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PH.D. THESIS

- ABSTRACT -

DYNAMIC ADAPTIVE HYPERMEDIA SYSTEMS FOR E-LEARNING

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- 2008 -

Today's e-learning is dominated by the Learning Management Systems (LMS), such as Blackboard, Moodle, ATutor or dotLRN; these represent integrated systems which offer support for a wide area of activities in the e-learning process. Thus teachers can use LMS for the creation of courses and test suites, for communicating with the students, for monitoring and evaluating their work; students can learn, communicate and collaborate by means of LMS.

The problem is that LMS don't offer personalized services, all the students being given access to the same set of educational resources and tools, without taking into account the differences in knowledge level, interests, motivation and goals. Adaptive educational hypermedia systems (AEHS) try to offer an alternative to this non-individualized instruction approach, by providing various services adapted to the learner profile. The purpose of this adaptation is to maximize the subjective learner satisfaction, the learning speed (efficiency) and the assessment results (effectiveness).

There are two basic questions in AEHS:

- "What can we adapt to?" - The answer includes several learner characteristics, such as knowledge, goals, tasks or interest, background and experience, learning style, context and environment.

- "What can be adapted?" - The answer includes the presentation (adapting the actual content, the presentation of that content, or the media used) as well as the navigation (adapting the link anchors that are shown, the link destinations, the overviews for orientation support).

Identifying the learner characteristics represents the first stage of adaptation, called learner modeling. Adaptation decision making is the second stage, in which particular adaptation actions are taken, based on the information gathered in the first stage.

The focus of our thesis is on the learning style as the adaptation criterion, since it is one of the individual differences that play an important role in learning, according to educational psychologists. Learning style refers to the individual manner in which a person approaches a learning task. For example, some learners prefer graphical representations and remember best what they see, others prefer audio materials and remember best what they hear, while others prefer text and remember best what they read. There are students who like to be presented first with the definitions followed by examples, while others prefer abstract concepts to be first illustrated by a concrete, practical example. Similarly, some students learn easier when confronted with hands-on experiences, while others prefer traditional lectures and need time to think things through. Some students prefer to work in groups, others learn better alone. These are just a few examples of the many different preferences related to perception modality, processing and organizing information, reasoning, social aspects etc, all of which can be included in the learning style concept.

The subject requires an interdisciplinary approach, demanding the synergy of computer science and instructional science (adaptive hypermedia, learning management systems, user modeling, educational psychology).

The thesis is organized in seven chapters.

In **Chapter 1 ("Introduction")** we discuss the motivation and problem statement of the thesis, outlining the research issues that will be investigated.

More specifically, the research questions that we addressed throughout this paper are:

1. What learning style model is most appropriate for use in AEHS and how can learning style be diagnosed?

Furthermore we address questions such as: What learning style characteristics should be diagnosed and adapted to? How can we create a quantitative model of complex psychological

constructs? What type of information is needed from students' behavior to identify their learning preferences?

2. How can an AEHS perform adaptation according to different learning styles?

It is of a particular importance to filter the large quantity of learning resources available, in order to avoid cognitive overload of the learners. Furthermore, it is important to decide how to best present this content and in what sequence (the navigation type). Within this thesis we try to identify the adaptation technologies that best serve learners with different learning styles and define the corresponding adaptation rules.

3. How can we build a learning style based adaptive educational system and how efficient is it?

Based on the methods and techniques proposed for modeling and adaptation, we designed and implemented such an e-learning platform, called WELSA (**W**eb-based **E**ducational system with **L**earning **S**tyle **A**daptation). We had to answer several questions, such as: what is the best way of representing domain, learner and adaptation model? What is the relationship between individual differences and the adaptive features of the system? What criteria are needed for evaluating the resulted system?

Brown et al. (2006) launched a doubt casting question: "just because we *can* use learning styles in adaptive web based educational systems, does this mean that we *should*?" We will prove throughout this thesis that the answer is a definite "yes".

Chapter 2 ("Adaptive Educational Hypermedia Systems") gives an overview of the state-of-the-art in the AEHS field. The chapter includes a comprehensive literature review, covering aspects related to adaptive hypermedia and adaptation engineering, adaptivity in e-learning, learner modeling, adaptation levels, technologies and models, evaluation methodology. Some representative adaptive educational hypermedia systems are also briefly presented.

Chapter 3 ("Learning Styles in Adaptive Educational Systems") introduces the concept of learning styles, as well as their implications for pedagogy.

According to (Keefe, 1979), learning style designates the "composite of characteristic cognitive, affective, and psychological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment."

Issues regarding the incorporation of learning styles in AEHS are discussed: first we address the specificities of learning style based adaptive educational systems (LSAES) and then we provide some examples of the most representative LSAES to date. The first step towards providing adaptivity is selecting a good taxonomy of learning styles; however, most of the educational systems developed so far rely on a single learning style model, such as Felder-Silverman, VARK, Honey and Mumford, Biggs' surface vs. deep student approach to learning and studying, Witkin's field dependence/field independence.

Next the controversial issues and critiques related to learning styles are covered: i) there is a very large number of learning style models proposed and no unanimously accepted one, which leads to theoretical incoherence and conceptual confusion; ii) there is a practical limitation in the number of learning style models that teachers could accommodate in traditional classroom teaching; iii) some of the dedicated measuring instruments are flawed (not being able to demonstrate internal consistency, test–retest reliability or construct and predictive validity); iv) questionnaires can be done only once and it is difficult to motivate students to fill them out; v) learning styles are not a stable cognitive

factor over time or over different tasks and situations; vi) present theories are only oriented to the classical way of teaching, ignoring technology related preferences.

As a response to these challenges we introduce our own approach by proposing: i) an integrator learning style model, which includes characteristics from the major models proposed in the literature, thus establishing a unified core vocabulary; ii) an implicit modeling method, based on the direct observation and analysis of learner behavior, thus avoiding the psychometric flaws of the measuring instruments; iii) a dynamic modeling method, based on continuous monitoring and analysis of learner behavioral patterns, which is in line with the flexibly stable approach; iv) a simple description of the learning preferences, with no danger of labeling or pigeonholing the students; v) a more pragmatic approach, with instructional prescriptions for each learning preference.

Our intention was to offer a basis for an integrative learning style model, by gathering characteristics from the main learning styles proposed in the literature, which meet three conditions: i) have a significant influence on the learning process (according to the educational psychology literature); ii) can be used for adaptivity purposes in an educational hypermedia system (i.e. the implications they have for pedagogy can be put into practice in a technology enhanced environment); iii) can be identified from student observable behavior in an educational hypermedia system.

We thus introduced a Unified Learning Style Model (ULSM), which integrates characteristics related to: perception modality, way of processing and organizing information as well as motivational and social aspects. The model was created based on a systematic examination of the constructs that appear in the main learning style models and their intensional definitions. The model presents several advantages: i) it solves the problems related to the multitude of learning style models, the concept overlapping and the correlations between learning style dimensions; ii) it provides a feature-based modeling approach, which is simpler and more accurate than the traditional stereotype-based modeling approach; iii) in turn, this offers the possibility of finer grained and more effective adaptation actions.

An answer to the first part of the research question 1 is thus provided, by introducing and motivating the use of the "unified learning style model".

Chapter 4 ("Modeling the Learner from the Learning Style Point of View") deals with the first stage of the adaptation process: the learner modeling, answering the second part of the research question 1.

We start this chapter with a critical review of the methods that have been proposed in the literature to this end: while the majority of the current LSAES use dedicated psychological questionnaires for identifying the learning preferences of the students (explicit method), there are some systems that also use an implicit modeling method, based on analyzing the behavior of the students in the system. Our approach is included in the latter category. The main behavioral indicators refer to the relative frequency of learner actions, the amount of time spent on a specific action type and the order of navigation, all of which can be obtained from the system log, either directly or after some preprocessing. More specifically, the behavior patterns that we will take into account in our analysis refer to: i) Educational resources (i.e. learning objects - LOs) that compose the course: time spent on each LO, number of accesses to an LO, number of skipped LOs, results obtained to evaluation tests, order of visiting the LOs; ii) Navigation choices: either by means of the "Next" and "Previous" buttons or by means of the course Outline; iii) Communication tools: a synchronous one (chat) and an asynchronous one (forum) – time, number of visits, number of messages.

This implicit modeling method presents a challenge, in that it is difficult to determine what are the learner actions that are indicative of a particular learning style. This is why we performed an

exploratory study, trying to identify correlations between students' patterns of behavior and their learning preferences. The study involved 22 undergraduate students; as test platform we used WELSA educational system and a course module in the area of Artificial Intelligence, dealing with search strategies and solving problems by search. The preliminary results that we reported seem to be in agreement with the intentional definitions of the ULSM dimensions. However, a larger student sample as well as a more in-depth analysis of the data is required in order to confirm our findings.

Therefore we repeated the experiment with 75 undergraduate students. We applied statistical analysis tests to identify significant differences in the patterns of behavior exhibited by students with different ULSM preferences. To this end, we divided the students in two groups, with regard to each of the opposite ULSM preferences and we applied two-tailed t-test or two-tailed u-test on the two groups, depending on the distribution normality. This analysis showed that students with different ULSM preferences indeed behave differently in an EHS, emphasizing also some relations between these preferences and students' behavioral patterns; statistical significance ($p<0.05$) was obtained for 30 behavioral patterns.

Based on these results, as well as the findings from the literature, we conceived a rule-based method for diagnosing the ULSM preferences. The approach was validated through experimental research, obtaining good precision results, as can be seen in the following table:

ULSM dimension	Precision
Perception modality (Visual / Verbal)	73.94%
Abstract concepts and generalizations / Concrete, practical examples	82.39%
Serial / Holistic	78.17%
Active experimentation / Reflective observation	84.51%
Careful / Not careful with details	71.13%
Individual / Team work	64.08%

Table 1. Precision of the rule-based modeling method

Finally, once we identified the ULSM learning preferences, we devised a method of using them to categorize the student in one of the traditional learning style models. The applicability of the approach was proved with three of the most popular models (Felder-Silverman learning style model, Herrmann Whole Brain Model and Kolb learning style model), again yielding good precision results (constantly over 70% and with an average higher than 80%).

To sum up, our main contribution presented in Chapter 4 is the proposal of an implicit learner modeling method, based only on the interpretation of students' actions, not requiring any additional effort from the part of the students and bypassing the reliability and validity problems of the existing learning style questionnaires. Furthermore, the approach is not tied to any learning style model, being based on a comprehensive set of learning preferences.

Being able to identify the learning style of the student is an important step, since it can be used to raise students' awareness regarding their strengths and weaknesses in learning as well as give teachers valuable information regarding the learning preferences they should try to accommodate in their courses. In the context of our research, learning style diagnosis is the prerequisite for adaptation provisioning.

Chapter 5 ("Adaptation Provisioning with respect to Learning Styles") focuses on the adaptation decision making stage and answers the second research question, by proposing adaptation strategies for each of the student learning preferences identified in the previous chapter.

We start with a critical review of existing approaches, overviewing the adaptation methods used in state-of-the-art LSAES, as well as summarizing the findings of the reported experimental results. Next we introduce our own approach, in the form of adaptation rules and their implementation as adaptation techniques.

The main achievements of our work are threefold: i) separation of knowledge about learning styles as modularized sets of rules; ii) explicit representation of the rules, encouraging their understandability, maintainability and reusability; iii) facilitation of appropriate implementation of the rules in an adaptive educational hypermedia system. Conceiving these adaptation rules was a delicate task, since it involved interpretation of the teaching guidelines that accompany each of the learning style models, which usually have a descriptive rather than prescriptive character.

The adaptation logic can be decomposed into elementary actions, such as annotating, inserting, eliminating, sorting or moving learning objects. In the case of our LSAES, an adaptation rule can be abstracted as follows:

General adaptation rule
IF
$X \in Pref(L)$
THEN
<u>Action</u> $Object$ {*Value*}

Object can be either a metadata element of a learning object, carrying a specific *Value* (as described in more detail in Chapter 6), or an interface element or a communication tool.

Our pedagogical goal was to offers students recommendations regarding the most suitable learning objects and learning path, but let the students decide whether they want to follow our guidelines or not. We therefore decided to rely on sorting and adaptive annotation techniques rather than direct guidance or hiding/removing fragments. We also decided to use the popular "traffic light metaphor", to differentiate between recommended LOs (with a highlighted green title), standard LOs (with a black title, as in case of the non-adaptive version of WELSA) and not recommended LOs (with a dimmed light grey title).

The effectiveness of the adaptation process was confirmed by means of an experimental study, involving 64 students who were split in two groups: one which was provided with a matched version of the course (further referred to as "matched group") and one which was provided with a mismatched version of the course (further referred to as "mismatched group"), with respect to the students' learning preferences. Since we used the same subjects for the adaptive and non-adaptive sessions we will be able to perform both an intrasubject and an intersubject comparability study. In order to evaluate the adaptation process, we used two kinds of data: i) the behavior of the students in WELSA, as monitored and logged by the system; ii) the students' opinion about the adapted course, as stated in the dedicated surveys.

The results obtained are very encouraging: the matched adaptation approach greatly increased the efficiency of the learning process, with a significantly lower amount of time needed for studying and a lower number of randomly accessed resources (lower level of disorientation). The effectiveness of the matched adaptation and its suitability for addressing students' real needs are also reflected in the significantly higher time spent on recommended versus not recommended resources, as well the higher

number of accesses of those recommended learning objects. Finally, the recommended navigation actions were followed to a larger extent than the not recommended ones.

As far as students' subjective evaluation of the system is concerned, the greatest improvements between the adaptive and non-adaptive sessions were perceived by the students in the matched learning group in terms of enjoyment (65.63%), overall satisfaction (65.63%), motivation (56.25%) and learning effort (56.25%). At the same time, students in the mismatched learning group reported lower levels of overall satisfaction (71.87%), enjoyment (59.38%), motivation (59.38%), as well as an increase in the learning effort (62.5%).

The overall results of the experimental study proved the positive effect that our adaptation to learning styles has on the learning process. The study also underlined the importance of using fragment sorting (i.e. resource ordering), one of the simplest adaptive hypermedia techniques, but as it turns out, also one of the most efficient. This technique also implies the least amount of work from the part of the teacher, who only has to ensure that the examples / exercises / simulations etc are formulated as independently as possible from the fundamentals they complete.

It should be mentioned also that this experiment was performed with second year students, who had little experience with web-based educational systems and therefore preferred to be guided during their study. Perhaps more advanced students would know better how to organize their learning path and would also benefit from the challenging advantages of the mismatched adaptation strategy. Further studies are required to validate this hypothesis.

Chapter 6 ("WELSA System") addresses the third research question, by presenting the dedicated e-learning platform called WELSA (**W**eb-based **E**ducational system with **L**earning **S**tyle **A**daptation), which implements the modeling and adaptation techniques proposed in the previous chapters. Various aspects are covered, related to system architecture, intelligent way of organizing the learning material, functionalities, technologies, design and implementation.

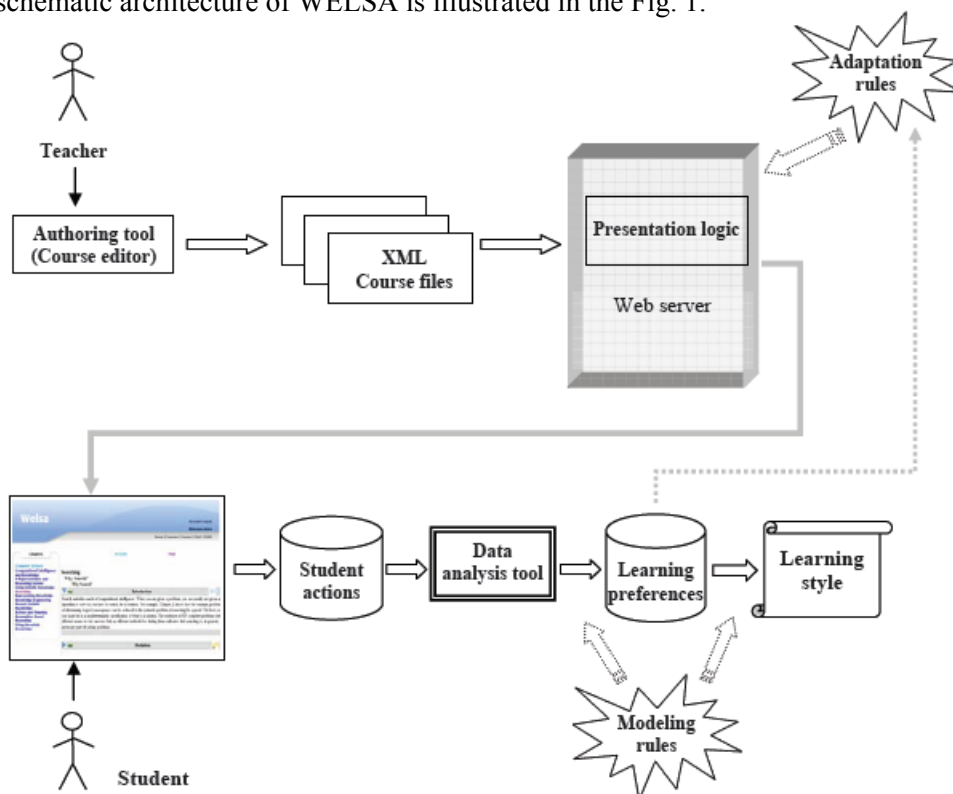The schematic architecture of WELSA is illustrated in the Fig. 1.

Figure 1. Overall WELSA architecture

WELSA offers several functionalities:

- an authoring tool for the teachers, allowing them to create courses conforming to the internal WELSA format

- a course player (basic learning management system) for the students, enhanced with two special capabilities: i) learner tracking functionality (monitoring the student interaction with the system); ii) adaptation functionality (incorporating adaptation logic and offering individualized course pages)

- a data analysis tool, which is responsible for interpreting the behavior of the students and consequently building and updating the learner model.

As far as the implementation is concerned, Java-based and XML technologies are employed for all WELSA components. Apache Tomcat 6.0 is used as HTTP web server and servlet container and MySQL 5.0 is used as DBMS.

Among the main contributions presented in Chapter 6 is the intelligent way of organizing and indexing the learning resources and the introduction of a set of educational metadata that are independent of any learning style (see Fig. 2). These metadata were created by enhancing core parts of Dublin Core (DCMI, 2008) and Ullrich's instructional ontology (Ullrich, 2005) with some specific extensions to cover the requirements of a LSAES.
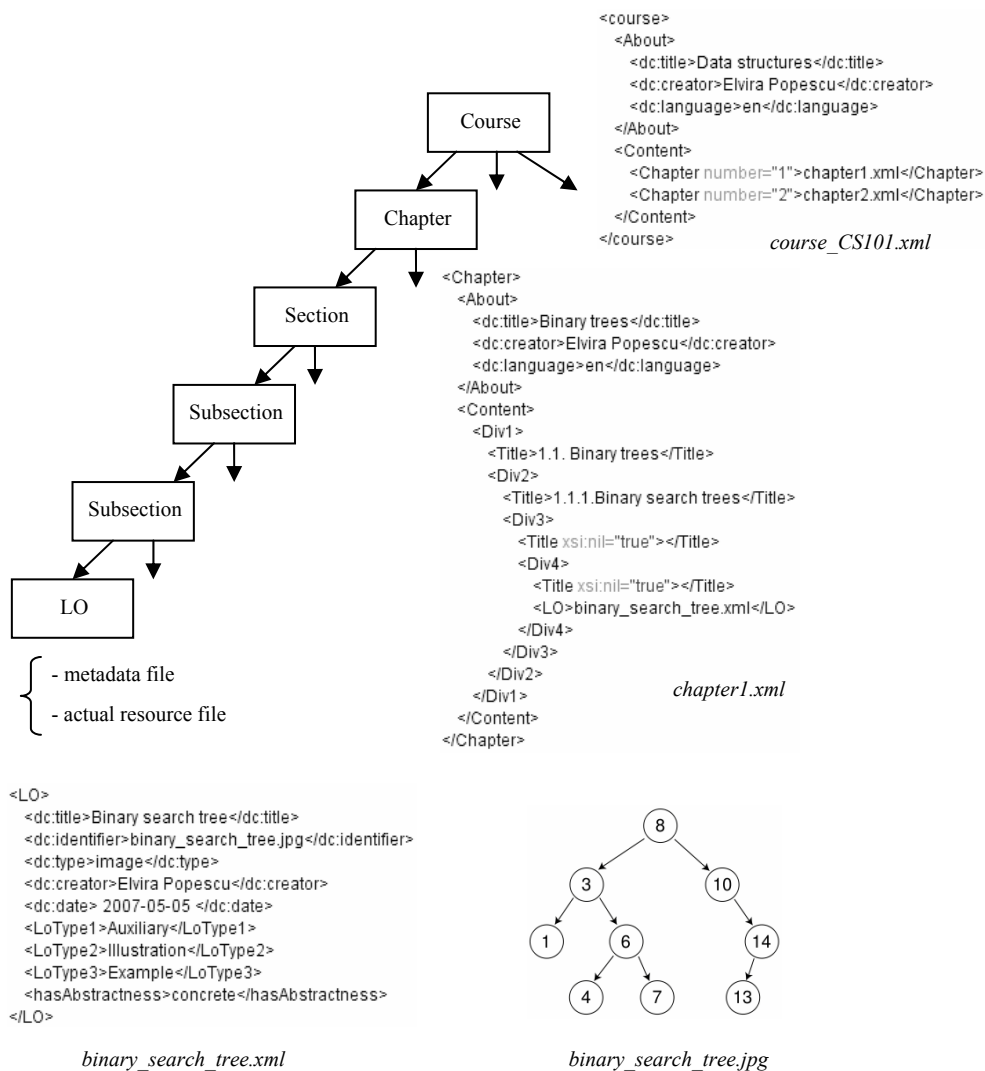

Figure 2. Organization of learning content in WELSA

Unlike many other AEHS, which are only aimed at students, WELSA also offers support for teachers, by means of the course authoring tool which assists them in the process of assembling and annotating the learning resources and automatically generates the appropriate file structure.

Another important feature of the system is the Analysis tool, which implements the learner modeling rules defined in Chapter 4, and at the same time offers various aggregated data that can be used by the researcher for comparisons and statistical purposes.

Finally, the adaptation component performs a dynamic adaptation, by automatically generating the individualized web pages for each student (see Fig. 3). Thus the system is able to include a large number of learning preferences, without an increase in the teacher workload; indeed, she/he will have to prepare the same amount of educational materials, which will be dynamically combined by the system, according to each student's preferences.
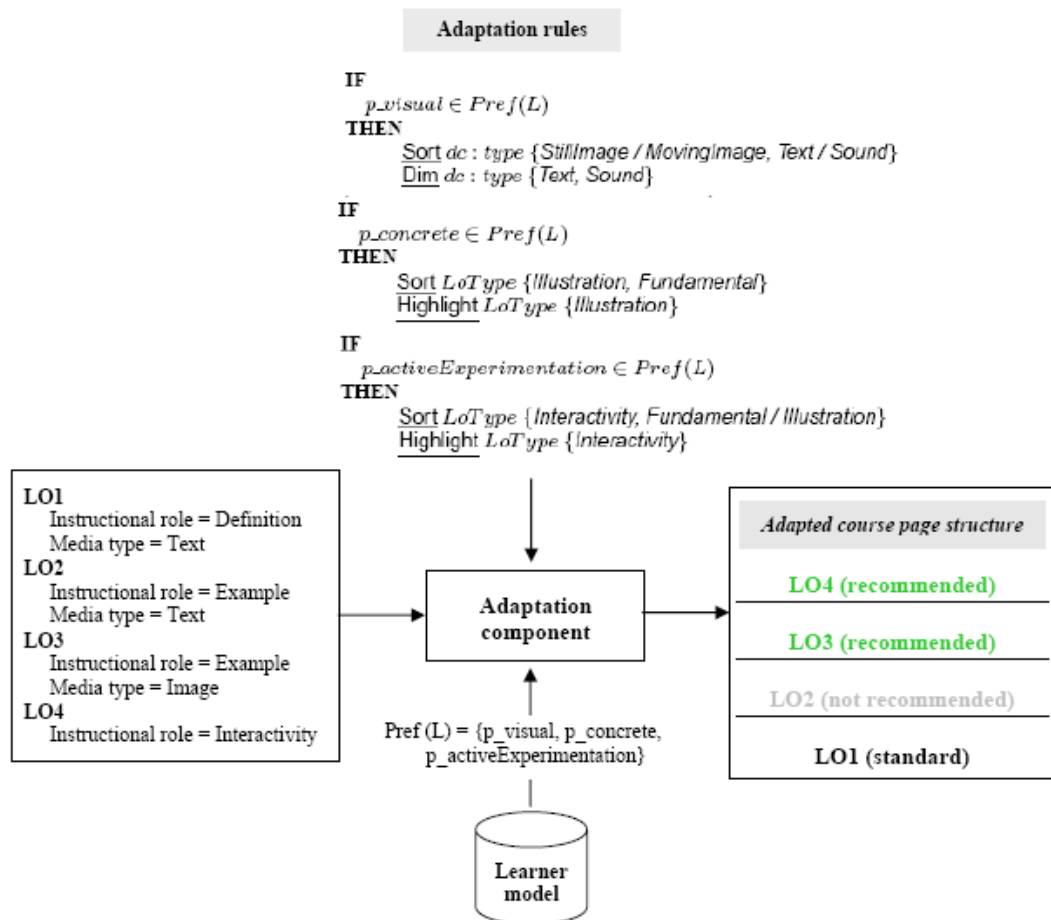

Figure 3. Automatic generation of an adapted course page for a student with preferences towards visual perception modality, concrete examples and active experimentation

The final step of our research was the global evaluation of WELSA system. In order to assess the validity and effectiveness of our system, we used the empirical evaluation approach (which is of a particular importance in the field of adaptive systems) involving two experiments with undergraduate students. The analysis of students' answers to the survey instruments revealed the high degree of learner satisfaction with the system, as well as their desire to use WELSA system on an everyday basis.

Chapter 7 ("Conclusions") concludes the thesis, giving a summary of its main contributions, discussing its limitations and pointing towards future research directions.

We do not claim to have solved the "wicked problem" of learning style modeling and adaptation. We do however hope to have shed light on some aspects and filled in some of the gaps. Further research is of course needed to clarify the remaining and newly raised issues.

A limitation of this thesis is represented by the relatively restricted student sample that was used in our experiments – in order to allow for generalization, the modeling and adaptation methods should be tested on a wider scale, with users of variable age, field of study, background knowledge and technical experience. However this is a limitation that most studies in the e-learning area suffer from; indeed, the number of students in our experiments is greater than the average reported in related work. Furthermore, the laboratory settings could be seen as a limitation. When students know they are observed, the Hawthorne effect (i.e. a short-term improvement caused by observing user performance) might alter their normal behavior. However, it should be noted that students were not aware of the purpose or expected outcome of the experiment, so it is unlikely that they deliberately tried to confirm researcher's expectations. Nevertheless, it would be interesting to conduct the experiments in more realistic settings, with students working from the privacy of their own homes and for longer periods of time.

We have also identified several research directions:

- Provide further support for the teacher / author: while a dedicated course editor is already included, an import / export facility, allowing for conversion between various course formats and standards (e.g. SCORM, IMS LD etc) would be very helpful, providing for greater reuse.

- Extend the adaptation component, by incorporating a wider variety of adaptation actions and investigating whether there are some adaptation features that have more impact than others.

- Individualize the adaptation techniques to the characteristics of the students, by creating a meta-adaptive system (which should adaptively select the adaptation technology that is the most appropriate for the given student and context)

- Extend the modeling component to take into account the perturbations introduced by the adaptation on students' actions. Students' behavior in the adapted version could then be used as a valuable feedback on the effect of adaptation. In this context, our research can be seen as the basis for a truly dynamic learner modeling approach.

The findings and results obtained in this thesis open up many research perspectives for the AEHS field in general and LSAES field in particular. We believe these future directions to be worthwhile endeavors, since throughout this thesis we showed that we both *can* and *should* use learning styles in adaptive web based educational systems.