno University of Technology and funded by the European Community via the Leonardo da Vinci 2006 programme, is remote controlled laboratory for experimentation in basic fields of Electrical Engineering especially in Power Electronics, Electrical Drives and motion control. It grants access, via a web-based tool, to remotely controlled and monitored real experiments that are located in different universities (Bauer, Fedák and Rompelman, 2008).
- *RemotElectLab*: developed at the University of Porto, is a reusable, easy replicable and highly flexible remote lab platform for experimenting electric and electronic circuits. It offers an exact replication of the real lab that enables the students to modify certain predefined parameters in the Circuit Under Test (CUT), implement all the circuits proposed during normal electronics teaching lab classes, and allows voltage or current measurement at different nodes of the circuit remotely (Sousa, Alves and Gericota, 2010).
- *VISIR* (Virtual Instrument System in Reality): developed at Bleking Institute of Technology. It is an open source remote laboratory project that uses a breadboard that allows the user build a CUT from the beginning virtually, uses

a switching matrix to transform the student's scheme to a real circuit and then enables him to retrieve real measurements (Tawfik *et al.*, 2013).

- *ArPi Lab*: developed at the Slovak University of Technology in Bratislava, is a general purpose and operative remote laboratory which is physically built on Raspberry Pi and Arduino development boards. It's designed for practical experimentation in automation and process control related education and provides various experiments in thermal plants, magnetic levitation, and hydraulic systems (Kalúz *et al.*, 2014).
- *LaboREM*: developed at the Bayonne Technological University Institute, is a platform that promotes distance learning for the engineering students. It incorporates a video camera and a remotely controlled robotic arm for placement of components to allow students to build their circuits. It's based on the design and control of Virtual Instruments for the management of remote experimentation through the web, Implements a game-like scenario as learning approach and uses Chamilo and Dokeos Learning Management Systems to manage students and supervise the collaborative work (Luthon and Larroque, 2015).
- DC Electrical Panel remote laboratory: developed at the Federal University of Santa Catarina,is a platform that allows students to do PW concerning resistors association and electronic circuit analysis into direct current using the basic laws of circuits analysis (Silva *et al.*, 2016).
- As part of a partnership, researchers at Al Azhar University of Gaza and Dublin City University developed a remote CBL system that uses a cart-inverted-pendulum, LabVIEW and an Arduino UNO board to teach the principles of PID controller tuning of the Inverted Pendulum for an undergraduate control systems course laboratory (Issa *et al.*, 2018).

6.2.2 Online repositories

- *LabShare*: funded by the Australian government and led by the University of Technology of Sydney and sponsored by six universities. Its aim is to create a national network of remote sharable laboratories to support cross-institutional sharing of remote labs as a consortium of Australian Technology Network Universities who would share remote laboratories. LabShare targets civil, mechanical, and electrical engineering and offers several functionalities (ie: booking, system and queuing option...) (Lowe *et al.*, 2009).

- *LILA* (Library of labs): developed at the University of Stuttgart and is co-funded by the European Commission, is an online portal that allows sharing and exchange of experiments. It's a project that aims at building a repository of online lab experiments shared between universities on a worldwide scale and integrating virtual and remote lab experiments into Learning Management Systems (Richter, Tetour and Boehringer, 2011).
- *WebLab-Deusto*: developed by the University of Deusto, is an Open Source remote laboratory management system that provides a scalable software infrastructure and uses web standards suitable for mainstream web browsers, and adapts to mobile devices. It provides an inter-institutions coalition of remote laboratories and can host remote experiments developed by other projects (Orduña *et al.*, 2011).
- *UNILabs* (University Network of Interactive Laboratories): developed at the National Distance Education University in Madrid. It constitutes a network of web-based laboratories in which different Spanish universities take part. The network is used to host an expanded range of virtual and remote laboratories and provide a large collection of web-based labs. Based on the use of a free authoring tool for building user interfaces, it offers several updated modules in the automatic control field. Theses virtual and remote labs are deployed into Moodle, which facilitates their management and maintenance (Saenz *et al.*, 2015).
- *Lab2Go*: developed at the Carinthia University of Applied Sciences, is a repository project that offers a common framework to gather and depict online laboratories according to the semantic web technology. It provides references to online resources and implements enhanced search mechanisms and other data handling features to enhance the browsing of the repository (Zutin *et al.*, 2010).

6.3 TYPES OF LABORATORIES

Actually, and for many years, hands-on activities have been the only way to conduct well-structured experiments *(see Figure 6.1)*. Thanks to the advancement in information technology, conventional hands-on laboratories structure and processes have been redesigned and expanded to distance laboratories to meet the aforementioned needs. This kind of labs is now playing a crucial role in teaching technical courses. Thus, virtual labs, simulators and remote labs can be used in engineering education as alternatives for regular hands-on labs.

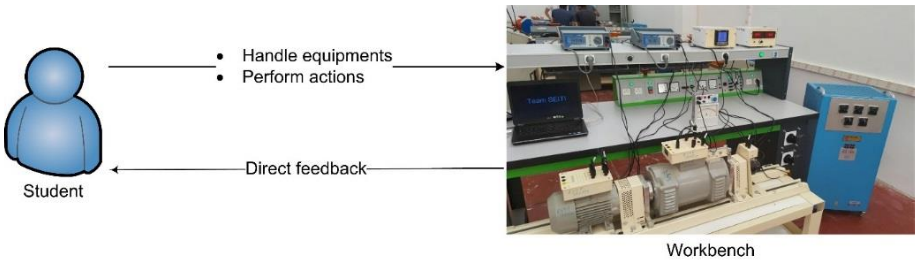

Figure 6.1: Hands-on lab

Diverse terminologies are used in the literature to depict labs offering online or virtual experiment. To avoid confusion all the different types of distance labs are explained in the following:

6.3.1 Virtual labs

Virtual labs, simulation labs and simulators can be used interchangeably and refer to labs where each real experiment is simulated or virtualized via the use of a software (Auer, 2001) and doesn't involve the use of any specific device or instrument *(see Figure 6.2).* It can be used in certain experimental activities where simulation is enough, does only require the use of an ordinary computer and can be accessed through an interactive user interface with usually high visual rendering where students can handle the experiment parameters and view its outcome.

In virtual laboratories, the instrument is replaced by a software program that reproduces, approximately or fully, all its functions (Uribe *et al.*, 2016). The platform may also incorporate several distinct virtual devices necessary for the implementation of the experiment as for workbenches in electrical engineering.

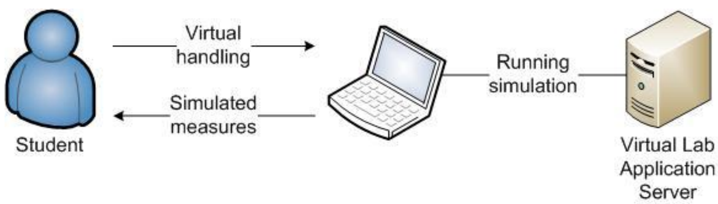

Figure 6.2: Virtual lab

6.3.2 Remote labs

Alternatively, remote or online labs have been available via internet for nearly two decades (Aktan *et al.*, 1996) and can be defined as educational resources that provide an interface to interact remotely with real workbenches. Those workbenches contain lab instruments (e.g. multimeters, power supplies, motors, and generators) that are separated from the learner, but can be accessed, configured, manipulated and monitored using the Internet to perform the experiment *(see Figure 6.**3**)*.

Remote labs allow learners to have access to practical learning materials without time and location restrictions. Which means that the experiment can be performed anywhere there is Internet. In other words, ‘‘If you can’t come to the lab the lab will come to you” (J.A. Del Alamo, 2007).

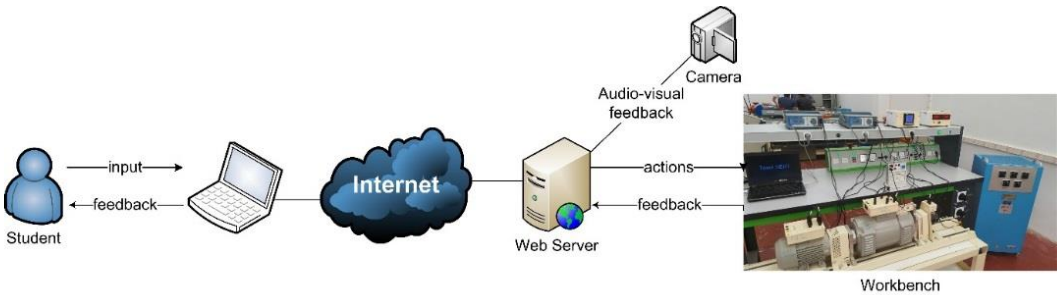

Figure 6.3: Remote lab

Each type of lab has thorough pros and cons. While virtual laboratories can be used by a large panel simultaneously, with only the computational power as a limit without additional costs, remote ones are more expensive to create and maintain because they require real hardware to run experiments and additional equipments for online access.

Both types allow learners to carry out experiments safely from any place in the world which means that learners cannot damage the instruments while adjusting settings, because in one hand virtual labs are just made of software and on the other hand, we can easily define limits and restrictions in remote ones.

Unlike virtual labs, remote ones provide a valuable lab experience by providing extended access to real devices, and simulators can never perform exactly the same as real hardware in all cases because it is impossible for them to include all the experiment’s parameters. Moreover, remote labs offer the chance to work in the remote mode that has gained a lot of importance in the professional field *(see Table 6.**1**)*.

	Virtual labs	Remote labs
Accessibility	Not limited	Must respect a schedule
Cost	Low	High
Learning	Suitable for unlimited use	Learn how to work in a remote mode
Maintenance	Software updating	Instrument maintenance and software updating
Realism	Reasonable	Low
Reliability	Yes	Yes
Safety	Yes	Yes

Table 6.1: Characteristics of virtual and remote laboratories

6.4 RATIONALE FOR REMOTE LABORATORIES IN ELECTRICAL ENGINEERING

Practical work is essential for developing skills of applying theoretical knowledge in real-life problems. In fact, institutions need to find a solution to provide learners with relevant online practical experiences. In the case of electronic engineering and while learners need to handle real devices to retrieve authentic measures and gain the targeted practical skills, virtual labs cannot provide such kind of real experiences. This lab should not only allow students to send commands, receive feedback and measurements, and execute the experiment on real instruments in the lab remotely but should provide solutions to the needs in terms of:

6.4.1 Accessibility

In hands-on activities access to the laboratory is limited by the availability of both the instructor and the lab simultaneously. Online labs offer flexibility to the learners to operate experiments anytime and anywhere subject to having access to a computer or terminal capable of running the application, while in remote labs learners must queue and follow a certain schedule to conduct experiments and a common web browser is the only required application for the remote user.

Moreover, and to reduce discrimination against disabled, institutions should grant access to students with disabilities who may not be able to access a laboratory and operate laboratory equipment. In this sense, no one can argue with the potential benefit of remote experiments to remove or at least minimize accessibility barriers.

6.4.2 Economic burden

The institution should look at the financial resources and equipments before considering doing some PWs. Under-equipped institutions are coping with the heavy financial charges of buying and maintaining required instruments in conventional laboratories with the intention of maintaining the effectiveness of laboratory practical education.

To deal with those economic factors, remote laboratories should be accepted as new possibilities for under equipped institutions, and so we can think of collaboration between institutions in order to share equipments and resources to expand their list of experiments, enrich the educational experience, and produce better learning as well as reduce costs and satisfy economic constraints.

The table below (*see Table 6.2*) shows an exact estimation of a complete workbench cost that can be used by only a group of students at a time and in one experiment, and considering the increasing number of students the need is clear for a low-cost and financially sustainable laboratory.

Equipment	Code	QTY	Unit Price	Line Total
Autonomous position 4000VA	BZV-40D-	1	3814.52	3814.52
Asynchronous machine	MAS20	1	771.39	771.39
DC machine	CB50	1	5112.98	5112.98
Tachymetric dynamo	DYTA2	1	598.98	598.98
Bench with wheels for machines		1	358.93	358.93
Resistive load	CH20	1	1291.91	1291.91
Torque / Speed display case	TAGA	1	2025.91	2025.91
Electrical quantities measuring station	DIRIS A40	1	1622.21	1622.21
Portable automatic multimeter	MX5060	2	390.78	781.56
Ampermeter		1	448.66	448.66
Black security cable	402S-N	20	4.92	98.40
			Total (excluding tax)	16925.45 €

Table 6.2: Estimated workbench cost

6.4.3 Pedagogical needs

Low budget institutions can only provide students with a small number of accessible systems compared to large numbers of students. Equipment units are insufficient for all the potential users within some experimentation, which makes their hands-on labs have highly poor utilization rates.

To cope with that, we might think of working in groups. Unfortunately, this solution is not effective enough because the students' available time slots are limited which makes scheduling more sessions considerably impossible. Tutors claim that, sometimes, PW sessions do not take place in the most appropriate order for all groups and so, some students have no choice but to conduct their experiments before taking the corresponding lecture which is pedagogically ineffective.

In the current subject, and for pedagogical purposes, the number of students per workbench should be between two and three.

Because of the handling of high voltage equipment and for safety reasons, a workbench should not be used by a single student. The presence of another person is mandatory, if a sudden threatening event occurs, to trigger the emergency stop and alert administrators.

It is also hard for a single student to take instant measurements on multiple devices at the same time. And in case of misunderstanding or partial assimilation of a concept each student will automatically refer to the teacher which will restrain his analytical skills.

The use of the workbench by two or three students gives them the opportunity to discuss about the experiment and to help each other, which will enhance their collaboration and analytical skills.

On the other hand, if the number of students exceeds three, we find ourselves in a situation of congestion where all students won't have the opportunity to act on equipments. Limiting their interactions with equipments will surely weaken the skills acquired during the session.

These conditions made us explore the possibility of adopting an online lab. No one can argue that it is crucial to identify the experimentation's needs, objectives and expected outcomes to choose the suitable kind of online lab. In electrical engineering, learners need to interact with real instruments and collect real data. While virtual labs might discard some important aspects of the real experimentation and "oversimplify" it, the remote lab should be preferred.

6.4.4 Flexibility

A well-designed remote laboratory is capable of accommodating new experiments, PWs and instruments easily. And it can be replicated and adapted to the needs of each institution.

6.4.5 Accuracy in the measurements' retrieval

A remote system guarantees the accuracy of real-time measurements as those obtained in hands-on experiments.

6.5 PEDAGOGICAL WORK

6.5.1 The Workbench

The workbench consists of test and measurement devices plus various other electrical devices. The figure below (*see Figure 6.4*) shows the typical experimental setup.

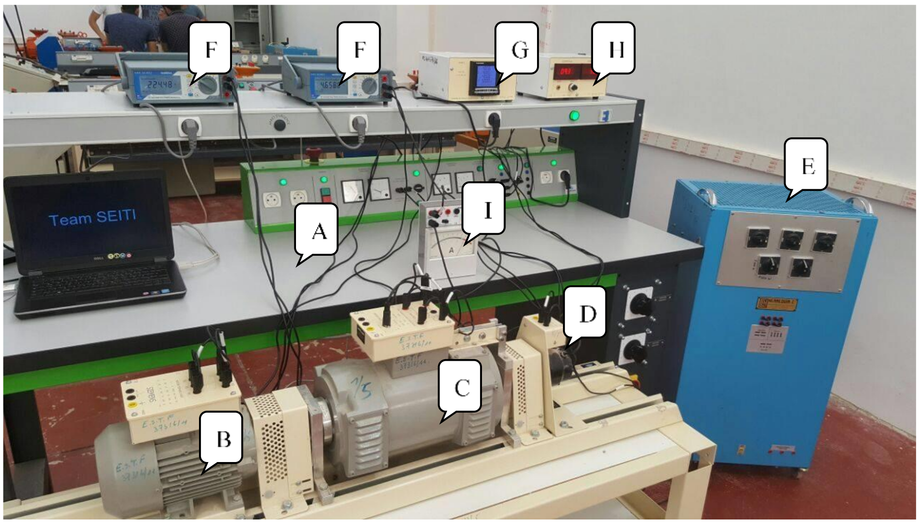

Figure 6.4: Hardware resources of the PW

The power part of the system consists of a squirrel cage induction machine (B) and a DC machine (C). Each of these two machines can be operated in the two operating modes: motor mode and generator mode. The machine that operates in generator mode supplies a resistive electric load (E) with a maximum power of 3000 W.

The measurement part incorporates two multimeters (F) for measuring electrical quantities (currents / voltages), an amperemeter for measuring the excitation current absorbed by the DC machine, a mechanical-quantities (torque/speed) measuring device (H) which receives data in the form of a voltage from a tachymetric dynamo (D) and a measuring station DIRIS A40 which is used to measure and display the characteristics of the electrical network (G) that can be analyzed and operated remotely. The power supply and safety of all these devices is ensured by an electro-technical autonomous position (A).

6.5.2 Prerequisites

The prerequisites of this PW are the basics in mathematics and electrical engineering.

6.5.3 Structure and Objectives

The experimental system is designed with the intent of reproducing as well as possible the behavior of the conventional lab. And the lab work is suggested to undergraduate students working in the fields of electrical engineering.

The objective of this practical work is the study of the three-phase asynchronous machine and the DC machine at the same time. First, the nameplates of both machines are studied, then a no-load test is carried out and finally a load test is realized. The three-phase network of the laboratory is: 220V / 380V, 50 Hz. The bench below is the subject of two possible experiments:

The first one deals with the study of the three-phase squirrel cage asynchronous motor:

- The stator winding resistance is measured using a DC source in order to calculate the stator Joule losses.
- A no-load test is carried out in order to determine the iron losses P_{fer} and the mechanical losses P_{meca} of the studied machine. $P_{fer} + P_{meca}$ is called constant or collective losses.
- A load test is conducted in order to plot the torque-speed characteristic. To achieve this, a separately excited DC machine is placed on the same shaft as the asynchronous machine. Since the two machines are connected, the torque of the induction machine and the one absorbed by the DC machine will be equal. By measuring the torque by a sensor linked to the DC machine, the asynchronous machine torque will be measured.

The second one regards the study of a separately excited DC generator:

- A no-load test is achieved in order to plot the magnetization curve of the machine which matches the influence of the excitation current on the no-load voltage delivered by the generator at a constant rotational speed (n): $E = f(i_{ex})$at $n = cst$.

- The speed of the DC generator is varied with a constant nominal excitation current in order to see the evolution of its no-load electromotive force in terms of the armature rotational speed.

A load test is performed in order to determine the influence of the load on the generator voltage at a constant rotational speed and a constant excitation current (i_{ex}): $U = f(I)$ at $n = cst$ and $i_{ex} = cst$.

6.5.4 Pedagogical Approach

Aware that PW has a strong impact on students' learning outcomes (Ma and Nickerson, 2006) and the fundamental challenges of a remote lab are technical and didactical, this work deals with both perspectives. The pedagogical outcome of remote laboratories in engineering has been figured out by tutors and teachers and related in the literature. Remote experiments have a considerable potential for collaborative teamwork and constructivist learning strategies by allowing students to benefit from a richer learning experience.

On the one hand, adopting an Inquiry-based learning and making in charge of their own learning process through an active exploration and interpretation of the materials has been proved useful to provide students with a better conceptual understanding and a stronger critical and logical thinking skills.

On the other hand, offering to the students to work in a self-paced way rather than imposing them to work on a strict schedule, allowing them to carry on uncompleted experiments from home and to repeat experiments to confirm uncertain measurements, giving them the possibility to view lectures, examples, and take assessments at their own convenience when impediments occur, will surely make them work at ease and lead to satisfactory learning experiences (Cooper and Ferreira, 2009). Finally, in these approaches, problem conception must be motivating and inspiring for students to make them more interested in learning the required concepts on their own. And the use of an interactive platform may enhance learners' motivation.

6.5.5 Learner assessment

Assignments play a key role in any learning process and are considered as an important activity within any practical experimental work for the reason that they represent an inquiring approach to knowledge acquisition.

Assessments in our platform are used to evaluate students and their capacities according to explicit educational concepts (summative), and to revise and adapt the learning process to meet student needs (formative) in order to ameliorate the learning materials or even the platform.

To do this and at the end of the PW, students are asked to fill a multi-choice question (MCQ) quiz to assess their acquired knowledge and to fill a table to check the measurements they retrieved during the experimentation.

6.6 SEITI RMLab v1.0

The figure below (*see Figure 6.5*) depicts a scheme of the overall system architecture.

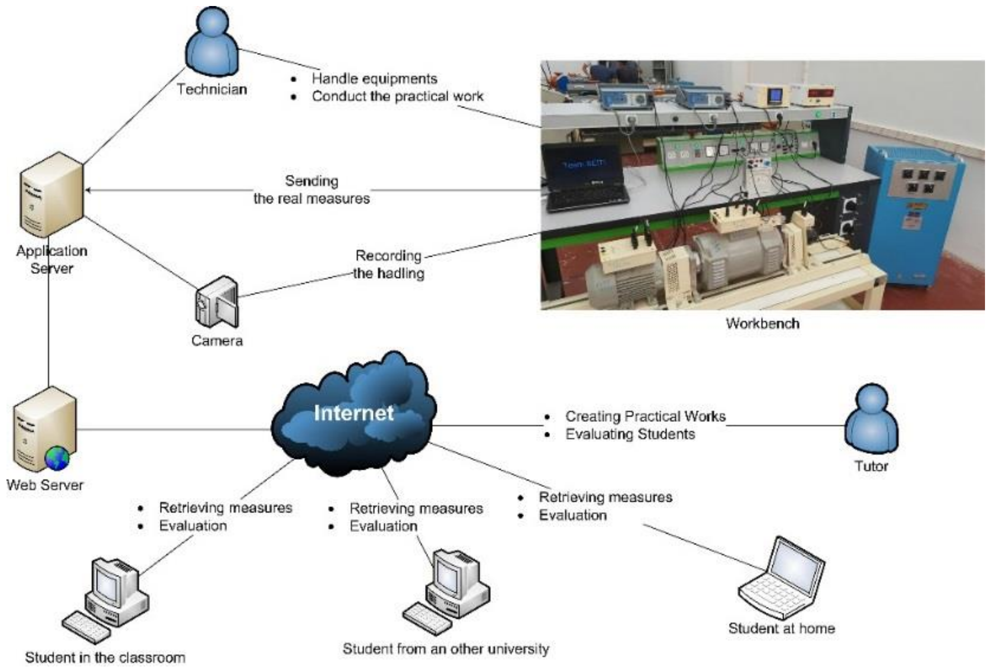

Figure 6.5: SEITI RMLab v1.0 system architecture

6.6.1 Actors of the system

Tutors: produce the PW statement, schedule sessions, assist and evaluate students.

Technicians: act on equipments, provide assistance to learners, monitor the workbench and intervene in case of problems.

Learners: view the manipulation via video streaming, inspect real-time measured data and variations, consult the statement of the PW, consult the technical documentation of each equipment, set for the assessment associated with the PW.

6.6.2 Workbench

The workbench contains several electrical equipments needed for the experiment and measurement instruments that can be connected to the application server in order to retrieve real-time measurement remotely.

6.6.3 Application Server

The application server is a computer that hosts the equipments control software or drivers and is connected directly to the equipment by standards such as USB or Ethernet.

The measuring instruments that are incorporated are of two types: i) instruments that possess a LAN connection and an embedded web server that provides a web page interface, ii) instruments that possess a USB connection and can be accessed via a proprietary software.

This server is linked to a digital camera through a USB cable to ensure workbench supervision.

The Open Broadcaster Software is used to capture the video of the workbench; the obtained measures are integrated in the video in order to have only one flow that will incorporate all the information. And YouTube streaming services are used to ensure a good quality streaming at the beginning before developing our own solution.

6.6.4 Web server

Web browsers are software tools that we are sure that the user would be mastering and using on any computing device, including mobile platforms. Therefore, distributing pedagogical material only through a Web browser is a judicious and sufficient choice.

The web server (Apache) contains all the information on the available experiments (workbench description, used equipment description, experiment, and learner evaluation) and integrates a database (MySQL) for saving authentication data, PW information and student results.

Once authorized, the user may subscribe to a remote PW session, which will take place during an already defined schedule. Then he can access the web page of the PW that includes: i) PW statement, ii) Links to information about the used equipment, iii) Link to the corresponding course, iv) video streaming, v) A set of questions that the student must answer and a table where they must enter the obtained measures for evaluation purposes *(see Figure 6.**6**)*.

The video of the remote PW will only be available at the aforementioned session. This video will incorporate a live stream of the workbench and set of real-time extracted measures.

HTML5, CSS3, JavaScript and PHP, were chosen to develop the web platform, which will allow to handle the matters of flexibility and ubiquitous use of the application on mobile devices. This platform offers several interfaces for teachers to allow them to add easily new remote lab activities and for learner to enable them to carry out each experiment on the required hardware infrastructure through a user interface transparently.

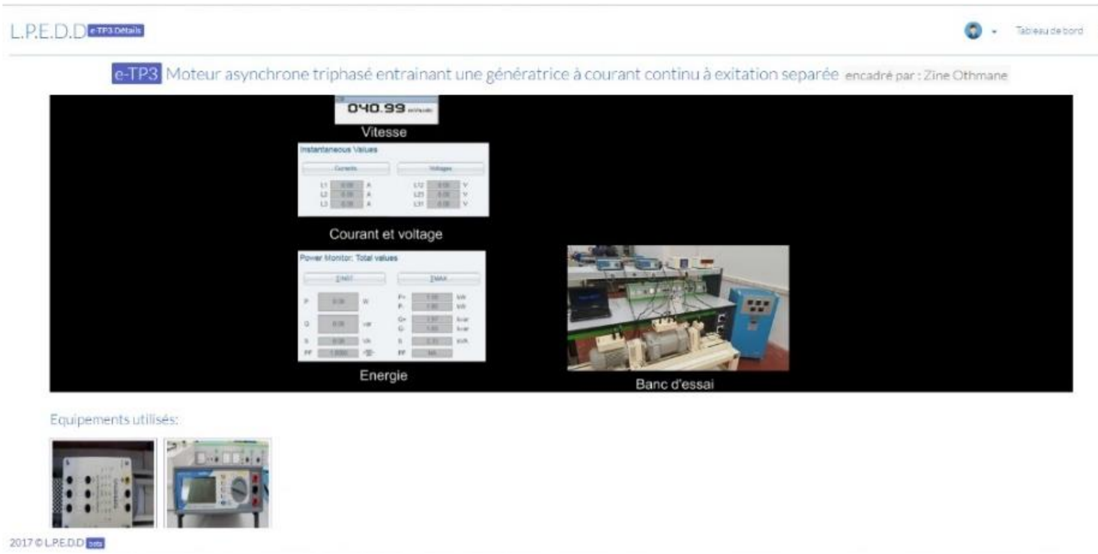

Figure 6.6 : SEITI RMLab v.1.0 GUI

6.6.5 Communication

Our platform uses two different technologies to provide communication between clients and server, while JSON structures are used to transmit the data. The first one is provided through asynchronous AJAX/HTTP requests that are processed in the server side by a set of PHP scripts. The second uses a socket handler module to ensure a real-time data (data concerning the electrical measures retrieved) delivery.

6.7 SEITI RMLab v2.0

6.7.1 Challenges

The main originality of the first proposition was the fact that the setup of the remote lab costed nothing in term of extra budget as we already had a camera and a server in the laboratory. Now, with a Raspberry Pi (RPi) that costed approximatively 40€, an inverter that we built ourselves and a rectifier already available in the laboratory, we intended to make the system fully remotely controllable and enhance the quality of the platform by:

- Allowing the students to configure remotely the handled equipment, which will make the platform 24-hour accessible and increase the availability of the system.
- Investigating the source code of measuring equipment software to extract and redirect the measures that we need only to display them on the new GUI.
- Incorporating a booking system to manage the access.
- Enriching the guiding documents (PW statement, datasheets, FAQ…) and the enhancement of their quality, as their nature and completeness play a key role in the easing of the conduction PW.
- Incorporating a wiki and chat platform to allow students to ask for help, to enhance collaboration and to ensure communication between learners and tutors.
- Improving of the learner assessment system, by refining the quizzes by diversifying the types of questions (single choice, multi-choice, correspondence, cloze questions) and integrating an interface that allows to plot graphics online and another one that allows the generation and upload of PW reports.
- Creating a featuring video and a how-to to help students to get accustomed with the platform, as we noticed, when evaluating the platform, some reluctance from students who do not master or are not used to the computer tool.

6.7.2 Conceptual design

The learner represents the main actor in our online laboratory. His main mission in this context is the study of the three-phase asynchronous motor and the DC machine at the same time. Indeed, this study is done through the acquisition of the main electrical measurements during no load and load tests, graphs plotting and conclusions drawing. In fact, the learner needs an environment that will enable him to carry out the following actions *(see Figure 6.7)*:

- Schedule a PW session: every learner should consult the calendar in order to check the free time slots before booking a PW session.
- Conduct the remote experiment: the learner that has previously booked a PW session should connect to remote laboratory platform at the scheduled time to carry out the PW.
- Sit for a test: at the end of the PW session, in order to be assessed, the student is asked to:
  - Respond to the quiz: the learner should respond to several questions in order to assess his acquired knowledge.
  - Fill the measurements table: the student has to fill the table with the right measures in order to plot the graphics that will be integrated in the report.
- Generate and send the report: A report automatically created and can be downloaded and/or send to the corresponding teacher.

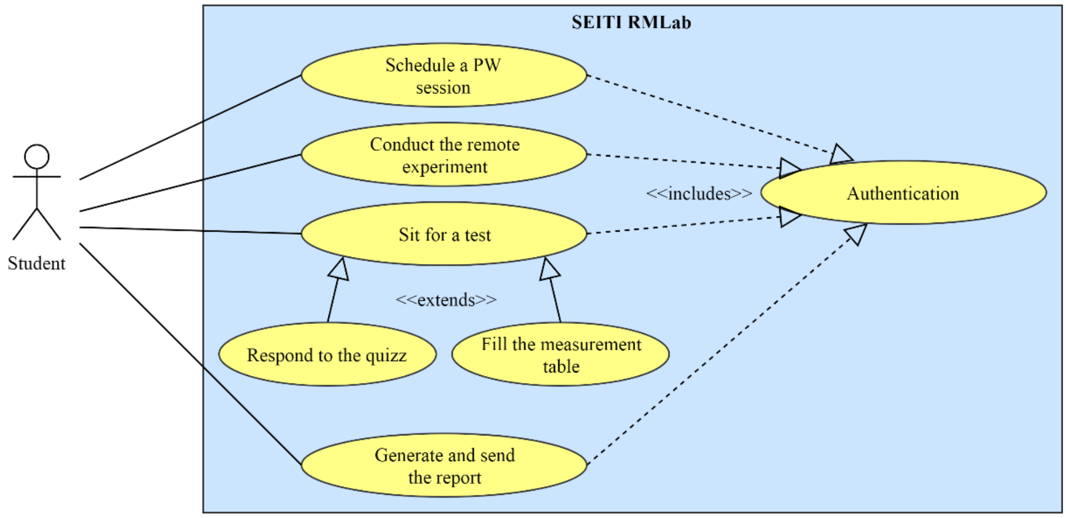

Figure 6.7: Student's Use Case Diagram

6.7.3 Web-services & Graphical User Interface (GUI)

The dynamic web application was built using the free and open-source *MEAN* software stack. The *MEAN* stack outperforms the traditional tool stacks such as *LAMP (i.e. Linux, Apache, MySQL, PHP)* as it enhances the productivity by reducing the development effort required and allows efficient and highly-scalable implementation.

MEAN stands for *MongoDB*, *Express.js*, *Angular*, and *Node.js* and provides both client & server-side components for interactive web applications. The first tool allows taking advantage of the benefits offered by object databases as the platform is intended to be used by a high number of students. The second provides us with a framework to hand web routing and *HTTP* operations. The third supplies with a client-side framework for *MVC* single-page web applications. And the last one furnishes a JavaScript engine, and a web server component.

The combination of *Node.js* & *Express.js*, and *MongoDb* provides an excellent implementation of a highly scalable *JSON*-based web-service as all of the tools within the stack natively utilize the underlaying *JSON* data. *JSON* best fits data that needs to be both human and machine-readable. Furthermore, *JSON*'s key-value pair format is ideally appropriate for use with regular parametric data such as data produced by a measurement device, or data transmitted as a command message to vary the speed and torque of the machine.

The web-service provided the back-end to a single page web application too. This web application was implemented using the combination of *Angular* and *Materialize* which is a modern responsive CSS framework based on Material Design by Google. The GUI supplies the students with a means to view the devices measurements and the real-time streaming of the workbench, in addition to offer a medium to vary the speed and torque at the mechanical shaft *(see Figure 6.**8**)*. Moreover, it allows the student to book a PW session according to the available timeslots. Furthermore, it provides an evaluation system where students are asked to respond to a questionnaire, fill a table with the retrieved measures and plot the graphics for both tests, and then generate and send the report.

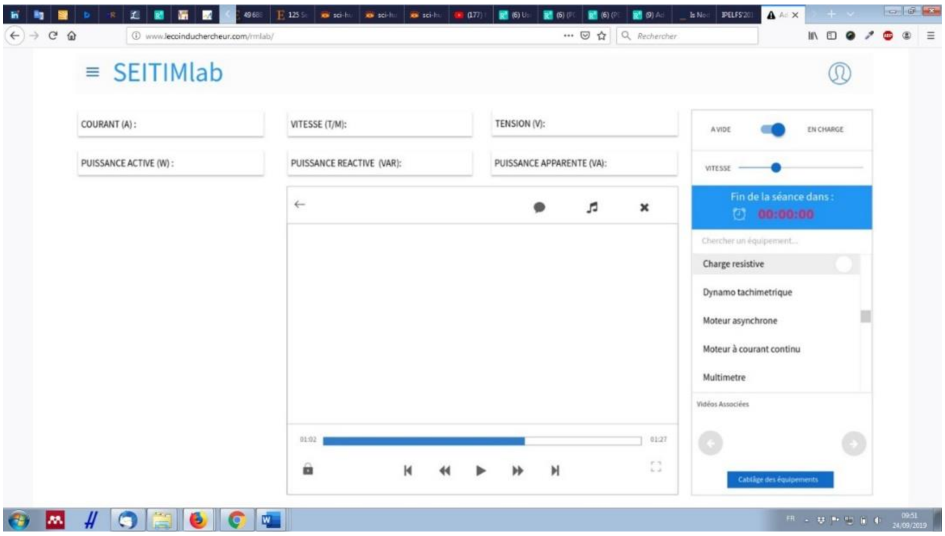

Figure 6.8: PW main GUI

6.7.4 Hardware

The central device of the improved version of the SEITI RMLab is the RPi Embedded Computer. The RPi is a small computer based on a system on a chip (SoC) Broadcom BCM2711 and a Quad-core Cortex-A72 processor running at 1,5 GHz.

The main function of the RPi is to provide interfacing and management for the connection between the end-users and the workbench. It acts on the same time as an application server and a web server and is linked to a camera that allows streaming a real-time video of the workbench. Moreover, it mediates the access to the measurement equipment, send commands to the inverter and at the same time collects the measured data and displays it through the web interface.

In order to vary speed and torque at the mechanical shaft remotely, the three-phase induction motor should be appropriately supplied by adjustable voltages in terms of amplitude and frequency. The component in charge of this task is the power electronic converter. The most commonly used topology is composed of three elements *(see Figure 6.9).*

- The first one is the *rectifier*. It converts the AC voltage to a fixed DC voltage. This component employs uncontrollable switches which are the Diodes since the flow of energy is unidirectional from the AC source to the electrical machine.

- The second is the *DC bus capacitor*. It is used to smooth the voltage generated by the rectifier.

- The last is the *inverter*. It uses the DC voltage from the DC bus and converts it to AC sine waves by means of controllable power semiconductors that are the Insulated-Gate Bipolar Transistors (IGBTs) with an antiparallel diode to enable the current flow in the two directions.

This inverter is continuously governed by six pulse commands generated based on a control algorithm. This algorithm, accommodated in Raspberry Pi board, receives the student command that can be power or speed and the measured magnitudes such as the mechanical speed given by the Dynamo Tachymetric and the electrical variables (voltage, current, and power). Based on those magnitudes, the voltage references are generated by the control strategy and modulated using Pulse Width Modulation technique (PWM) to produce 5V pulse commands. The gate driver is adopted mainly to amplify the output signals of the Raspberry Pi in order to drive the semiconductor gates at 12V.

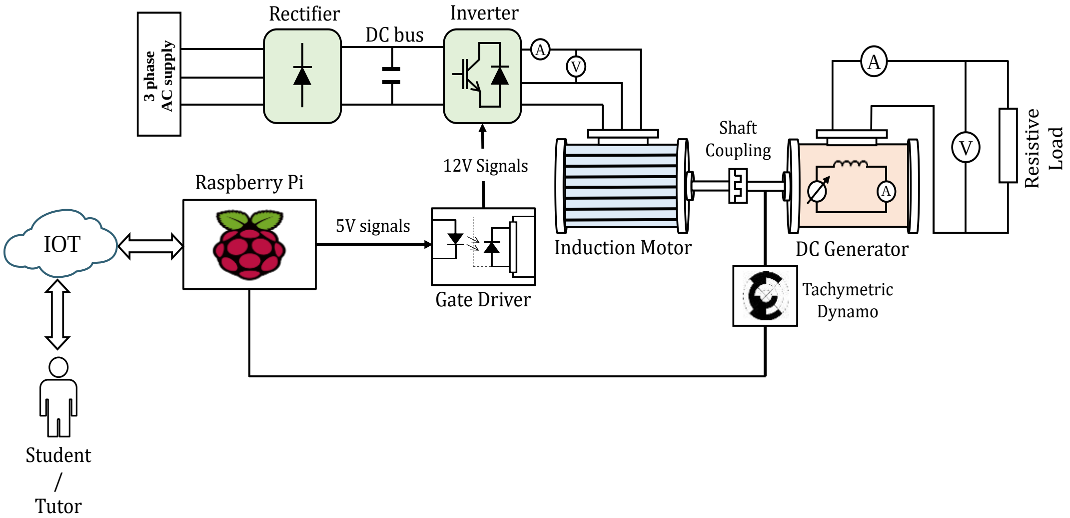

Figure 6.9: SEITI RMLab v2.0 detailed system architecture

6.8 PLATFORM EVALUATION

The process of the platform evaluation is intended to contribute to continuous improvement. The main reasons of the evaluation are the optimization, upgrade and correction of bugs. The environment is evaluated with regard to its effectiveness, the perception and expectations of students, and the learning effect and outcome with regard to the budget allocated by the institution.

The purpose of our investigation was to determine the opinion of students about our remote laboratory, in the Moroccan university context and especially in our own institute. We wanted to know whether the experiment was as effective as we assumed it would be and scroll through the problems and difficulties students might face while using it.

At the end of the course, students that followed the PW were asked to respond to a survey to assess the quality and impact of the use of our remote lab; both a technical evaluation and a pedagogical evaluation were conducted.

We divided a panel of 31 students into three groups: G1: 9 students, G2: 11 students and G3: 11 students.

The first group (G1) conducted the PW in a conventional laboratory first, whereas the two last ones (G2, G3) started conducting it remotely via SEITI RMLab. The first remote PW took place in a classroom equipped with computers and internet connection at school, while the other was done by each student at home. Then we switched the groups two times in order to make all students try conducting the experiment in all the offered ways.

G1: hands-on -> remote at the university -> remote at home.

G2: remote at the university -> remote at home -> hands-on.

G3: remote at home -> hands-on -> remote at the university.

The interval of time between each experiment for the same group was 2 weeks. And all the experiments took place in the first semester of 2017.

For the evaluation purpose a questionnaire, scoring the twelve main issues *(see Table 6.**3**)*, has been worked with about 20 questions *(see Table 6.**4**)*. A sample is given in table 4. The answers were rated on a 5-point Likert-type scale and for each question, the student should select the adequate grade from very bad (grade 1) to excellent (grade 5) and for the questions that addressed the same issue, an average mark was calculated.

i01: Availability	**i02**: Ease of use	**i03**: Real-time
i04: Level of interaction	**i05**: Autonomy	**i06**: Collaboration
i07: Documentation	**i08**: Accuracy of measurements	**i09**: Pedagogical and didactic efficiency
i10: Evaluation	**i11**: Help and Support	**i12**: Safety

Table 6.3: Evaluated issues

Question	Corresponding issue
Q01: Is the interface easy to use?	Ease of use
Q05: Being far from the remote Lab, did you feel yourself to be in control of it?	Autonomy
Q13: Are the technical details of instruments and other documents good and clear?	Documentation
Q18: Did the remote laboratory help to deepen your prior knowledge of the subject?	Pedagogical and didactic efficiency

Table 6.4: Questionnaire sample

The average overall satisfaction is about 3.47/5 for group 1 (Hands-on).

The average overall satisfaction is about 3.36/5 for group 2 (Remote access, in a classroom).

The average overall satisfaction is about 2.74/5 for group 3 (Remote access, at home).

Results can be used to show us whether it is reasonable to continue the project or not and guide us on the possible improvements and rectifications. Despite these results are not meaningful enough to draw categorical conclusions from, they give rational indications for further research *(see Figure 6.**10**).*

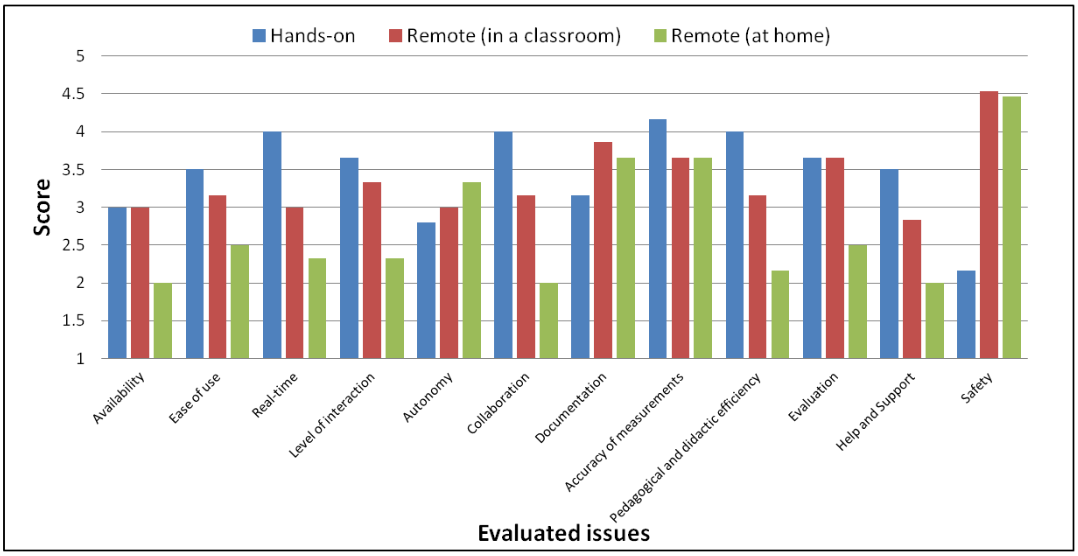

Figure 6.10: Evaluated issues students' ratings

In order to fetch more accurate information, all the students were interviewed. The feedbacks gave us a clearer perception regarding students' ideas and position about the concept. Instead of discussing questions results here, we opted for discussing the issues that were addressed by these questions, which highlights more significantly our findings.

When exploring the students' satisfaction with the availability (issue 1) of the platform and real-time response (issue 3) we found that students claim not to have a good enough quality of internet connection at home or don't have internet at all, and so they cannot access the platform anytime they want to, which affected their impression of conducting a real-time experiment too. Furthermore, there was diverse opinion regarding the ease of use (issue 2) of the platform and that is due to the fact that some students are accustomed to the computer tool and so they didn't have any problems when conducting the remote experiment, while others have difficulties in handling the computer to conduct the experiment.

On the one hand, students assumed that they felt more autonomous while conducting the PW at home because they had to do it by themselves (issue 5) and acknowledged that all necessary documents were available whenever needed, unlike the real laboratory where they have to share a limited equipment documentation (issue 7). All of them argued that remote laboratory yielded reliable data measures which are also accurate and easy to retrieve while using the platform (issue 8) compared to the hands-on laboratory, and that when talking about security, obviously, remote experiments are safer than handling equipments directly (issue 12).

On the other hand, when asked about the efficiency (issue 9) students believed that conducting the PW in a conventional laboratory is more efficient on the grounds that: i) handling equipment in a conventional lab was far more interactive than handling it remotely (issue 4), ii) conducting the PW remotely reduced the opportunities of collaborating and made them feel isolated from each other (issue 6), iii) their work cannot be accurately evaluated and their acquired knowledge correctly assessed without the presence of the teacher (issue 10), the lack of immediate tutor support to conduct the experience and of the teacher who can give extra information, explanations and assistance when needed disadvantages the use remote laboratories (issue 11).

Pedagogical efficiency was investigated deeper by comparing the academic results of each student in the different modes. Knowing that it is the same PW, students got approximately similar mark regardless of the type of the PW.

In assessing the overall outcome of the experience, students asserted that the remote laboratory was a valuable complement, enrichment and alternative to hands-on experiments, since, for a matter of safety, remote access is becoming the trend even in the professional world. They gave us some suggestion that were taken into consideration for future works.

6.9 SUMMARY

This chapter introduces and summarizes all concepts of distance PW in engineering curriculum and presents the development of an effective remote lab at low cost and using open source software products. Furthermore, it describes all the features of the old and new versions of the SEITI RMLab that allows a better management of the platform. The key improvement of the new version is the fact that we will no longer need an onsite technician and the incorporated booking system, which will allow the students to register for a PW session accordingly with their availability and grant the 24-hour service.

The project aims to offer an alternative to hands-on experiments to those who cannot access the real laboratories for the previously cited reasons. The conducted study results turned out to be promising and encouraging results concerning the feasibility and the outcome of the project especially for low budget institutions in underdeveloped countries.

The system described hereby proved to be of notable value for lecture demonstrations and student training either at school or at home, principally in an autonomous and student-centered context, but needs some improvements and ameliorations to better enhance the learner motivation and the learning outcome, indeed. Moreover, it turned out to be useful even for self-study, if instructions and assignments were well formulated. And the opportunity to conduct real experiments via any device that has an internet connection and incorporates a web browser seemed to be attractive for students, which is a highly desirable educational impact.

Finally, the next section we will summarize our contributions and propose perspectives that can be perceived as a continuation and improvement of our AEHS and RL.

Conclusion and Perspectives

Several questions were asked at the beginning of this thesis, we recall here some of them: Which learner's characteristics are best to be modeled to provide an accurate adaptation? What are the learner model standards? What are the most frequently used modeling techniques? What is the most suitable learning style for use in AEHS? What are the different types of online laboratories? What are the advantages of RLs?

At the end of this work, a brief assessment of the ideas that we have put forward is presented and the different ideas to ameliorate our proposal are outlined.

Conclusion

Learners acquire different skills and competencies depending on whether they are exposed to behaviorist, cognitivist, constructivist, socio-constructivist, or connectivist instructional approaches. Many e-learning systems have been inspired by combining features of all of these theories since an accurate learning system should incorporate aspects that are encouraged by all these perspectives such as interaction, practice, collaboration, feedback, and decision making.

Computer-Aided Education over time has known a considerable evolution during the past decades, starting from simple and inflexible environments to adaptive ones that customize the courses to each learner apart taking advantage of the evolution of the fields of ICT an AI in order to optimize and facilitate the presentation of information.

Most of the works presented in this thesis are in the context of CEHL in general and AEHS in particular. AEHS originates and beneficiated from studies on several fields such as hypertext systems and intelligent tutoring systems and thus are able to adjust their performance and customize the presentation of the courses in accordance with each learner's profile, behavior and context of learning and grant a learner-centered educational process. Several notions and background information regarding this kind of systems such as the technical components, reference models and adaptation techniques were reported.

Then, a concrete problem was tackled, that of the construction of a learner model compliant with international standards and which incorporates at the same time the different characteristics necessary to provide an accurate adaptation such as the accessibility preferences and psychological features as well as coherent and well-constructed log files that can provide a detailed view of the learner's activities. Through the review of learning style research, several models and assessment instruments were found and many of them have been adapted as online tests. The review showed that the Felder Silverman model is the best to be integrated learner model.

Moreover, this model was represented by mean of an ontology, since ontologies proved to ensure a better knowledge representation and enhance interoperability, reusability and shareability of the model. Also, the use of interoperable representation of learner models allows adaptive e-learning systems to build, maintain and update a learner model with data from all of the different systems that this learner uses.

The design of the domain model accommodate material related to any application domain or course. Each course can be represented by a set KOs that can be LOs for learning tasks and EOs for evaluation purposes. A set of KOs defines a section. Sections are grouped in a chapter. And consequently, a course is composed of on or multiple chapters.

The adaptation model is not a major part of this research, and no significant contribution is claimed in this regard.

Three different components of the AEHA were implemented at the end of this research as part of the proposed prototype. The first component provides forms and settings allowing the retrieval of learner's personal data, learning style and preferences. The second allows the creation of new courses with respect to the architecture of the domain model. The third uses the preferences retrieved from the first one to adapt the presentation of a page of the course.

On the other hand, PW is essential for developing skills of applying theoretical knowledge in real-life problems. In fact, the need of providing these students with relevant online practical experiments is clear. While learners need to handle real devices to retrieve authentic measures and gain the targeted practical skills, virtual labs turned out to be unsuitable for providing such kind of real experiences. From there, the idea of creating a RL to extend our AEHS came to us and the study of the needs presented in this report has confirmed the importance of implementing this kind of laboratories.

We have thus focused on electrical engineering students. The need to provide a RL with nearly no extra cost was actually imposed from the start of our research. This condition bounded the possibilities of experiments. However, we succeeded to provide a cost effective RL allowing measurement retrieval experiments.

The system described hereby proved to be of notable value for lecture demonstrations and student training either at school or at home, principally in an autonomous and student-centered context. And allowing the engineering learners to carry out real experiments via any device that has an internet connection and incorporates a web browser is a real success.

Perspectives and future work

As we pointed out above, the proposed AEHS is not yet finalized to be tested directly on learners, unlike the RL which has been finalized and tested, but which requires some improvement following student comments. This work opens up to broad perspectives which we will expand on in the following.

Regarding the realization of the AEHS, the components/modules of this system deserve to be enriched. As an example, for the learner model, we have not detailed all the representative characteristics of the learner. As an example, we cite the learner's cognitive style, emotional state and metacognitive skills which allows our system to choose the types of activity to present to the learner in accordance with his style. Furthermore, we need to implement artificial intelligence techniques and biometrics to dynamically assess all the psychological features.

Furthermore, we can exploit the semantics contained in the metadata of the learner model and apply semantic indexing and clustering to group learners that share similar characteristics. This would lead to more accurate resources and learning activities recommendation to learners belonging to the same group and help us to deal with the cold start limitations. we aim to detect learners’ learning style in a hybrid manner by combining the use of the revised form of the Felder Silverman Learning Styles Questionnaire to initialize the model and automatic detection techniques to update it after each learning session.

Other modules also deserve to be integrated to enhance the functionality of our proposal. We refer in particular to synchronous and asynchronous collaboration and communication tools which will help to increase the collaboration skills of the students as well as security modules such as electronic signature and data encryption to ensure more privacy. In fact, when we were developing the RL, we noticed that we were just opening a direct connection from the end-user (or the learner) to the devices. However, this presents risks for the security of the devices and the system by potentially exposing the device to erroneous and malformed instructions from the user. So, there is a real need of securing the communications using security techniques applied to web applications, such as Transport Layer Security (TLS).

The lack of available course material (i.e. video and audio) and laboratory equipments necessary for the creation of courses and experimentations was obvious. To cope with this, we plan to work in collaboration with the teachers of our university to constitute repositories of open-source educational content from several areas of learning and we aim at developing cooperation between Moroccan universities and establishing a national network of online laboratories to facilitate and manage the sharing of the different institutions' laboratories by mean of remote real experiments.

Finally, we intend to create featuring videos and a how-to to help students to get accustomed with the AEHS and the RL platforms, as we noticed, when evaluating the RL, some reluctance from students who do not master or are not used to the computer tool.

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