Personalizing the Interaction in a Web-based Educational Hypermedia System: the case of INSPIRE

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Abstract. In this paper we present an Adaptive Educational Hypermedia prototype, named INSPIRE. The approach employed in INSPIRE emphasizes the fact that learners perceive and process information in very different ways, and integrates ideas from theories of instructional design and learning styles. Our aim is to make a shift towards a more "learning-focused" paradigm of instruction by providing a sequence of authentic and meaningful tasks that matches learners' preferred way of studying. INSPIRE, throughout its interaction with the learner, dynamically generates learner-tailored lessons that gradually lead to the accomplishment of learner's learning goals. It supports several levels of adaptation: from full system-control to full learner-control, and offers learners the option to decide on the level of adaptation of the system by intervening in different stages of the lesson generation process and formulating the lesson contents and presentation. Both the adaptive and adaptable behavior of INSPIRE are guided by the learner model which provides information about the learner, such as knowledge level on the domain concepts and learning style. The learner model is exploited in multiple ways: curriculum sequencing, adaptive navigation support, adaptive presentation, and supports system's adaptable behavior. An empirical study has been performed to evaluate the adaptation framework and assess learners' attitudes towards the proposed instructional design.

Key words. Adaptive educational hypermedia systems, Adaptation, Adaptivity, Adaptability, Learner control, Learner model, Distance learning, instructional strategies, instructional design, learning styles, curriculum sequencing, adaptive navigation support, adaptive presentation

1. Introduction

A Web-based classroom (or virtual classroom) is an educational environment in which learners and educators are able to perform classroom-like tasks: the *Web* provides the medium and accommodates the educational environment; the *educators* design the learning experience by preparing the educational material, deciding on the pedagogical approach, outlining the learning objectives of the course and how these are fulfilled, and support the learners; lastly, *learners* are mainly responsible to plan, carry out and evaluate their own learning.

Using the Web as an instructional medium can benefit learners more when technology is used effectively following a learner-centered pedagogical approach to enhance the learning experience (Lin and Hsieh, 2001). Towards this direction, Adaptive Educational Hypermedia (AEH) systems (Brusilovsky, 1996; 1999; 2001) are a relatively recent area of research that aims at effectively combining two opposed approaches to computer assisted learning: the more directive *tutor-centered* style of traditional Intelligent Tutoring Systems and the flexible *learner-centered* browsing approach of Hypermedia systems (Eklund and Zeilinger, 1996). *Adaptation,* in this context, is defined as the concept of making adjustments in an educational environment in order to accommodate a diversity of learner needs and abilities, maintain the appropriate context for interaction, and increase the functionality of hypermedia by making it personalized (Brusilovsky, 1996; 1999; 2001). Several levels of adaptation can be distinguished, depending on who takes the initiative: the learner or the system (Kay, 2001; Murray, 1991). Thus, a critical point in designing AEH systems is how to balance the two different forms of adaptation: (*i*) *adaptivity*, i.e. the system adapts its output using some data or knowledge about the learner in a *system controlled* way and (*ii*) *adaptability*, i.e. the system supports end-user modifiability providing *learners control* over several functionalities.

Personalization in an educational context needs a certain understanding of the learner as well as of the tasks that are important to learning. Thus, the design of the learner model (Kay, 2001) and the instructional model adopted mainly influence system's adaptation. The learner model should represent those discriminative characteristics of the learner which can be proven relevant to learning in a particular educational environment, such as prior knowledge of the domain, experience, learning preferences, learning/cognitive style etc. During interaction, the system builds a learner model for each individual learner and continuously updates it in order to keep always the "current state" of the learner. However, in order to exploit information provided by the learner model, it is necessary to determine which instructional strategies are suitable for learners of a particular model and how these strategies could be supported by the knowledge representation scheme of the Web-based environment. Theories from Instructional Design, Adult Learning and Learning Styles are valuable resources to support instructional decisions and enhance the educational perspective of an AEH system.

In this paper, we present the instructional design, and the adaptivity and adaptability features of a recently developed AEH system, named INSPIRE (INtelligent System for Personalized Instruction in a Remote Environment), as well as the underlying techniques used to support these features. Based on the learning goal that the learner selects from a set of meaningful goals proposed by the system, INSPIRE generates lessons tailored to the learning style and knowledge level of each learner by making use of information gathered through learner-system interaction, with the aim to individualize instruction. Furthermore, it provides learners with the option to intervene in the lesson generation process, express their opinion about their own characteristics or about the lesson contents, and, in this way, offers instructional control over the system.

The paper is organized as follows. In Section 2, adaptivity and adaptability are considered in the context of existing AEH systems. Moreover, several technologies used to implement adaptation in AEH systems are presented as well as several representative systems proposed in the literature. Section 3 describes the framework of instructional design, the domain model and the learner model of INSPIRE. In Sections 4 and 5 the adaptive and adaptable features of the system are presented. Section 6 presents evaluation results and the paper ends, in Section 7, with conclusions and future work.

2. Adaptation in Educational Hypermedia Systems

AEH systems incorporate the idea of offering learners personalized support and/or instruction. To this end, several issues should be considered. First of all it is important to consider how learner characteristics and needs are reflected to the design of the system (Höök et al. 1996; Kay, 2001). AEH systems reflect several learner characteristics to the design of the learner model, and apply this model to adapt various visible aspects of the system to individual learners (Brusilovsky, 1996; Kobsa, 2001). Another important issue is to effectively design the sharing of control between the system and the learner (Hannafin and Sullivan, 1996; Shyu and Brown, 1995), as many researchers acknowledge that learners appear to benefit from learner control opportunities (Jonassen et al. 1993; Shyu and Brown, 1995). Moreover, it is also important to consider the educational potential of adaptation (McCalla, 1992) and investigate the educational implications of the use of adaptive educational environments. Thus, although many questions are still open in the area of Cognitive Science about *instruction*/*learning* and how it is efficiently provided/attained (Vosniadou, 1996), it is important to consider adaptation within the framework of current learning theories and models, and thoroughly plan the sharing of the task of adaptation between the learner and the system (Hammond, 1992; Lawless and Brown, 1997).

In general, adaptivity is system-controlled and, usually, assists in: (*i*) planning the content; (*ii*) planning the delivery and presentation of the educational material; (*iii*) supporting learner's navigation through the domain knowledge; (*iv*) problem solving. On the other hand, adaptability allows the learner to: (*i*) control several aspects of the system, such as screen design issues and intelligent features, and *(ii)* intervene and guide instructional decisions. This range of adaptation, i.e. from system driven to user driven, has been described through several taxonomies. Dieterich et al. (1993) recognize four different stages that have to be considered when examining the adaptation process: initiative (decision to suggest adaptation), proposal (alternatives of adaptation have to be proposed), decision (selection of one of the alternatives for adaptation) and execution (execution of adaptation). Depending on who performs or controls these stages, i.e. the system or the user, a classification of systems is defined. Thus, based on the terms proposed, in case that the system performs the tasks for all stages, the system is classified as a Self-Adaptive system. Accordingly, adaptable systems are considered those using Computer-Aided Adaptation (user performs initiative and decision), User Controlled Self-Adaptation (user performs decision), or Adaptation (user performs initiative, proposal, decision while execution is optionally performed by the user or the system). Also, according to Kobsa et al. (2001) there are different basic types of adaptation depending on the amount of control a user has over the adaptation. Thus, systems where the user is in control of initiation, proposal, selection (an alternative to the "decision" proposed in (Dieterich et al.,1993)) and production of adaptation (an alternative to the "execution" proposed in (Dieterich et al.,1993)), i.e. the user has the option to control these functions or let the system perform some of them, are called adaptable. Accordingly, systems that perform all functions autonomously are called adaptive. Moreover, intermediate forms are also possible such as user-controlled adaptivity (the user makes the selection and performs the selected adaptations) and user-initiated adaptivity (the user initiates the adaptation). Lastly, two different dimensions proposed in (Kobsa et al., 2001) that outline the adaptation process are volatility and complexity. The *volatility* of the adaptation addresses the timing and the dynamics of adaptation production, whilst the *complexity* of adaptation is a relative measure of the complexity and directness of the process that produces the adaptation based on a number of input data, i.e. if there is a direct relationship between the input and the adaptation then the complexity is low.

Several adaptive and intelligent technologies have been applied to introduce adaptation in AEH systems (Brusilovsky, 1999). Thus, with respect to the adaptive dimension of AEH systems, technologies from

Intelligent Tutoring Systems, such as *curriculum sequencing* (DCG, ELM-ART, InterBook, AST, ACE), *problem-solving support* (ELM-ART, ELM-PE, Lisp-Tutor, SMILE, PROUST, CAMUS II), have been adopted, as well as technologies from Adaptive Hypermedia Systems, such as *adaptive presentation* (MetaDoc, Hypadapter, Anatom-Tutor, C-book, KN-AHS, PUSH, AHA) and *adaptive navigation support* (ISIS-Tutor, Interbook, Hypadapter, ELM-ART, AST, ACE, KBS Hyperbook, AHA). In curriculum sequencing, the system provides learners with the most suitable, individually planned, sequence of knowledge units to learn and learning tasks to work with. In *problem-solving support*, the main idea is to help learners in solving an educational problem. In *adaptive presentation*, the content of a hypermedia page is adapted to the learner, whilst in *adaptive navigation support*, the system alters a number of visible links to support hyperspace navigation.

In designing AEH systems developers should take into account several technical and educational aspects. The platform (e.g. web-based or stand alone), technology used for adaptation (curriculum sequencing, adaptive navigation support, adaptive presentation, problem-solving support) and adaptability features are examples of technical aspects considered. The application domain, learner characteristics captured by the learner model and pedagogical framework (teaching/learning theories/approaches) adopted to guide the adaptation are examples of educational aspects considered.

In more detail, the adopted pedagogical framework that affects systems' adaptive behavior takes into account several characteristics of the learner and exploits the adopted domain model, which is usually defined by the expert-teacher based on his/her teaching experience. As opposed to Intelligent Tutoring Systems where the main focus is in problem-solving support, one of the main attractions of a Web-based educational system is to present a solid amount of educational material (Brusilovsky, 1999). Several teaching/learning theories/approaches have been used in AEH systems providing the central concept of the interactions that take place between the system and the learner and in many cases formulating specific teaching strategies included in the system. These strategies are usually responsible for deciding how to sequence the content and the educational material in relation with specific learning outcomes, and thus they imply the type of educational material to be developed. In the KBS Hyperbook system (Henze et al., 1999), which is a project-based learning environment, learners work with projects and the system adapts the project resources to their knowledge level and/or learning goals. Thus, learner-system interaction is based on activities which have been developed according to project-based learning. In AST (Specht et al., 1997) several teaching strategies have been adopted, which simulate strategies used by teachers when teaching different types of concepts in statistics: learning by example, learning by reading texts, learning by doing. The approach of adopting multiple teaching strategies has been also adopted in DCG (Vassileva, 1997; 1998), where the course is generated dynamically depending on the given teaching goal and can be dynamically changed following specified teaching rules proposed by Van Marke (1992; 1998) to suit better to learner's individual progress and preferences.

AEH systems maintain a learner model for each individual learner that includes several learner characteristics, learner's navigation history, etc. In particular, learner models usually represent learner's knowledge level on the concepts of the domain, goals, learning preferences of different types of educational material, etc. The domain model in most of the cases provides a structure for the representation of learner's knowledge of the subject matter, and thus it is used in parallel with the learner model, which stores for each domain concept a value, i.e. an estimation of the knowledge level of the learner for a particular concept. Learner's observable behavior is, in many cases, the basis for the diagnosis of certain characteristics of the learner such as his/her preferences of the learning material but also his/her knowledge level. In particular, their knowledge level with respect to different elements of the domain is determined by learners' navigation through the domain, i.e. it is history–based (based on the web pages that learners have visited) or pre-requisite-based (based on the web pages that learners have visited and how these are related), or by the submission of assessment tests, i.e. it is knowledge-based (based on learners' demonstrated knowledge of the content) (Eklund and Sinclair, 2000). For example, in Hypadapter (Hohl et al., 1996) each time a topic reference is followed, learner's knowledge level – represented by a numerical value from 0 (unknown) to 10 (well-known) – is slightly incremented. Alternatively, in DCG the knowledge level of the learner is defined as the extent to which the learner knows a concept and is represented by a probabilistic estimation. A simple formula that takes into account the number and the difficulty of successfully solved tests-items related to each concept is used to calculate these estimations (Vassileva, 1997).

Other learner characteristics that are important to learning, such as learners' individual traits (these refer to learner features that define a learner as an individual, such as personality factors, cognitive factors, learning styles) have not taken considerable attention as a source of adaptation (Brusilovsky, 2001). User's individual traits are traditionally extracted by specially designed psychological tests and not by simple interviews (Brusilovsky, 2001). Actually, the main problems in exploiting such information is to determine which features should be used (are worth modeling) and how (what can be done differently for learners with different styles). However, different approaches have been adopted in several AEHSs. In DCG, learners' personal traits and preferences, such as intelligence, self-confidence, motivation, concentration and learner's preferred type of media, are assigned by the learner himself, and are used by the method-selection rules, which are responsible for the selection of instructional tasks for a concept and of the appropriate task-decomposition method employed (Vassileva, 1997). In Arthur (Gilbert and Han, 1999), learner's learning style is considered as the style of instruction to which learners exhibit a satisfactory performance. Alternative styles of instruction used in Arthur differ in the type of media they utilize. Thus, their implementation requires the development of multiple types of educational material that use different types of media for each particular section of the course. In AST, the learning style of each learner is approached from the perspective of preferred learning materials and teaching strategy (learning by example, reading texts or learning by doing), as specified by the learner in an introductory questionnaire. As learner interacts with the system, the teaching strategy is adapted based on his/her actions and on the success of the currently employed strategy, which is determined by learner's performance on the tests s/he submits (Specht et al., 1997). In AST the alternative teaching strategies mainly differ in the sequence of the learning materials they propose.

Furthermore, with respect to the adaptable dimension of AEH systems, several levels of adaptability have been adopted, ranging from learners' control over the learning goal/next section to study, or learners' intervention to system decisions, to full learners' control over the system. In AST and in Hypadapter when learners first log on the system they submit an introductory questionnaire to initialize their own learner model. Questionnaires provide a means of controlling and customizing various aspects of the system at the beginning of the interaction. Learners have the option to express their changing needs and introduce further adaptations into the system at any time, as it happens to Hypadapter, by dynamically modifying entries of questionnaires during interaction. In DCG, learners undertake control over the system depending on their aptitudes. For example, if the learner is motivated and success-driven then s/he is allowed to select what to study next, and how (i.e. the instructional task and method); in case s/he is unsure and not confident then the system takes on the initiative to decide what to do next. Another approach is providing learners access to their model in order to define their own characteristics, such as in ELM-ART (Weber and Brusilovsky, 2001) where the learner can see and update his/her screen design preferences, knowledge level on the different topics of the domain structure, preferences about system's adaptive behavior. Lastly, an interesting approach was proposed by Oppermann (1994), who suggested the usage of adaptive tips that the system provides to learners in order to lead them to the adaptation and explain its use.

Table I compares several Adaptive Hypermedia (AH) systems proposed in the literature in terms of their adaptive and adaptable characteristics. Thus, in Table I the technological (platform, adaptation technology) and educational dimensions (application domain; characteristics of learners used as source of adaptation; pedagogical framework that guides system's design; adaptability) of several AH systems are summarized.

INSPIRE, the AEH system presented in this paper, builds on and expands further the above-mentioned ideas of introducing adaptivity and adaptability in educational hypermedia systems. In INSPIRE, instructional design theories are combined with the learning styles theory to develop an adaptation framework that is educationally effective and technologically feasible. This framework unifies several processes that mainly affect system's adaptation, such as structuring the domain model and developing the educational material, assessing learner's knowledge level, planning the content, delivery and presentation of educational material, and providing the appropriate navigation support to learners. INSPIRE supports several levels of adaptation, which range from full system-control to full learner-control. The adaptable functionality of the system is mainly based on externalization of the learner model. With regards to the adaptive dimension of the system, INSPIRE generates and provides individualized web-content by exploiting the learner model and in particular information about learners' knowledge level and individual traits, such as their dominant learning style which is approached through the classification proposed by Honey and Mumford (1992). INSPIRE also utilizes the learner model to determine the appropriate instructional strategy for selecting the lessons contents (curriculum sequencing), presenting the educational material (adaptive presentation technology), and annotating hyperlinks in the domain hyperspace (adaptive navigation support).

AH Systems	Web-based	Application/Title	Adaptation Source	Adaptation Technology	Adaptability	Teaching/Learning theories/approaches
MetaDoc (Boyle and Encarnacion, 1994)	No	"Managing the AIX Operating System"	Knowledge level on Unix/AIX and computer concepts	AP	Manipulation of concepts presentation through the user model	N/A
Hypadapter (Hohl et al., 1996)	No	"Common Lisp"	Knowledge level, Preferences and Navigation behavior	AP and ANS	Manipulation of specific entries of user model through questionnaires	Example-based & Action-oriented learning strategies
Anatom-Tutor (Beaumont, 1994)	No	"Anatomy for medical learners"	Knowledge level	AP	N/A	Task Analysis (Gagné, 1977)
Dynamic Course Generation (Vassileva, 1997; 1998)	Yes	Domain Independent	Knowledge level, Learning goal, Personal traits & preferences	CS	Direct manipulation of learning goal, personal traits & preferences	Generic Task Model (Van Marcke, 1992)
ELM-ART (Weber and Brusilovsky, 2001)	Yes	"Programming in Lisp"	Knowledge level and Preferences	PSS, ANS, and CS	Direct manipulation of user model	Example-based programming
ISIS-Tutor (Brusilovsky and Pesin, 1994)	No	"Print formatting language of information retrieval system CDS/ISIS"	Knowledge level and Educational goals	ANS and AP	Direct manipulation of next teaching operation, educational goal	Multiple teaching operations: concept presentations, problems to solve, examples to analyze
Interbook (Brusilovsky et al., 1998)	Yes	Domain Independent	Knowledge level	CS and ANS	N/A	N/A
PUSH (Höök et al., 1996)	No	"Software development method SDP"	Information seeking needs	AP	Direct manipulation of task stereotypes, User verified plan recognition	N/A
KBS Hyperbook (Henze et al., 1999)	Yes	"Introduction to Programming (based on Java)"	Knowledge level and Learning goals	ANS	Direct manipulation of learning goal	Project-based learning
AST (Specht et al., 1997)	Yes	"Introductory Statistics"	Knowledge level and Learning style preferences	CS and ANS	Submission of introductory questionnaire about preferred type of material, teaching strategy, level of detail for texts	Multiple teaching strategies: Learning by example, by reading texts, by doing
CS383 (Carver et al., 1996)	Yes	"Computer Systems"	Learning style (Felder & Silverman, 1988)	AP	Initiation of adaptation	Media selection based on learners' learning style
Arthur (Gilbert and Han, 1999)	Yes	"Computer Science Programming"	Learning style preferences	CS	N/A	Mastery learning (Bloom, 1968) Multiple instructional styles: visual-interactive, auditory-text, auditory-lecture, text style

Table I. Comparison of AH systems, where ANS: Adaptive Navigation Support; AP: Adaptive Presentation, CS: Curriculum Sequencing, PSS: Problem Solving Support

3. INtelligent System for Personalized Instruction in a Remote Environment (INSPIRE)

INSPIRE is an AEH system that aims to facilitate learners during their study, by restricting the domain knowledge at the beginning of the interaction, an approach appropriate to novices (Bransford et al., 1999), and enriching it, progressively, following their performance. Based on the notion of learning goals that the learner selects, INSPIRE generates lessons that correspond to specific learning outcomes, accommodating learner's knowledge level, progress and learning style. Furthermore in INSPIRE, learners are provided with the option to decide on the level of adaptation of the system. Thus, we avoid predefining the framework of learners' interaction with the system and provide learners opportunities to control the dynamic lesson generation process, as well as, their model, which is used further as a source of adaptation by the system.

In Figure 1, the main screen of INSPIRE is shown. It is divided into three different areas to better support system's functionality: Navigation area, Content area and Toolbar. Learners have access to the whole structure of the domain of each particular lesson (see Figure 1–Navigation Area) and are able to select the concept and the educational material to study next (see Figure 1–Content Area). When the learner clicks on a concept link in the Navigation Area, the concept "opens"-links to material pages are listed under the name of the concept and the introductory page of the selected concept is presented in the Content Area. In addition, Toolbar (see Figure 1 - Toolbar) provides direct access to several facilities and to system's adaptive functionality.

Personalization in INSPIRE affects both the Navigation and Content Areas. The first time learners enter the system, they select the learning goal that they want to study and then the first lesson is generated. The lesson contents appear in the Navigation Area as hyperlinks whilst in the Content Area, the pages of educational material that the learner selects from the Navigation Area appear. Following the knowledge level of the learner, INSPIRE provides navigation support by adapting the Navigation Area accordingly. The presentation of the educational material in the Content Area is adapted to the learning style of the learner. The Toolbar provides learner with access to several tools, such as accessories that facilitate learners while studying and interacting with the system, i.e. *Personal Notes*, *Favorites, Glossary*, and *Help*; tools that support communication with the virtual classroom through e-mail, chat, discussion lists and bulletin boards, i.e. *Communication*; and tools that allow learners to modify their learner model, i.e. *Learner Model*, and to deactivate the dynamic lesson generation process and manually select the next lesson contents, i.e. *Lesson*.

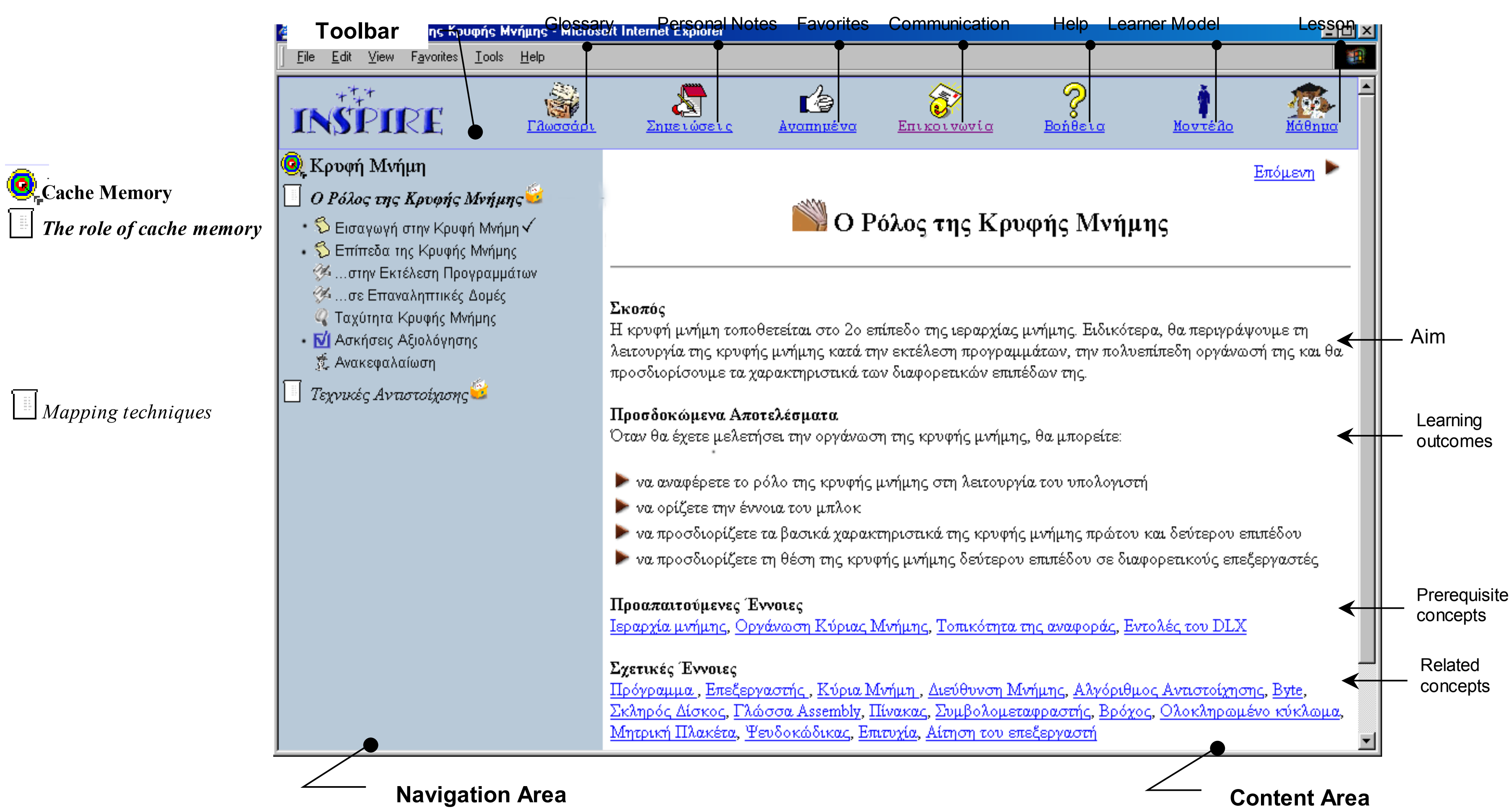


Figure 1. The introductory page of the concept "The role of cache memory". INSPIRE's main screen is divided into three areas: (i) the Navigation Area shows the contents of the lessons in a hypertext form as links; (ii) the Content Area presents the pages of educational material that the learner selects from the Navigation Area; (iii) the Toolbar contains several tools/icons (Glossary: link to a glossary of terms, Notes: link to this page notepad, Favorites: link to the educational material pages the learner has marked as favorites, Communication: communication capabilities, such as e-mail, chat, discussion lists and bulletin boards, Help: information on system functionality, Learner Model: link to a page where the learner can inspect and modify his/her model, Lesson: link to a page where the learner can deactivate the dynamic lesson generation process and select the contents of the next lesson).

Currently INSPIRE is used to support an introductory course on Computer Architecture offered to second level undergraduate learners of the Department of Informatics and Telecommunications of the University of Athens. INSPIRE is used as a supplementary resource to traditional classroom-based teaching and includes material about the type, technology, organization, performance and cost of *computer memory*. The system targets adults with an elementary background in Computer Science.

3.1. A Framework for Instructional Design

Designing an instructional framework on which the adaptation of an AEH system could be based should take into consideration two different perspectives: educational and technological. The educational perspective, in particular, relates to pedagogical decision-making, which concerns two different options: planning the content (what concepts to focus on) and planning the delivery of instruction (how to present the concepts) (Wasson, 1992). Thus, the design of a comprehensive instructional framework should exploit theories that provide the necessary guidelines to develop both options. However, it is argued that one issue that instructional designers face when designing courses based on specific instructional design theories is how to operationalize the prescriptions they provide, as in many cases instructional design theories are breadth (although comprehensive) and offer few specific instructions for implementation (Reigeluth, 1987). In fairness, it should be also mentioned that many of the more recent theorists have opted to sacrifice breadth in order to achieve greater depth and provide more detailed guidance for instructional designers and teachers (Reigeluth, 1987).

Especially in the case of AEH systems, where the domain knowledge model is incorporated in the system and mainly affects the effectiveness of adaptation, the principle that pedagogical decision making concerns both the content and the delivery of instruction could be exploited further to formulate guidelines for structuring the domain knowledge and developing the appropriate educational material resources. Thus, in our approach we integrate ideas from two distinct theories from the area of Instructional Design, which provide detail prescriptions about the selection and sequencing of instruction, and we combine them with the learning style theory in order to individualize instruction based on learners' individual traits. Following the theory of learning styles, (Schmeck, 1988; Riding and Rayner, 1998; McLoughlin, 1999), the effectiveness of instructional manipulations is mainly influenced by educational experiences geared toward learners' particular style of learning. This approach to learning emphasizes the fact that individuals perceive and process information in very different ways. This framework for instructional design, that will be presented in detail below, guides both the adaptation of INSPIRE as well as the development of its domain knowledge model.

In INSPIRE, the synergy of two traditional instructional design theories with the learning style theory helps us to make a shift towards a more "learning-focused" instructional design framework by providing learners with various authentic and meaningful tasks, which are presented in a sequence that matches learners' preferred way of studying. This is in accordance to a new trend in instruction which is moving from standardization to customization, from a focus on presenting material to a focus on making sure that learners' needs are met, and thus is heading to a "learning-focused" paradigm, which should be accompanied by a shift from decontextualizing learning to authentic, meaningful tasks. Reigeluth (1999) argues that this paradigm of instructional design theory should focus on multiple kinds of learning, which consequently require multiple methods of instruction. According to Reigeluth (1999) this paradigm requires the definition of instruction to include what many cognitive theorists refer to as "construction": a process of helping learners to build their own knowledge as opposed to a process of merely conveying information to the learner; instruction must be defined more broadly as anything that is done to facilitate purposeful learning. This is essential especially in a web-based environment where tutors are mainly facilitators rather than the main agents, and thus other valuable agents supporting learners to their study are well-designed resources. Instructional design theories and instructional technology can play a major role in the development and delivery of resources offering, at the same time, guidance for their use towards a "learning-focused" paradigm of instruction.

As outlined above, the proposed instructional framework for modeling the domain knowledge of INSPIRE integrates ideas from two distinct instructional theories. The first theory refers to the macro level providing prescriptions for selecting, sequencing, synthesizing and summarizing instructional content, called Elaboration Theory (Reigeluth & Stein, 1983). The aim is to organize instruction in order to show interrelationships among the different concepts of the domain following specific strategies (Hoffman, 1997). The second theory refers to the micro level providing prescriptions for the development of the educational material of the main domain concepts tailored to specific performance levels, called Component Display Theory (Merrill, 1983). To this end, specific strategies are adopted that concentrate on organizing instruction of a single topic and include strategy components such as definitions, examples, and practice (Hoffman, 1997). Lastly, an important aspect of the two theories, as well as of the adaptation framework of INSPIRE, is that they all value learner control and allow learners to undertake control over the instruction. Learner control in this context may offer learners options for the selection and sequencing of the content and instructional strategies, and thereby control over how they study and learn.

Building elements of the Elaboration Theory (ET) that have been considered in the development of the instructional design framework of INSPIRE are selection, sequencing, synthesizing and summarizing. Selection refers to choosing those concepts from the domain that should be taught. Thus, it deals with extracting the fundamental concepts of a specific domain to be presented to the learners. Sequencing refers to organizing the contents, i.e. the fundamental concepts, so that learning would be facilitated. The approach of ET to sequencing is from the general to the specific, or in other words from the simple to complex. The purpose of synthesizing is to show the interrelations among related ideas, such as the relationships that exist between the domain concepts and the general context, as well as among the various concepts of the domain, for example through prerequisite links. Lastly, summarizing enhances learning and could take place in both preview and review materials. Furthermore, ET is compatible to hypermedia, as it provides prescriptions that determine the framework for building structures to model knowledge whilst hypermedia provides the perfect tool for putting the theory into action and outlining these structures (Hoffman, 1997).

Component Display Theory (CDT) formulates the general framework for combining a classification of performance levels and content types with strategy components for teaching or, as happens in INSPIRE for providing the appropriate content for the domain concepts on the different levels of performance. Three levels of learner's performance are defined: *Remember*, *Use* and *Find*. According to the CDT, each different performance level is associated with a different combination of Primary Presentation Forms (PPFs) with the aim to increase learner achievement and learning efficiency (Merrill, 1987). Merrill advocates four PPFs, which can be classified into two dimensions: (*i*) content mode (*Generality* which is a statement, definition, principle or the steps in a procedure, or *Instance* which is a specific illustration of an object, a symbol, event, process or procedure) and (*ii*) presentation mode (*Expository* which means to present or to show, or *Inquisitory* which means to question or to require practice). In general, the suggested PPFs are: Expository Generality; Expository Instance; Inquisitory Generality; Inquisitory Instance. In order for the provided material to be consistent, specific types of PPFs are required at each level of performance to *present* the underlying concepts (with the exception of the Find level), and provide opportunities for *practice* and *assessment*. With respect to other taxonomies of educational objectives, such as those suggested by Bloom (1956), the CDT concentrates on the cognitive domain and deals only with the microlevel strategies for teaching a concept, principle, procedure, etc. providing detailed instructional prescriptions about how to support specific instructional outcomes with the appropriate material.

With regards to the adaptive dimension of INSPIRE, the selection of the lesson contents (curriculum sequencing) and the provided navigation support are both based on the domain model of the system which is formulated according to the above theories. Moreover, the presentation of the educational material (adaptive presentation) to the learners follows their studying attitudes, which are mainly determined by their learning style. In particular, the learning style model of Honey and Mumford (1992) has been adopted as the basis of determining the presentation of the educational material on each of the performance levels. Based on Kolb's theory of experiential learning (Kolb, 1984), Honey and Mumford suggest four types of learners: *Activists*, *Pragmatists*, *Reflectors*, and *Theorists*. According to the proposed instructional design framework, in the generated lessons of INSPIRE, the same educational material modules are reused following different instructional strategies that focus on different perspectives of the presented topic depending on the learning style of the learner (for more details see Section 4.3 - Adaptive Presentation). This approach alleviates the problem of rewriting the same content for each learning style category; a commonly used approach for the development of instructional material tailored to different learning style categories (McLoughlin, 1999). Furthermore, it enhances learning by matching the dominant learning preferences of the learners with the appropriate presentation of educational material, and stimulates learning style growth and collaboration by providing learners with multiple types of educational material resources to study and work with. Learners are motivated to cover the provided educational material exploiting their own capabilities and developing new ones (Kolb, 1984).

3.1.1 Domain Model

The instructional design framework presented in the previous section provides the main guidelines for modeling the domain knowledge of INSPIRE. With the aim of providing learners with control over their learning, the domain model of the system is based on the notion of learning goals that the learner can select and study, and provides learners with a plurality of learning activities and resources. Thus, the domain model is represented in three hierarchical levels of knowledge abstraction (see Figure 2): *learning goals, concepts and educational material* (Papanikolaou et al., 2000). A learning goal corresponds to a topic of the domain knowledge, which can be recognized and selected even by a novice learner. Each goal is associated with a subset of concepts of the domain knowledge, which formulates a conceptual structure that represents all the concepts of a goal and their relationships. Each concept is associated with educational material consisted of *knowledge modules*, which constitute multiple external representations of the concept, such as theory presentations (definitions, descriptions, conclusions), questions introducing or assessing the concept, examples (concrete instantiations of concepts, application examples, analogies), exercises, activities (activities using computer simulation, exploration activities, case studies), definitions in the glossary, etc. In particular, both the structure of the concept level and the development of the educational material level are guided by the ET and CDT theories.

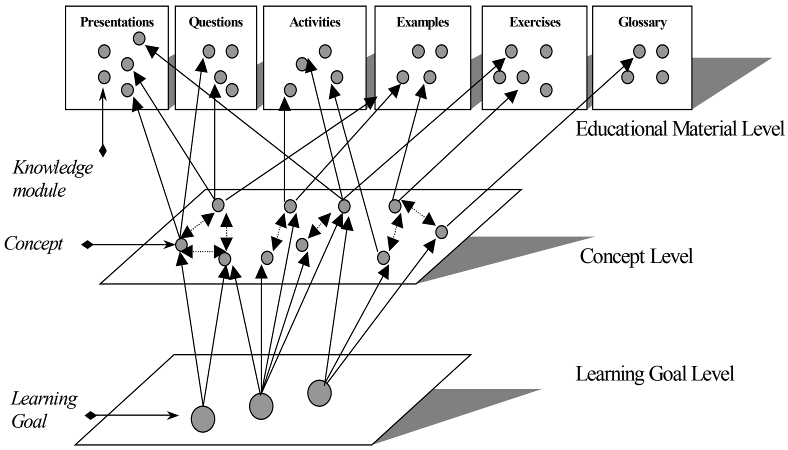


Figure 2. The structure of the domain knowledge of INSPIRE.

Learning goals. The expert-teacher defines a set of meaningful learning goals. Learners are able to select and study the learning goal they prefer independently of their previous selections; all the material necessary for their study is provided when a learning goal is selected. Table II presents the learning goal "Describe the role of cache memory and its basic operations" and its associated concepts for a session on *Computer Memory Hierarchy* of the undergraduate course "Computer Architecture". An educational site for the particular course had been developed before INSPIRE. The course is available online at http://di.uoa.gr/architecture and includes educational material in a hypermedia form organized in chapters, sections and subsections. The educational material of the session on *Computer Memory Hierarchy* was used as the basis for the development of the content of INSPIRE following the domain model described in this section. Examples of learning goals designed for INSPIRE include: "Describe the role and organization of main memory", "Compare the role of cache memory with the main memory", "Describe the role of cache memory and its basic operations", "Evaluate the performance of cache memory" and so on. Currently we have developed educational material for the third learning goal, as we have found experimentally that learners encounter difficulties with this topic (Grigoriadou & Kanidis, 2001). The difficulties refer to a lack of understanding of cache memory internal operation and implementation, and of the role cache memory plays in the communication between the processor and the main memory. The main cause of these difficulties is that the operation of cache memory is not directly observable by learners as well as that cache memory is an abstract concept, which sometimes is obscure even to experts/low-level programmers that use Assembly language (Grigoriadou & Kanidis, 2001).

Concepts Level. The conceptual structure of each learning goal includes concepts that should be taught according to ET prescriptions (selection). These concepts have different degree of importance for the accomplishment of a goal. The concepts that are *fundamental* to the accomplishment of a goal are named *outcome concepts*. In order to fulfill the learning goal, the learner should study all the outcome concepts and be successfully assessed to all of them. Prerequisite and related concepts are associated with each outcome concept complementing its presentation. *Prerequisite concepts* are *essential* to study and work with the educational material of the outcome concept, and *related concepts* are primitive concepts used in the educational material of the outcome. In this way, interrelations among the different concepts of a learning goal are defined following the ET prescriptions (sequencing, synthesis). In the proposed structure, the concepts of the domain knowledge are independent elements that can be reused in different learning goals.

In accordance with the ET prescriptions for sequencing, the outcome concepts of a learning goal are organized further into a layered structure: at the first layer the simplest and more fundamental concepts are included, providing an overview of the learning goal, and then, subsequent layers add complexity or detail to a part or aspect of the learning goal. In Table II the layered structure of the outcome concepts is presented in the column labeled "Layer". For example, the outcome concept "Mapping Techniques" belongs to the first layer as shown in Table II, whilst the second layer includes five outcomes: "Basic Cache Operations", "Identification", "Placement Operation", "Replacement Operation", and "Write Operation".

N	Layer	Outcome Concepts	Prerequisite Concepts	Related Concepts
1	1	The Role of Cache Memory	Memory hierarchy, Main memory organization, Locality of reference, DLX instructions	Sequential program execution, CPU, Main memory, Looping constructors
2	1	Mapping Techniques	Main memory organization	Modulo operation, Block, Memory capacity
3	2	Basic Cache Operations	Main memory organization	Byte-addressable memory, Block
4	2	Identification	Digital circuits, CPU Read/Write operation	Bus organization, Comparator, Multiplexer, Logic gates
5	2	Placement Operation	Digital circuits, CPU Read/Write operation	Bus organization, Multiplexer
6	2	Replacement Operation	Digital circuits, CPU Read/Write operation	Bus organization, Multiplexer
7	2	Write Operation	Digital circuits, CPU Write operation	Bus organization, Buffer
8	3	Cache Performance (CP)	CPU performance, Memory performance	Access time, Clock cycles per instruction

Table II. The conceptual structure of the learning goal "Describe the role of cache memory and its basic operations". Each row contains an outcome concept followed by its prerequisite and related concepts. The order of the outcome concepts corresponds to their order of appearance in the lesson contents (Navigation Area). The layer in which each outcome concept belongs is also presented.

Educational Material Level. The importance of the various concepts of a learning goal with regards to the accomplishment of this goal determines the extent of their presentation. Thus, the educational material pages developed for each outcome concept include knowledge modules that support learners to achieve the three levels of performance of the CDT:

1. The *Remember* level of performance includes knowledge modules that introduce the concept and make learners speculate on newly introduced ideas, such as theory presentations of the concept, questions (introductory or self-assessment), and instances of the concept (real examples or analogies of the concept).
2. The *Use* level of performance includes knowledge modules that support learners to apply the concept to specific case(s), such as hints from the theory, application examples, exercises, activities using computer simulation and/or exploration activities.
3. The *Find* level of performance includes knowledge modules that aim to stimulate learners to find a new generality, principle, procedure, such as activities using computer simulation, exploration activities, and case studies. At this level, the learner submits an essay to the tutor and collaborative work is proposed.

One or more educational material pages are developed for each level of performance. These pages depending on the performance level, consist of the various knowledge modules that described above. In all cases, knowledge modules are associated with the different levels of performance following the prescriptions of the CDT according to which each level of performance should include presentation, practice and test items. Moreover, the educational material is enriched by multiple types of resources to study and authentic and meaningful tasks to perform, in order to support learners to build their own knowledge, as described in Section 3.1. Thus, in our approach theory presentations and hints from the theory correspond to Expository Generalities; introductory questions followed by theory presentations correspond to Inquisitory Generalities; examples and solved exercises correspond to Expository Instances; lastly, self-assessment questions, exercises, exploratory activities, activities using computer simulation, case studies and assessment tests correspond to Inquisitory Instances.

In addition, the educational material of each outcome concept includes:

- an *introductory page* that introduces the concept, providing a special kind of overview of the simplest and most fundamental ideas that are covered, i.e. summarizes the ideas that follow, and provides relevant learning outcomes and links to educational material of prerequisite and related concepts (see introductory page in Figure 1);
- a *summary* that reviews the content presented for the particular concept;
- an *assessment test* that evaluates learner's knowledge level on the prerequisite concepts and the outcome, and relates to the relevant learning outcomes.

With regards to the prerequisite concepts of each outcome, brief descriptions are presented on a page of educational material of the Remember level of performance, whilst related concepts are associated with definitions included in the glossary of the system.

In the existing implementation of INSPIRE, the educational material pages of the prerequisites and of the outcomes, at each particular level of performance, are used as learning objects, i.e. entities, digital or non-digital, which can be used, re-used or referenced during technology-supported learning (LTSC, 2000). In particular, each educational material page constitutes a complete digital resource that can be re-used to support learning in an instructionally meaningful way as it is associated with a specific level of performance and includes enough information (a complete presentation or multiple knowledge modules) in order to support instructional decisions and specific instructional objectives. The representation of the educational material pages in the system, which defines the Educational Material Level of Figure 2, follows the ARIADNE recommendation (ARIADNE, 2000) as a technical standard to represent descriptive information about learning objects. Thus, the metadata description of a page is presented using three types of descriptors (ARIADNE, 2000): *(i) pedagogical attributes*, *(ii) semantics* of the resource, and *(iii) general information* about the resource. Note that only the educational material level is currently metatagged.

3.1.2. A Generated Lesson

The content of each lesson generated for a particular learning goal is organized around specific outcome concepts. Thus, each lesson includes a learning goal, outcome concepts and educational material associated with each of the outcome concepts and their prerequisite concepts. Figure 3 shows the contents of a lesson for a learner who logs on the system for the first time and selects the learning goal "Describe the role of cache memory and its basic operations" or briefly "Cache Memory". Thus, the learner is considered to be novice and his/her knowledge level on the concepts of the domain is characterized as "Inadequate" (Section 3.2

discusses in detail the different characterizations assigned to learners' knowledge level). Accordingly, the outcome concepts of the first layer, i.e. "The role of cache memory", "Mapping techniques", are presented.

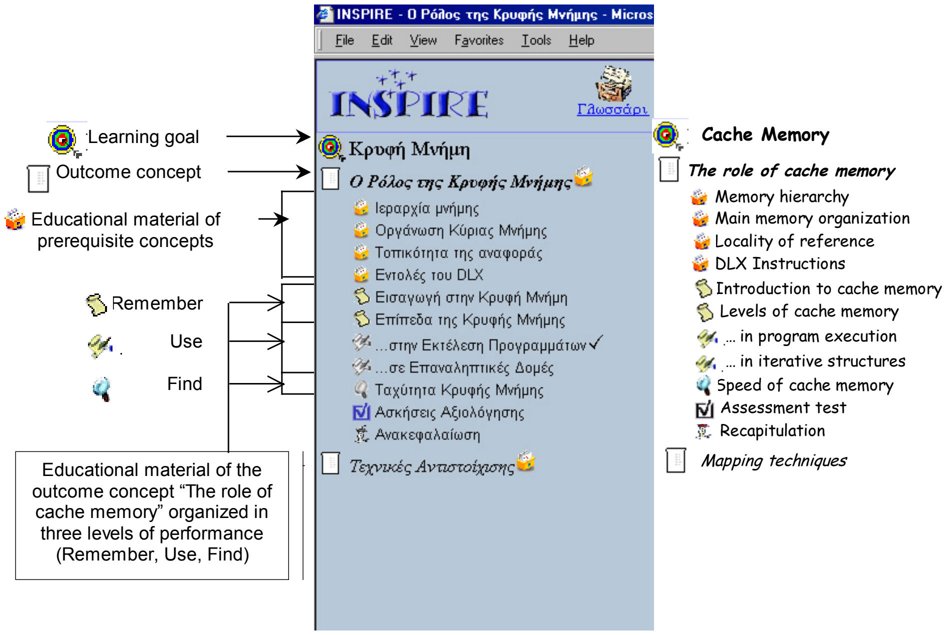


Figure 3. Lesson contents that include the concepts of the first layer of the learning goal "Cache Memory" (cf. with Table II). In the Navigation Area, the first outcome concept "The role of cache memory" has been expanded (only one outcome concept can be expanded in the Navigation Area at each time). The English translation of the lesson contents is shown on the right.

Once the learner selects an outcome concept to study, i.e. clicks on the corresponding title in the Navigation Area (see Figure 3), a page that introduces the outcome concept appears in the Content Area and the concept "opens", i.e. a list of links to educational material pages appears below the concept title (see in Figure 3 the educational material of the outcome concept "The role of cache memory"). The educational material of the outcome concept is organized in three levels, i.e. Remember, Use, and Find that are represented by specific icons. The material of each outcome is complemented by a "Recapitulation" (this is an educational material page including a summary, which reviews the content presented for the particular concept) and an "Assessment test".

Access to the prerequisite concepts of each outcome is also provided by clicking on the icon of prerequisites which appears next to the outcome's title in the Navigation Area (see Figure 3 – icon on the right of the outcome concepts' title). Prerequisite concepts are embedded just above the educational material of the outcome in the Navigation Area (see Figure 3 – links to educational material of prerequisite concepts). Alternatively, prerequisite concepts can be accessed through hyperlinks located on the introductory page of the outcome concept (see Figure 1 – links to Prerequisite concepts in the Content Area). Hyperlinks are also available providing access to the related concepts of an outcome (see Figure 1 – in the Content Area, the links to Related concepts).

3.2. Learner Modeling Issues

The adaptive behavior of INSPIRE is mainly guided by the learner model which reflects specific characteristics of the learner. The learner model exploits the domain model of the system and captures various aspects, such as learner's knowledge level with respect to the concepts of the learning goals s/he studies, learner's level of performance on the outcome concepts (based on CDT), prerequisite structures connecting the concepts, learner's studying attitude in relation with the provided educational material, learner's preferred learning style.

INSPIRE builds up and uses a learner model that has the following characteristics:

- it employs an overlay model that follows the domain structure recording learner's knowledge level on the various concepts/goals;
- it records information that "describes" learner's interaction with the conveyed content and represents the studying attitude of the learner;
- it stores general information about the learner, such as username, profession, sex, learning style;
- it is transparent to the learner and controllable by him/her;
- it is dynamically updated during interaction to make possible for learner's current state to be stored in the database, and therefore to deal with the HTTP protocol's stateless nature (Berners-Lee et al., 1996), which is one of the major problems when developing an Internet based application.

During learner's interaction with the system a learner model is constructed for each particular learner based on the structure shown in Figure 4. This structure provides a complete description of the current state of the learner with respect to the elements of the lessons s/he attends, and is in accordance with the adopted approach for modeling the domain knowledge as presented in Section 3.1.1.

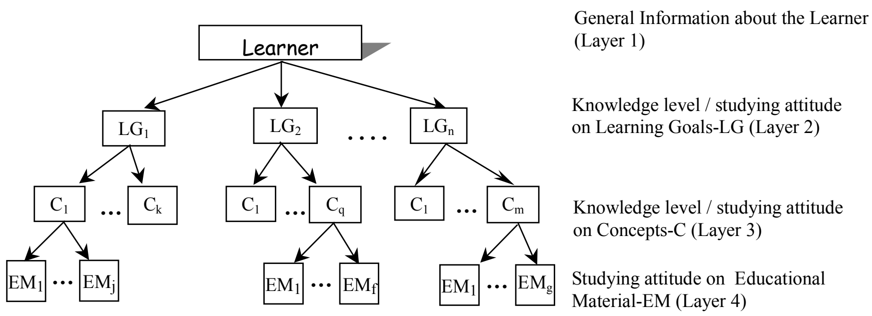


Figure 4. The structure of Learner Model. The nodes at each layer hold specific information about the learner: *(i)* the root node stores general information, *(ii)* nodes of the 2nd and 3rd layers store information about the knowledge level and the studying attitude of the learner on the selected learning goals and their concepts, respectively, and *(iii)* nodes of the 4th layer store information about the studying attitude of the learner in relation with the educational material of the selected goals.

The root includes general information about the learner, such as username, profession, sex, learning style, and information concerning the general interaction of the learner with the system, such as whether or not s/he deactivated system's adaptive behavior, last date and time the learner logged on, learner's favorite pages. The second layer maintains information about the knowledge level and the studying attitude of the learner in relation with the selected learning goals, such as the total time s/he has spent on each goal, the title of current goal. The third layer maintains information about the knowledge level and studying attitude of the learner on the concepts of the selected goals, such as the total time s/he has spent studying each concept, whether or not s/he "opened" the prerequisite concepts in the Navigation Area, the concepts s/he is currently studying. The last layer includes information about the knowledge level and the studying attitude of the learner in relation with the educational material pages of the selected goals, such as the study time s/he has devoted on each page and on the different knowledge modules that each page includes, the total number of times the learner visited each page/module. If the page includes an assessment test, supplementary information about learner's answers on different categories of questions (see below for more details) and number of attempts to answer them are also maintained.

This approach resembles the multi-layer overlay model described by Weber et al. (2001a), where information with respect to different sources for each particular concept is stored at different layers so that it can be updated independently. Our approach expands this idea further to model learner' s interaction with the entire structure of the domain model, including learning goals, concepts and educational material.

In the current implementation of the system, the knowledge level and the learning style of the learner are used as the main sources of system adaptation. Learners' knowledge is approached through a qualitative model of the level of performance that learners exhibit on the concepts they study, whilst learners' learning style is exploited as valuable information about the way learners perceive and process information.

In particular, learner's knowledge level on the different concepts of a learning goal is estimated using the assessment tests that learners submit to the system. Assessment tests are part of the educational material of each outcome concept and are available to the learner during studying that concept. Assessment questions included in the tests are grouped in several categories that correspond to specific abilities that the learner should demonstrate and which are in accordance with the three levels of performance of CDT, i.e. questions that test learners' ability to understand and recall the meaning of presented concepts (*Remember Level)*, questions that test learners' ability to apply the provided information to specific case(s) (*Use Level*), and questions that test learners' ability to propose and solve original problems (*Find Level*).

Based on the performance of the learner on the different categories of questions included in the assessment tests, INSPIRE makes estimations about his/her knowledge level on the outcome concepts of a learning goal using the learner diagnosis process that was described in (Grigoriadou, et al., 2002). In this diagnosis process, a method that exploits ideas from the fields of fuzzy logic and multicriteria decision-making has been proposed in order to deal with uncertainty, incorporate a comprehensive and accurate description of expert's knowledge into the system, and make the system flexible enough to accommodate the personal way of assessment of each individual teacher. The main aspects of the proposed diagnosis approach are the following:

- The assessment process is based on three qualitative criteria that correspond to the three levels of performance *Remember*, *Use*, *Find*, aiming to assess learners' knowledge level following the structure of the educational material.
- Different weights are assigned to the above criteria expressing their relative importance with respect to learner's knowledge level at the time of assessment as well as to the type of the topic under consideration, i.e. theoretical concept, procedure, etc. To this end, the Analytical Hierarchical Process (AHP) (Saaty, 1980) is adopted. In multicriteria decision-making, Saaty's AHP is widely used to define the relative importance of a number of criteria, which in our case emulate the criteria used by the expert-teacher in order to assess learner's knowledge level.
- The relationship between learner's correct answers and his/her performance on the topic is modeled through the use of fuzzy sets aiming to combine quantitative measurements (number of right answers

in the different categories of questions) in order to get qualitative characterizations of learner's knowledge.

- Learners' knowledge level on the outcome concepts of the selected goal is classified according to the following categories: {Inadequate, Mediocre, Advanced, Proficient}. Note that learners always have the option to select a new learning goal to study. In that case, learners' knowledge level on reused concepts initializes the estimation of their knowledge level for these concepts of the new goal.

Learners' preferences of the different types of the educational material follow the learning style classification proposed by Honey and Mumford (1992). Two methods of assessing learning preferences have been widely used (Riding and Rayner, 1998): self-report measures through questionnaires, and observed behavior choices. Following the first approach, in INSPIRE, the learning style of the learner is initialized through the submission of the questionnaire developed by Honey and Mumford (1992). Thus, the first time learners log on INSPIRE, they submit the questionnaire and, automatically, their learning style is classified according to the categories: {Activist, Reflector, Theorist, Pragmatist} using the procedure defined in (Honey, & Mumford, 1992) and this information is stored in their learner model. Alternatively, the learning style can be directly initialized or updated by the learner himself, who is offered the option to select his/her dominant learning style based on information provided by the system about the general characteristics of the different learning style categories.

The learner model is open to learners (see Figure 1 – icon "Learner model" on the Toolbar), in order to stimulate them to reflect upon its contents and support system's adaptable behavior. Learners have always the option to update their learner model and this way to guide system's instructional decisions. In more detail, learners can modify dynamically their knowledge level on the different outcome concepts of the learning goal that they study, as well as their learning style, as will be described in Section 5. This externalization of the learner model provides a means of communication between the system and the learner (Hartley et al., 1995), as the learner is able to access the model, interact with it and change it, intervening to system's instructional decisions (see Section 5-Adaptability in INSPIRE). Therefore, it is important that the learner model is maintained in a manner that allows it to be understandable, transferable and usable (Hartley et al., 1995). To this end, the multi-layered structure described above has been adopted and specific information is provided to learners with respect to the contents of their models and the way these are used by the system (see Section 5 for details). This allows INSPIRE to inform learners of system's estimations about their knowledge level, learning style and system's instructional decisions. Moreover, learners can update their model accordingly, in case they disagree.

The learner model can be exploited further as a means of communication between the system, the learner and the tutor. Externalizing the information that the learner model maintains for the studying attitude of the learner provides tutors with a tool for monitoring learners' progress, and evaluating the educational material. A quantitative evaluation of learners' preferences of the educational material, in the sense of the time learners spent on it, their performance, etc., would provide tutor with useful information about the quality of the educational material. Furthermore, the tutor can use the learning style information, as the basis for the construction of groups to support collaborative learning. Following Honey and Mumford (1992), groups with full range of learning styles exhibit better performance compared to randomly constituted groups.

4. Adaptivity

INSPIRE possess the ability to make intelligent decisions about the interactions that take place during learning aiming to support learners without being directive. This functionality employs the underlying learner model of the system in a number of ways: curriculum sequencing, adaptive navigation support, and adaptive presentation. In particular, as source of adaptation INSPIRE uses the goals, learning style and knowledge level of each individual learner throughout the interaction with him/her. INSPIRE, based on the learning goals of the learner, his/her current knowledge level and progress, generates a sequence of lessons, i.e. plans the lesson contents and delivers the appropriate educational material, supporting learner to the accomplishment of each of his/her learning goals. Moreover, it adapts the presentation of the educational material of each lesson to learner's learning style and proposes a navigation route in the lesson contents based on his/her knowledge level.

In this section we will consider the technologies used to implement INSPIRE's adaptive behavior:

1. *Curriculum sequencing,* where the outcome concepts of a learning goal are presented gradually and specific educational material pages are recommended, exploiting learner's knowledge level provided by the learner model and using instructional strategies which follow the structure of the domain knowledge;
2. *Adaptive Navigation Support*, where the system supports learner's navigation and orientation in the domain by annotating the links of the lesson contents, exploiting learner's progress provided by the learner model and following the output of the curriculum sequencing process;

3. *Adaptive Presentation*, where alternative presentations of the educational material pages are used depending on learner's learning style provided by the learner model.

4.1. Curriculum Sequencing

In general, the goal of curriculum sequencing technology is to help learners to find an "optimal path" through the learning material (Brusilovsky, 1999). Two different approaches, which have been adopted in several AEH systems to implement curriculum sequencing, are presented below. Firstly, in AST (Specht et al., 1997) learners are free to explore the curriculum and receive system recommendations of the next unit to study and educational material to work with depending on their previous interactions. In particular, learners are able to select a section to study and then the system taking into account a probabilistic overlay model of the learner and the prerequisites of the possible next units suggests the best unit to study. Note that this is not an automatic process, but learner-activated.

Secondly, DCG (Vassileva, 1997) is a content-planner, able to generate content plans according to learner's goals and his/her current knowledge level. Based on a separate explicit representation of the domain structure (separated from a library of Teaching Materials - TMs), the system dynamically plans the contents of each course. In particular, the domain structure (a set of AND/OR graphs representing various aspects) can be traversed in different ways generating completely different content plans for achieving the same goal from different perspectives (viewpoints). Every node of the domain structure is associated with a set of TMs of different pedagogical type (for example, introduction to a concept, motivating problem, explanation, help, exercise, or test) and media (textual, graphical image, animation or video etc.). During course execution, TMs are selected by different teaching tasks to teach the concepts of a plan. A combination of the DCG with GTE which provides an instructional model that reflects the instructional knowledge and expertise that underlies human teaching (Van Marcke, 1992; 1998), has been proposed in (Vassileva, 1998). In the new system, the DCG part decides which concepts will be taught and the GTE allows the system to plan dynamically how to present the contents related to these concepts in an optimal way for each learner, i.e. what types of TMs to select and how to sequence them. In this approach the learner, depending on a given teaching goal, is provided with a course plan to study and the system is primarily responsible to produce goal-oriented courses.

PEPE (Wasson, 1992; 1998) also concentrates on content planning. Content planning, as defined by PEPE, is centered-around content goals, which are expressed in terms of concepts that a learner should study, and various abilities that s/he should demonstrate in using these concepts adopting a subset of Bloom's taxonomy of educational objectives (Bloom, 1956). In PEPE content planning has three phases: goal generation, plan generation and plan monitoring (Wasson, 1998). In all cases, learners must follow system's suggestions. They are directed to the achievement of a specific goal, and learners' knowledge state, which is represented through the different abilities that learners should have in using the domain concepts, is the main source of system adaptation. PEPE has addressed the dynamic pedagogical decision making by providing a computational framework for representing the pedagogical knowledge required to dynamically react to the current instructional situation and tailor instruction to each particular learner.

Thus, the two approaches to implement curriculum sequencing, discussed above, can be summarized as follows. In AST the aim of curriculum sequencing is to suggest which page is best to be visited next, leaving the learner free to explore the curriculum. This approach has also been adopted in Interbook (Brusilovsky et al., 1998) and in ELM-ART (Weber and Brusilovsky, 2001). To achieve this aim information about learner's learning state is used. On the other hand, the second approach, used in DCG and PEPE, aims at dynamically planning the content and/or the delivery of the generated courses based on specific instructional objectives and learner's learning state.

Curriculum sequencing in INSPIRE builds on a combination of the above approaches, providing course plans that include the concepts that should be presented and the appropriate educational material whilst and at the same time learners are free to navigate through the curriculum. In particular, although the curriculum sequencing process individually plans both the content and the delivery of the generated lessons based on a qualitative model of learners' knowledge and abilities, an approach that resembles the one adopted in PEPE, the system also allows learners to explore the curriculum in order to decide on the concept or the educational material to study next. To this end, a combination of curriculum sequencing with adaptive navigation support technology has been adopted. In more detail, the output of the curriculum sequencing process, i.e. the content and delivery of each subsequent lesson, is used to adaptively annotate the links of the domain knowledge in the Navigation Area. So, all the available educational material pages of the concepts included in a lesson are provided to learners and appropriate visual cues are used to outline the recommended pages. The only restriction to learners' navigation comes from the gradual presentation of the outcome concepts, which follows their layered structure as presented in Section 3.1.1-Domain Model.

More details on the adopted approach are provided below. In INSPIRE, curriculum sequencing is based on the domain model of the system which has been developed according to the instructional design framework presented in Section 3.1. Learners are not restricted to follow system suggestions, as they are always able to navigate through the hyperspace or to intervene in the adaptive behavior of the system (more details are given in Section 5). In INSPIRE, the aim of curriculum sequencing is to support learners to gradually meet the concept-related learning outcomes, and finally accomplish the selected learning goal. To this end, the system exploits the underlying learner model and in particular specific aspects that the model captures, such as the knowledge level of the learner on the concepts of the domain, the progress of the learner as it is represented through his/her performance level on the outcome concepts of the domain, and the prerequisite structures connecting the concepts.

The outcome concepts of a learning goal are presented gradually following their layered structure (see Section 3.1.1-Domain Model). The layer of the outcome concepts proposed to the learner is determined by the system based on learner's knowledge level on the outcome concepts of the previous layers, i.e. in order to go on to the next layer the learner should be "Advanced" on the outcome concepts of the current layer, as will be described below. However, the concepts of each subsequent layer enrich those of the previous ones, augmenting the domain presented to the learner. An example of the proposed approach is given in Figure 5. Two snapshots of INSPIRE Navigation Area are shown, corresponding to two instances of lessons generated for the same learner, named Lesson 1 and Lesson 2. In Lesson 1 the concepts of the first layer are presented to a novice, while in Lesson 2, as the learner progresses, the concepts of the first and second layers are both presented in the Navigation Area. Thus, the concepts of each subsequent layer (see Table II for the layered-structure concepts of the domain) enrich those of the previous layers, i.e. each subsequent lesson includes also the contents of the previous ones whilst visual cues inform learners about their knowledge level on the concepts of the lesson (more details are given in the next Section).

Furthermore, several strategies are used for planning the content and the delivery of a lesson at the proposed layer. To plan the content (determine the concepts of the layer that the learner should study next), the system exploits information from the learner model about the knowledge level of the learner as well as information about the degree of importance of each concept (i.e. outcome or prerequisite) with respect to the currently studied learning goal, and uses several strategies such as:

(A) The knowledge level of the learner has been evaluated as {Inadequate} on a number of outcome concepts. Then, these outcome concepts and their entire set of prerequisite concepts is recommended to the learner.

(B) The knowledge level of the learner has been evaluated as {Mediocre} or {Advanced} on a number of outcome concepts and {Proficient} on several of their prerequisite concepts. Then, these outcome concepts and the rest of their prerequisites are recommended to the learner.

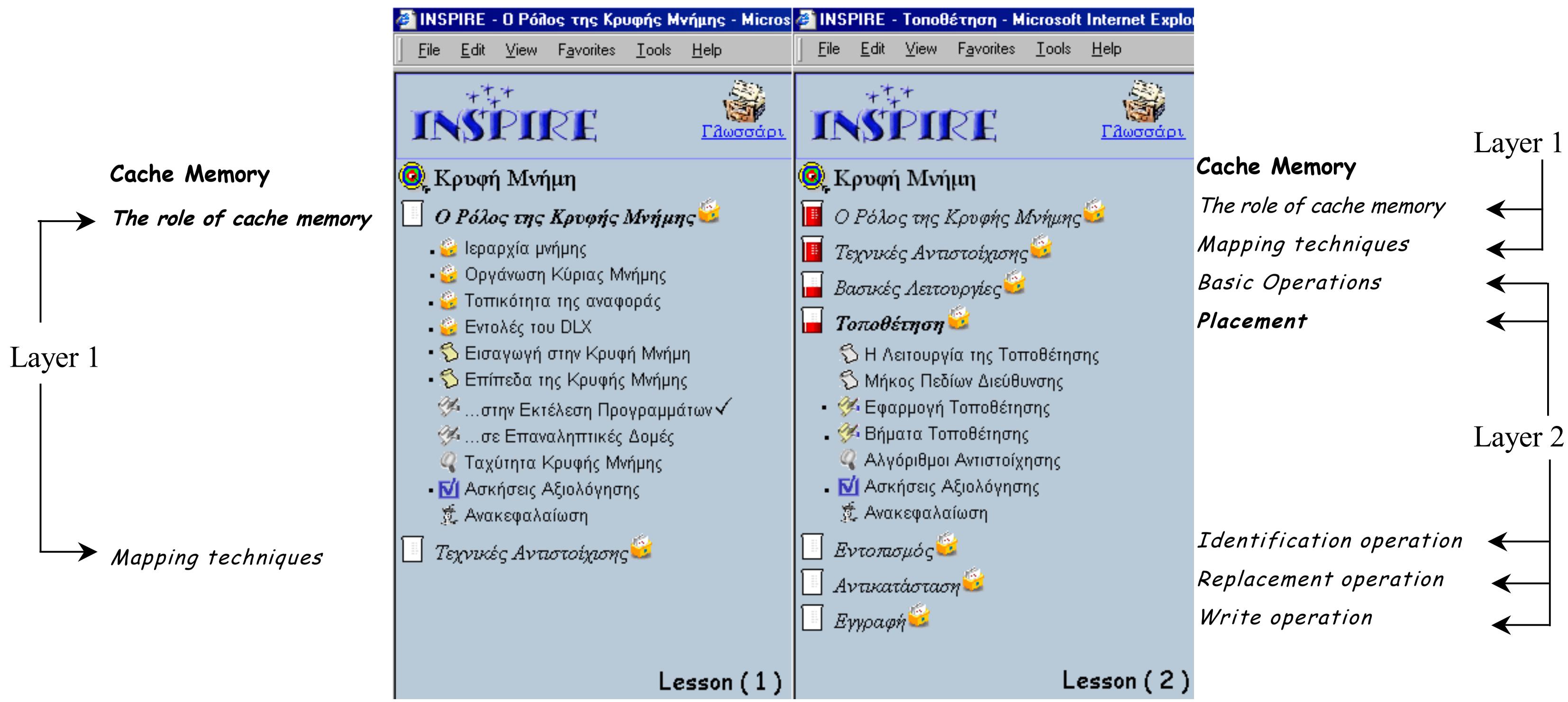


Figure 5. The Navigation Area for a particular learner in two different timeslots (colored icons of educational material pages are marked with a bullet for clarity). *Lesson 1*: The lesson contents include the concepts of the first layer: “The role of cache memory” and “Mapping techniques”. The learner is proposed to study the prerequisite concepts and the educational material of the first level of performance (Remember) for the concept “The role of cache memory”. *Lesson 2*: the lesson contents include the concepts of both the first and second layer. The learner is proposed to study the educational material of the second level of performance (Use) for the concept “Placement operation”.

Multiple strategies are also used for planning the educational material of a lesson. This process selects the appropriate educational material for the concepts of the lesson, as determined by the content planning process, taking into account learner's progress on those concepts. For example, three of the strategies used in the selection of the educational material for the generated lesson are:

(C) The knowledge level of the learner has been evaluated as {Inadequate} on a number of outcome concepts included in the lesson contents. Then, educational material of the *Remember* level of performance for these outcome concepts and material for their prerequisite concepts that are included in the lesson contents, is proposed to the learner.

(D) The knowledge level of the learner has been evaluated as {Mediocre} on a number of outcome concepts included in the lesson contents. Then, educational material of the *Use* level of performance for these outcome concepts and material for their prerequisite concepts that are included in the lesson contents, is proposed to the learner.

(*E*) The knowledge level of the learner has been evaluated as {Advanced} on a number of outcome concepts included in the lesson contents. Then, educational material of the *Find* level of performance for these outcome concepts and material for their prerequisite concepts that are included in the lesson contents, is proposed to the learner.

At this point, it is important to underline that although all the available educational material is provided for both the concepts of the proposed and all of its previous layers, visual cues are used to point out the pages that the learner is recommended to study next. This way, we provide individual navigation advice following learners' knowledge level, without restricting the educational material and limiting learners' freedom to browsing. Note that during studying a particular lesson, learners have always the option to select the concept and the educational material to study next, ignoring system's suggestions, as the lesson contents are presented in a hypermedia form. Moreover, learners are allowed to inspect their learner model and modify their knowledge level, as will be described in Section 5, influencing this way the curriculum sequencing process.

The proposed curriculum sequencing approach is demonstrated by means of a usage scenario. In Figure 5 (Lesson 1) the knowledge level of the learner is considered as "Inadequate" for the outcome concepts of the learning goal "Cache memory". INSPIRE, following Strategy (A), plans the content of a lesson which includes the concepts of the first layer, i.e. the outcome concepts "The role of cache memory" and "Mapping techniques" and all of their prerequisites, i.e. the concepts "Memory hierarchy", "Main memory organization", "Locality of reference", and "DLX instructions". Note that both outcome concepts are associated with an empty measuring cup, denoting that learner's knowledge level on the corresponding concepts is "Inadequate" (for more details see Section 4.2. - Adaptive Navigation Support). When learner's knowledge level is evaluated as {Advanced} on both outcome concepts, the generated lesson (see Figure 5 - Lesson 2), following Strategy (B), includes concepts of both the first and second layers. Different icons are associated with the outcome concepts of the first and second layers, denoting variations of learner's knowledge level on the corresponding concepts. Figure 5 also shows how INSPIRE plans the delivery of the educational material for the concepts included in a lesson. Thus, although Lesson 1 includes all the available educational material for the two outcome concepts, the system using visual cues (colored icons) outlines the recommended pages of the Remember level of performance for both outcome concepts and the entire set of their prerequisites (Strategy C).

4.2. Adaptive Navigation Support

In INSPIRE the adaptive navigation support technology is mainly implemented through the adaptive annotation technique aiming to support learners' orientation and navigation rather than provide direct guidance. Orientation informs learners about their location in the domain, the material they have visited (through the history-based mechanism), their current location (the active link is in bold) and the material they are ready to study (Eklund and Sinclair, 2000). Thus, the system allows learners to decide, on the basis of the provided information, what page may be best to proceed with. Experimental results on the usefulness of adaptive link annotation in educational systems have been reported in (Specht, 1998; Eklund and Brusilovsky, 1998).

In more detail, INSPIRE supports learner's orientation and navigation in the domain knowledge by using graphical icons to point out the lesson structure (see Figure 3 – Navigation Area, Descriptions of the components of the Navigation Area are provided on the left-hand side of the figure accompanied by the corresponding icons) and by changing the appearance of the links in the lesson contents in the Navigation Area in order to propose a navigation route based on the output of curriculum sequencing, inform learners on their knowledge level and progress on the concepts of each lesson, and denote the current and the already visited educational material pages.

Thus, the system adaptively annotates the lesson contents through color cues, supporting learners to find the optimal path through the lesson contents. In particular, the knowledge-based adaptive annotation technique has been adopted (Eklund and Sinclair, 2000) according to which the system annotates the links following learners' demonstrated knowledge of the content (estimated through the submission of assessment tests). To this end, a "flashlight" metaphor is adopted: the system colors the icons next to the links of the pages (in the Navigation Area) that the learner is proposed to study next. To this end, two state icons are associated with the links of the educational material pages of the outcome and prerequisite concepts; colored icons denote that a page is recommended for study, while black and white icons appear next to the rest of the links. The state of an icon changes as a result of the curriculum sequencing process, which defines the educational material pages the learner should study next.

Additional information, about the current knowledge level of learners on the different outcome concepts, augments the appearance of the concepts in the Navigation Area. In more detail, the outcome concepts are associated with appropriate colored icons following learner's progress, under the rules:

1. If learner's knowledge level has been evaluated as {Inadequate} with regards to a specific outcome concept then next to its title in the Navigation Area an empty measuring cup appears
2. If learner's knowledge level has been evaluated as {Mediocre} with regards to a specific outcome concept then next to its title in the Navigation Area a half empty measuring cup appears
3. If learner's knowledge level has been evaluated as {Advanced} with regards to a specific outcome concept then next to its title in the Navigation Area an almost full measuring cup appears

The cup will become full after learner's knowledge level has been evaluated as {Proficient} and s/he has submitted the essay at the third level of performance (Find).

So, using the metaphor of the familiar filling of a measuring cup we aim to keep always the learner informed about his/her progress on the different concepts of the lesson in a way that supports learner's expectations about the interface and increases cognitive directness (Hix and Hartson, 1993).

The combination of flashlight and filling of measuring cup metaphors provides qualitative representation of the progress of the learner on each particular concept. The main advantage of this approach compared to the use of colored bullets or to the traffic lights metaphor adopted in several AEH systems (e.g. ELM-ART, Interbook, KBS-Hyperbook) is that it keeps learner always informed about his/her level of performance on each particular concept and subsequently about his/her progress, and indicates on which of the educational material pages s/he should focus next.

Finally, a history-based mechanism has been developed so that as each page is accessed through links of the Navigation Area, a check mark appears next to the corresponding link.

4.3. ADAPTIVE PRESENTATION

The presentation style of the educational material differs depending on the learning style of the learner. The main objective is to match the learning preferences of learners to appropriate instructional material. Although there have been numerous studies on the association of learning preferences with the type of instructional material (Groat and Musson, 1995; Honey and Mumford, 1992; Fung et al., 1993; McLoughlin, 1999; Riding and Douglas, 1993; Riding and Watts, 1997; Valley, 1997), evidence remains contradictory. In an attempt to approach learning preferences of learners from an educational psychology perspective, we came across the debate of many different classifications of cognitive and learning styles. While it is clear that individuals can exhibit a preference for learning in a particular way, it is less than clear that their preference is stable and reliable (Valley, 1997). Although many issues remain open with regards to the psychological aspects of these approaches, several systems have been developed based on these ideas (Carver et al., 1996; Stoyanov et al., 1999) providing "test beds" for studying the reliability of such classifications and their impact on learner's study and performance. In INSPIRE, we use the learning style information as an indication of the way individual differences influence learners' studying and learning preferences. This information guides decisions on the instructional approach adopted for each individual learner aiming at supporting learners to follow their preferred way of studying. At the current implementation of the system we classify learners according to their dominant learning style, following the learning style categorization proposed by Honey and Mumford (1992). This approach to learning styles focuses on adults' preferences of specific types of activities and instructional material, and thus it was considered promising for a web-based educational system where the target group is usually adults with a common interest on the particular subject of the course they attend. Moreover this approach fits well within a "learning focused" paradigm of instruction providing useful guidance for associating the sequencing of type-specific instructional material with learners' preferences and studying attitudes in order to achieve certain learning outcomes. Lastly, this approach to learning styles focuses on learners' behavior and beliefs in the workplace and thus it shows potential for the distance learning setting.

Learners with different learning styles view different presentations of the educational material on the *Remember* and *Use* levels of performance. According to the proposed design, the various knowledge modules of the outcome concepts (questions, theory presentations, examples, exercises, activities using computer simulation, exploration activities, case studies) constitute different instructional primitives (Van Marcke, 1992), which are joined together in various ways following alternative instructional strategies for the presentation of the educational material and taking into account the learning style of the learner. In particular, for the Use level of performance such instructional strategies are:

1. *activity-oriented* with high interactivity level for Activists, who are more motivated by experimentation and challenging tasks;
2. *example-oriented* for Reflectors who tend to collect and analyze data before taking action;
3. *exercise-oriented* for Pragmatists, as they are keen on trying out ideas, theories and techniques;
4. *theory-oriented* for Theorists, giving them the chance to explore and discover concepts through more abstract ways;

According to the proposed approach, all learners are provided with the same knowledge modules. However, the method and order of their presentation is adapted, according to different instructional strategies that focus on different perspectives of the concepts. This is because the order and the manner in which topics are treated can produce very different learning experiences (Wenger, 1987). The various knowledge modules are presented in different areas of an educational material page, and they are either embedded in the page, or appear as links. Thus, if the instructional strategy adopted is example-oriented then the knowledge module "example" appears on the top of the web page while the rest of the modules appear below in a specified order as links. If the instructional strategy is activity-oriented then the knowledge module "activity" appears on the top of the page while the rest of the modules appear below in a specified order as links. In Figures 6 and 7, two different screen-shots show the same educational material page as viewed by Activists and Reflectors respectively. In both cases, the learner is a novice who is currently studying the outcome concept "Mapping techniques", and, in particular the educational material page "Address mapping between main and cache memory" (*Use* level of performance). In case that the learner is an Activist (see Figure 6) the instructional strategy suggests that s/he should start with an activity, e.g. run an experiment following a specified educational scenario using computer simulation. The learner undertakes an active role and through experimentation constructs his/her own internal representations of the concept that s/he studies. In case the learner needs more help, an example and hints from the theory are provided. Also, an exercise is available offering more chances for practicing. On the other hand, when the learner is a Reflector (see Figure 7) then INSPIRE proposes to start reading an example, continue with hints from the theory and then try to solve an exercise. Lastly, an activity using computer simulation is provided that aims to visualize the presented concepts and stimulate the learner, through the use of an educational scenario, to get an active role, experiment with already acquired knowledge or just test his/her knowledge.

Figure 6. The knowledge modules of the educational material page entitled "Address mapping between main and cache memory" of the outcome concept "Mapping techniques" are presented to an Activist following an activity-oriented approach. This is an educational material page of the Use level of performance that includes: (1) *Activity* using computer simulation; (2) link to an application *Example*; (3) link to *Hints from Theory*; and (4) link to an *Exercise*. English translation of the lesson contents is provided on the left hand side.

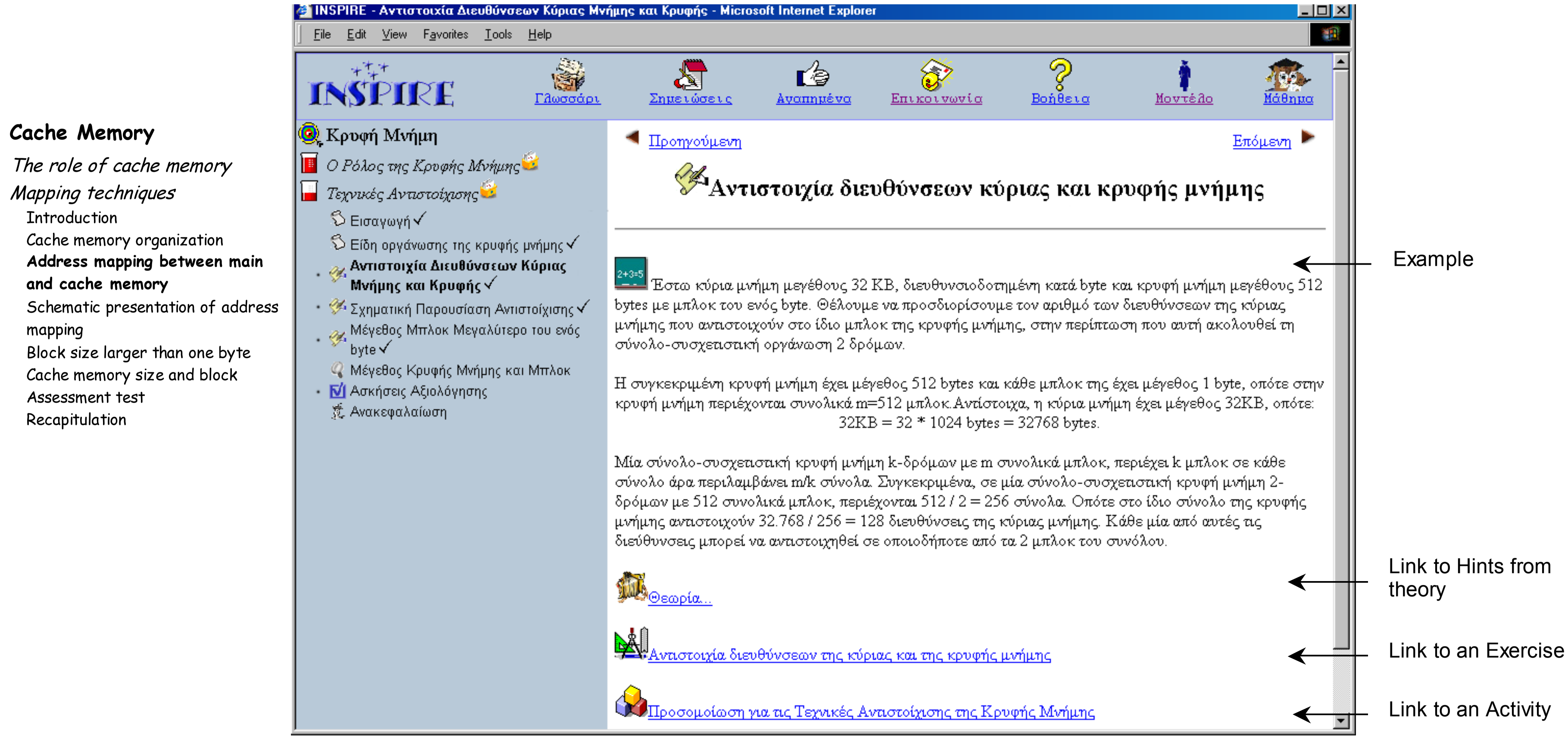


Figure 7. The knowledge modules of the educational material page entitled “Address mapping between main and cache memory” of the outcome concept “Mapping techniques” are presented to a Reflector following an example-oriented approach. This is an educational material page of the Use level of performance that includes: (1) Application *Example*; (2) link to *Hints from Theory*; (3) link to an *Exercise*; (4) link to an *Activity* using computer simulation. English translation of the lesson contents is provided on the left hand side.

Providing different types of knowledge modules as links ordered in a specific sequence resembles the approach adopted in ACE (Specht and Oppermann, 1998), where links to educational material of multiple types such as Introduction, Text, Example, Animation, Test, Summary, are sequenced following specific learning strategies. However, in INSPIRE the sequencing and the method of presentation of the various knowledge modules within each educational material page differ (they are embedded or appear as links) focusing on different perspectives of the corresponding concepts, depending on the learning style of the learner.

In INSPIRE the current approach reflects some tendencies of the different learning styles in approaching information and is in accordance with related work proposed in the literature (Groat and Musson, 1995; Stoyanov et al., 1999; Van Marcke, 1998). Moreover, the use of the same knowledge modules in INSPIRE from multiple instructional strategies formulating the presentation of the educational material pages alleviates the problem of rewriting the same content tailored to each learning style category.

5. Adaptability

INSPIRE supports end-user modifiability offering opportunities to learners to intervene in the lesson generation process directly, or by changing their model stored in the system. End-user modifiability allows learners to tailor the system to their preferences and adapt it to their needs that change over time (Fischer, 1993). Systems that integrate adaptive and adaptable components are based on shared decision making requiring shared knowledge between the learner and the system. However there is a broad spectrum of shared decision making between purely adaptive and purely adaptable systems in which learners and system components contribute to the modification of a system (Fischer, 1993). A factor that influences learners' intervention is their knowledge level, and as empirical data suggest (Specht, 1998) novices often need more guidance and want to be released from too complex tasks, while advanced learners want to have control over the system.

INSPIRE supports several levels of adaptation from purely adaptive to purely adaptable. Thus, as shown in Figure 8, learners have the option to select one of the learning goals of the course. The system provides learners with an overview of each learning goal and of the outcome concepts associated with it, in order to help them to decide. When a learning goal is selected, the system generates lessons that support learners to the accomplishment of the particular goal. During interaction, the system monitors learner's actions, updates accordingly the learner model and adapts its response to his/her progress.

Moreover, INSPIRE offers learners opportunities (see Figure 8) to undertake control over the system by intervening in the lesson generation process reflecting on their own perspective, and:

1. *plan the content and delivery of a lesson*: changing his/her knowledge level on the different concepts of the learning goal on his/her learner model, the learner guides the generation of the next lesson;
2. *plan the presentation of the educational material*: changing his/her learning style on his/her learner model, the learner formulates accordingly the presentation of the educational material;

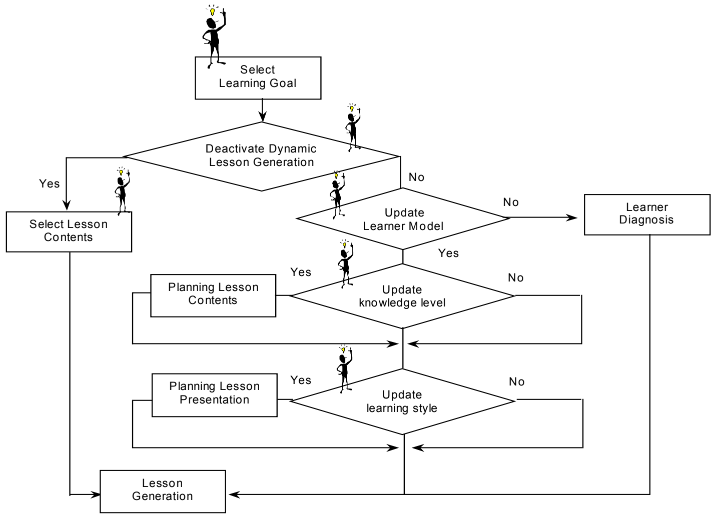


Figure 8. Learner's opportunities to intervene in the lesson generation process.

Thus, learners have always the option to access their learner model, reflect upon its contents and change them in order to guide system's instructional decisions. To support learners in updating their model, the system provides information on the different learning style categories (see Figure 9 – Information about the characteristics of different learning style categories and their impact on system functionality) and learners' performance on the assessment tests (see Figure 9 – Information about learner's performance on the assessment tests of each particular concept) of the different concepts of the learning goal and the way this was evaluated. Moreover the system provides information with regards to the different options that a learner has in updating his/her model and their implications on the functionality of the system. In this way learner is provided with a view of the internal workings of the system and of the influence of his/her actions on the system's functions (Höök., 1998).

In Figure 9, an instance of the learner model, which provides information about the knowledge level on the outcome concepts of the current lesson and the learning style, is exhibited for a particular learner. In case the learner wants to proceed to the next layer of concepts without submitting the tests on the concepts of the current lesson (in order to be automatically assessed by the system), then s/he has the option to manually change his/her knowledge level on both concepts, i.e. “The role of cache memory” and “Mapping techniques”, selecting the item {Advanced} of the drop down list that includes the characterizations {Inadequate, Mediocre, Advanced}(see Figure 9 – Learner’s knowledge level on the outcome concepts of a learning goal). In addition, in case that the presentation of the educational material does not fit into learner’s learning preferences, s/he has the option to modify it to a more appropriate one by changing his/her learning style category (see Figure 9 – Learner’s learning style).

Lastly, in case that the learner just wants to revise specific concepts of the domain, then s/he has the option to deactivate the dynamic lesson generation process and select the next lesson contents, i.e. the outcome concepts of the next lesson. In this case, all the available educational material of the particular concepts is provided. The tool “Lesson” in the Toolbar provides learners with full instructional control over the system.

Externalizing the learner model and providing learners control over the contents of the model is an approach that is also adopted in ELM-ART (Weber and Brusilovsky, 2001). In ELM-ART, learners are provided with the option to express their appreciation about their knowledge level on each particular page of the course. This information coexists with the system’s knowledge about the learner in their model. However, although the system uses learner’s appreciation to its adaptive functionality, it needs more evidence (from solving exercises, tests, or programming problems) in order to infer that the learner has already mastered the topic.

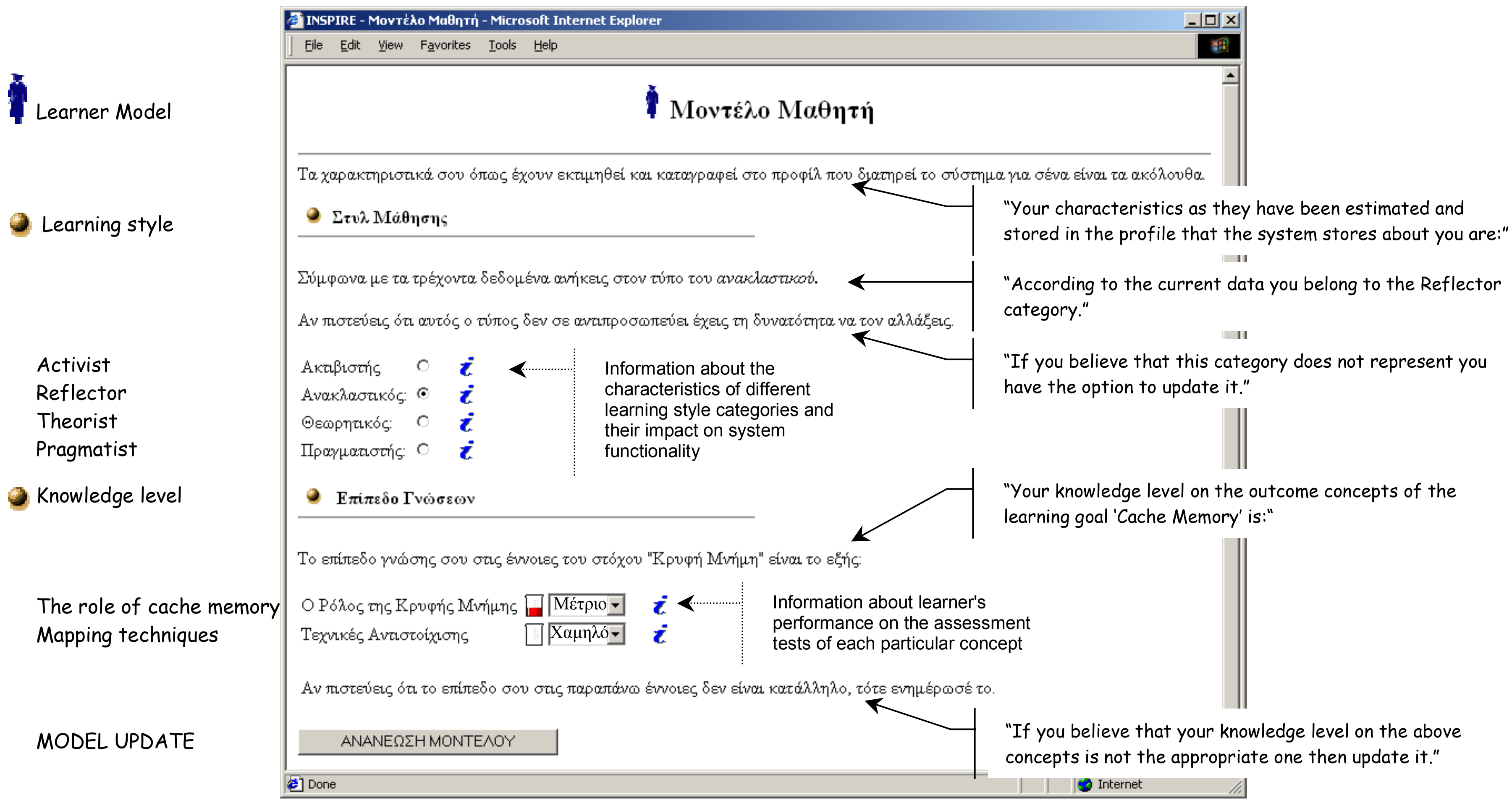


Figure 9. Externalization of the learner model. The system informs learner of his/her knowledge level on the concepts s/he is currently studying, as well as on his/her learning style. Details of the different categories of learning styles and of the way his/her knowledge level on each concept was evaluated are available through the *Information* icon.

6. Experimental Study

The experiment, presented in this section, is part of the formative evaluation of the system (Nielsen, 1993). It has been designed to evaluate the adaptation framework adopted in INSPIRE from the point of view of learners and to provide us with data about learners' interaction with the provided content. In particular, the experiment explored:

- learners' subjective estimations of the support provided by the system throughout their study by means of the adopted domain knowledge model and adaptive features
- learners' subjective estimations of the usefulness of system's adaptable functionality
- relations between learning styles and learners' studying attitude and interaction with the system

The first two targets evaluate the adaptation framework adopted in INSPIRE, whilst the third one investigates whether learners of a particular learning style exhibit consistent navigation behavior, i.e. how the presentation of the educational content relates to learners' studying attitude.

In particular, with regards to the adaptive functionality of INSPIRE, the three different adaptation technologies, i.e. adaptive navigation support, adaptive presentation, and curriculum sequencing, are considered. However, in this experiment the usefulness of the adaptive annotation technique which was adopted to outline the proposed navigational path through the content was not mainly evaluated. This was due to the fact that participants followed a usage scenario that described in detail the educational material pages that they should study during the experiment, and thus their navigational path was mainly predefined in the scenario.

With regards to the exploitation of the learning style information in designing system's adaptation, many questions are still open. For example, questions related to the way learners with different learning styles answer to assessment tests, exercises, activities, etc., the navigation traces followed by learners with different styles, the common characteristics of learners of the same style, evidence about the way learners of specific learning style select and use educational resources that are considered beneficial for their style, and so on.

In the experiment described in this section, we investigated learners' log files that record participants' interaction with INSPIRE and we provide several data that could serve as valuable indications of the navigation traces followed by learners with different styles and of common characteristics of learners of the same style. These data provided also some evidence about the way learners of different learning style categories select and use educational resources as well as the questionnaire proposed by Honey and Mumford (1992). One of the goals of our study was to check if learners prefer to submit the questionnaire proposed by

Honey and Mumford (1992) as a formal way for the identification of their learning style or if they prefer to select it on their own. Moreover, we tried to check the hypotheses that guided the development of the educational material and the planning of its presentation to each learning style category. For example, the hypothesis posed for Activists was: "*as* Activists are motivated by experimentation and attracted to challenging tasks (according to Honey and Mumford), *we should provide them* educational material that focuses on such tasks (Questions, Activities and Exercises) in order to motivate those learners to undertake an active role. Moreover, we should also provide theory and examples as supplementary resources in order to support Activists to accomplish the tasks successfully".

Of course at this point we should note that it is difficult to identify the degree that the proposed presentation influenced their studying attitude and selections. However, this investigation is the first step towards a comprehensive study of the issue of learning styles and their impact on learners' preferences and studying attitude in the context of web-based AEH systems.

6.1. METHOD

In this subsection an outline of the experiment is provided. The *goal of the experiment* was to provide us with: (*i*) direct information from INSPIRE's intended users with regards to their opinions of the support provided by the adaptive and adaptable features of the system; (*ii*) real data of the way learners of a particular learning style utilize the system.

The experiment *took place* in the main laboratory of the Department of Informatics and Telecommunications of the University of Athens, after the final exams of the winter semester (academic year 2001-2002) and lasted two hours and a half. All the computers used in the experiment were connected to the Internet and participants accessed INSPIRE through a common web browser.

The *test users* were 23 undergraduate learners (second year learners) of the Department of Informatics and Telecommunications of the University of Athens who had also sat the end of semester examination of the module "Computer Architecture". The learner cohort of the module was informed that marks gained in assessment tests, self-assessment questions, exercises and activities included in INSPIRE would count towards their overall mark; thus participants degree of motivation was high as this was considered as a form of supplementary assessment that could help them to improve their marks of the module. INSPIRE's intended users are University learners to whom access to an educational web-based system is provided as a supplementary resource as well as adults studying at a distance. Thus, the test users covered a main category of system's intended users.

The *experimenter* was a researcher of the team working for the design and development of INSPIRE. At the beginning of the experiment, she introduced the system to the participants, and explained the user interface, the structure of the domain knowledge as well as the adaptive and adaptable functionality of the system. During the experiment the role of the experimenter was limited to answering questions on the subject matter, exercises, and activities that the participants should perform and submit.

The participants worked independently, one on each computer, and studied several concepts of the learning goal "Describe the role of cache memory and its basic operations". All the tasks that the participants had to perform were listed in a usage scenario (Carroll and Rosson, 1990), which participants followed at their own pace. The scenario described the educational material pages that participants should study, the questions, exercises, activities that they should answer and submit using the notepad of each page (Figure 1- tool "Personal Notes" in the Toolbar), as well as when they should change their learning style category in order to check the alterative presentations of the educational material pages of the Remember and Use levels of performance (Figure 1 - tool "Learner Model" in the Toolbar). This way we aimed to ensure that they would experience most of system's functionalities in order learners to be able to evaluate them. Several closed questions, accompanied with a free space for comments, or open-ended questions were embedded in different steps of the usage scenario, reflecting likes and dislikes, problems identified, suggestions, etc. (a sample is shown in Table III). The first time participants logged on INSPIRE, they had the option to submit the questionnaire of Honey and Mumford in order to automatically identify their learning style, or select manually their dominant learning style category based on information about the specific categorization provided by the system.

6.2. RESULTS/QUESTIONNAIRES

The investigation of participants' satisfaction of the adopted adaptation framework explores their subjective estimation of the degree of support offered by the system throughout their study, and is based on the analysis of their answers to different questions included in the usage scenario. Both the adaptive and adaptable functionality of INSPIRE have been evaluated.

In Section A of Table III responses of the participants to questions about the adaptation framework of INSPIRE are summarized in three different groups: the first group refers to the adopted domain knowledge model; the second one, to the adaptive functionality of the system; the third one, to INSPIRE's adaptable features. In particular, participants stated their opinions about the usefulness of the domain knowledge model with respect to the conceptual structure, the educational material structure and the various types of knowledge modules provided for the outcome concepts (see Table III-Section A, *Questions about INSPIRE's domain model*). The data gathered showed participants' overall satisfaction of the adopted approach. Learners commented (whilst answering open-ended questions) positively on the structure of the content and they noted that especially the adopted conceptual structure (outcome, prerequisites, and related concepts) provides a general overview of the subject matter in an easy to follow way and a comprehensive presentation of the subject that includes all the appropriate material covering possible gaps in their prior knowledge. Also, they commented that the provided educational material (because of its type, variety and structure) is easier to study, to understand, and find specific information within it compared to the handouts of the module. Participants positively commented on the structure of the educational material of the outcome concepts (organized in three levels of performance). In particular, they noted that combining theory with application in a gradual way results in a simple and simultaneously comprehensive presentation of the fundamental concepts of the domain. Moreover, two of the participants commented that this way resembles the way people approach new concepts. Also, participants reported that the usage of multiple types of knowledge modules in the educational material "kept them concentrated" and provided them with the opportunity to "gradually approach the main concepts of the goal through various perspectives, satisfying learners with different ways of learning".

Participants' comments with respect to systems' adaptive functionality and in particular to the graphical way of representing the structure of the domain knowledge, the hypermedia form of representing the domain, and the different adaptation technologies adopted, are quite encouraging (see Table III-Section A, *Questions about INSPIRE's adaptive functionality*). Most of them found the graphical representation of the domain helpful and user-friendly. They also like the hypermedia form of the domain (lesson contents) because it provides them control over the selection of the material to study.

Contradictory comments were received with regards to the adaptive navigation support technology, and particularly regarding the navigation path proposed by the system, which is outlined by the use of colored, and black and white icons. Nine participants commented that the proposed navigation path provides a useful guidance, which made them focus on specific educational material pages and two of them that this guidance resembles their way of studying. Especially participants who seem to trust system's judgments found the guidance provided worthwhile. However, six participants commented that the notation (colored, and black and white icons) was not clear or informative (one possible reason being the resolution or the settings of the monitors that they used, as it was difficult to distinguish between the two states of the icons, i.e. black and white or colored), and in total 12 out of 24 participants didn't find this information helpful to their study (see Table III-Section A, *Questions about INSPIRE's adaptive functionality*).

With regards to the adaptive presentation approach of the system, participants focused on the presentation of multiple types of knowledge modules in each educational material page in the Content Area. They commented that although studying in front of a computer screen for an extended period of time is very fatiguing, the idea of structuring a page in multiple areas is very helpful. In addition, they noted that the representation of multiple types of knowledge modules as hyperlinks that open different windows, minimizes the text presented on each window and facilitates study. At the same time, this way the system supports them in efficiently organizing their study and provides learners with the initiative to select the educational material to study next. Most of them noted that they prefer the simultaneous use of multiple windows that each one presents a different perspective of the concept since this way more information is concurrently available. However, three participants noted that they were confused by the use of multiple windows. An interesting comment on the source of the adaptive presentation technology comes from a participant who said that his way of selecting knowledge modules to study depends mainly on his current knowledge level on the subject matter, i.e. when he already knows the theory of a concept, he starts from the exercises otherwise s/he goes directly to the theory.

Lastly, with regards to the gradual presentation of the concepts of the domain (curriculum sequencing), this approach seems to satisfy most of the participants, especially in the cases where they are not familiar with the subject. However, one participant commented that this approach prevents him from formulating an overview of the subject matter.

Thus, with regards to participants' subjective estimation of the three technologies adopted to formulate INSPIRE's adaptive behavior, i.e. adaptive navigation support, adaptive presentation, and curriculum sequencing, most of them seem to underestimate the adaptive navigation support technology. This is quite expectable, as explained in the introduction.

Participants' opinions of the systems' adaptable functionality are quite interesting. Most of the participants prefer to have access to the contents of their model and control over the system even in cases where they are unfamiliar with the subject matter (see Table III-Section A, *Questions about INSPIRE's adaptable functionality*). In particular, they comment that informing them of their knowledge level encourages and stimulates them to go on. It is worthwhile to note that even participants who trust system's decisions comment that they prefer to have control over the system. However, five participants found the option to inspect and modify their knowledge level and learning style in their model indifferent to their study.

Finally, a conclusion coming from participants' comments and from our observation of their interaction with the system during the experiment is that in several cases they avoid using system's adaptive features, as they are not familiar to them and to the adopted notation. Thus, using the system for longer periods is necessary in order learners to get used to all of its innovative characteristics and appreciate their functionality.

With regards to participants' opinions on the learning mode that they prefer for undergraduate and postgraduate studies (see Section B of Table III), they seem to tend to a mixed mode of classroom-based with access to INSPIRE. Most of them comment that having access to various resources facilitates their study, whilst they underline the direct communication and the social dimension of the traditional mode of education. When it comes to postgraduate studies, most of the participants who are in favor of a distance learning mode consider web-based learning eminently suitable for postgraduate studies since learners studying at this level have the background and skills necessary in order to study on their own and control their learning, whilst two of the participants comment that this learning mode helps them to better manage their time.

6.3 RESULTS/TRACKING DATA

In this section we describe in detail the contents of the participants' log files, the pre-processing procedure performed on the original files, and the main processing phase which aimed at identifying specific measurements that are indicative of participants' studying attitude.

The log files stored during the experiment *contain* information about: (i) learners' navigation in the domain knowledge and selections from the Toolbar, (ii) time spent on educational material pages, on different types of knowledge modules, on keeping notes, and on using several tools from the Toolbar, as well as (iii) scores obtained on assessment questions. For example, each time a learner selects an educational material page from the Navigation Area, a new line is added in his/her log file including the date and time of visit, the title of the page as well as the type of the knowledge module that appears "opened" in the page. Note that the first time a learner selects an educational material page, the method and order of appearance of its knowledge modules are formulated according to his/her learning style, i.e. one of the modules appears "opened" on the top and the others appear next as links. Then, each time the same learner selects a knowledge module within the page (from those that appear as links), a new line is added in his/her log file including the date and time of visit, the title of the page that includes the knowledge module as well as the type of the knowledge module s/he selected.

After the log files were collected, a *pre-processing* of their data was performed. Following this procedure, occurrences where participants spent less than 8 seconds on a particular knowledge module were deleted. Such selections of knowledge modules were considered as random, or as a step to another module. In the latter case belong occurrences where the learner visits an educational material page (first selection) and immediately s/he selects one of the knowledge modules that appear as links within the page (second selection). In such cases as described above, in the log file both actions are recorded in two different lines, even though the learner concentrated on his second selection. Thus, according to the pre-processing process the first line in the log file, representing learner's first selection, is deleted as non-informative.

The main *processing phase* of the log files focused on the estimation of specific measurements that were considered as indicative of their studying attitude. We decided to use three different measurements in order to support a more comprehensive analysis:

- the *total time* that a participant spent on each type of knowledge module (question, example, theory presentation, exercise, activity). This information is considered as an indication of learners' interest and concentration on each particular type;
- the *number of times* that a participant accessed each particular type of knowledge module within the educational material pages she studied. This information is considered as an indication of learners' preference of each particular type of knowledge module;
- the *history of* participants' *selections* of knowledge modules on each educational material page. This information denotes the way that a learner prefers to study. In case the learner consistently chooses the same knowledge modules, e.g. usually starts reading examples, goes on with the theory and then tries to solve exercises, or starts with the activities and uses the theory in order to complete the activity, then it is considered that this learner prefers a particular sequencing of the knowledge

modules within the educational material pages which is consistent with his/her preferences/selections.

In the following Figures 10, 11 and 12, a sample of data resulted from analyzing learners' log files is presented. In particular, Figures 10 and 11 provide data about Activists' studying behavior, whilst in Figure 12 the navigation patterns of both an Activist and a Theorist are compared.

Figure 10 presents data about the studying attitude of a sample of three Activists, (a), (b), and (c), on the educational material pages of the Use level of performance. In more detail, in Figure 10, two different diagrams are provided for each of the three participants (six in total):

- the *diagram on the left* shows the total study time that a participant spent on the different types of knowledge modules which comprise the educational material pages of the Use level, and the time s/he devoted keeping notes (denoted as "Notes" in the x-axis) in order to answer the provided exercises and activities (use of tool "Personal Notes" of the Toolbar on each particular page). Note that the educational material pages of the Use level are presented to Activists with the "Activity" module "opened" on the top of the page and the rest ("Example", "Hints from Theory", "Exercise") as links below-see also Figure 6;
- the *diagram on the right* shows the number of hits that a participant made on each of the types of knowledge modules which comprise the educational material pages of the Use level and on the tool "Personal Notes" of the Toolbar (the latter is denoted as "Notes" in the x-axis);

Thus, following the provided data, participant (a) spent most of his study time on Activities, i.e. 1379 seconds (left diagram), and Examples, i.e. 1141 seconds (left diagram). Moreover, although he also checked the exercises, he didn't work enough with them. Thus, even though participant (a) visited four times modules of types "Exercises" and "Examples"–same number of hits on the corresponding knowledge modules in the right diagram-, the study time he devoted on Exercises is only 279 seconds (left diagram). On the other hand, participants (b) and (c) concentrated on Activities and Exercises. Thus, participant (b) devoted 1900 seconds on Activities and 1237 seconds on Exercises and participant (c) devoted 1363 seconds on Activities and 425 seconds on Exercises. Furthermore, although they both checked the Theory and the Examples they didn't spent enough time to study them. Thus, even though participant (b) made four hits on Theory and one on Examples, and participant (c) made three hits on Theory and four hits on Examples, they both devoted less than 100 seconds of their study time on these types of knowledge modules.

In order to provide more evidence on the studying attitude of these learners in relation with the whole content, we provide in Figure 11 the same data as in Figure 10 for the whole period of the experiment. Thus, Figure 11 presents data about the studying attitude of the same three participants on the educational material pages of both the Remember and Use levels of performance. This way, learners' interaction with the educational material pages of the Remember level, where the theory of the concept is mainly provided, is also considered (the pages of Use level are concentrated on the application of the presented concepts providing just useful hints on the theory). Note that the educational material pages of the Remember level of performance for an Activist comprise of an Introductory Question, an Example, and a Theory presentation (the Introductory Question appears "opened" on the top of the page while the rest appear below as links).

The studying attitude of participants (a) and (b) towards the Theory didn't change. In Figure 11, we observe that although the hits made by participants (a) and (b) on modules of type "Theory" have been increased compared to Figure 10 (shown in the right diagrams of both Figures), the time they spent studying these modules has not been increased considerably. Thus, participant (a) is shown to have made one more hit on the "Theory" modules in Figure 11 (two hits) compared to Figure 10 (one hit), whilst participant (b) is shown to have made two more hits on the Theory in Figure 11 (six hits) compared to Figure 10 (four hits), but, in both Figures 10 and 11, they appear to have spent less than 200 seconds studying the "Theory" modules. Only participant (c) seems to have studied the "Theory" modules of the pages of the Remember level. Thus, in Figure 10, he is shown to have devoted less than 100 seconds on the Theory and in Figure 11 his total study time of Theory increased to 527 seconds. In Figure 11, we also observe that in the left diagram all three participants spent a considerable amount of their study time on modules of type "Question" which represent introductory questions that motivate learners to think about the new-presented concepts.

Concluding, a common aspect on the studying attitude of the three Activists is that the study time they devoted on activities, exercises and questions was higher compared to the total time they spent working with the theory and the provided examples. Thus, following the data provided by participants who studied according to the Activist learning style, we conclude that learners who belong to this category seem to confirm our hypothesis, which was presented in the introduction of the experimental study (Section 6), about the way learners of this category use different types of resources during their study.

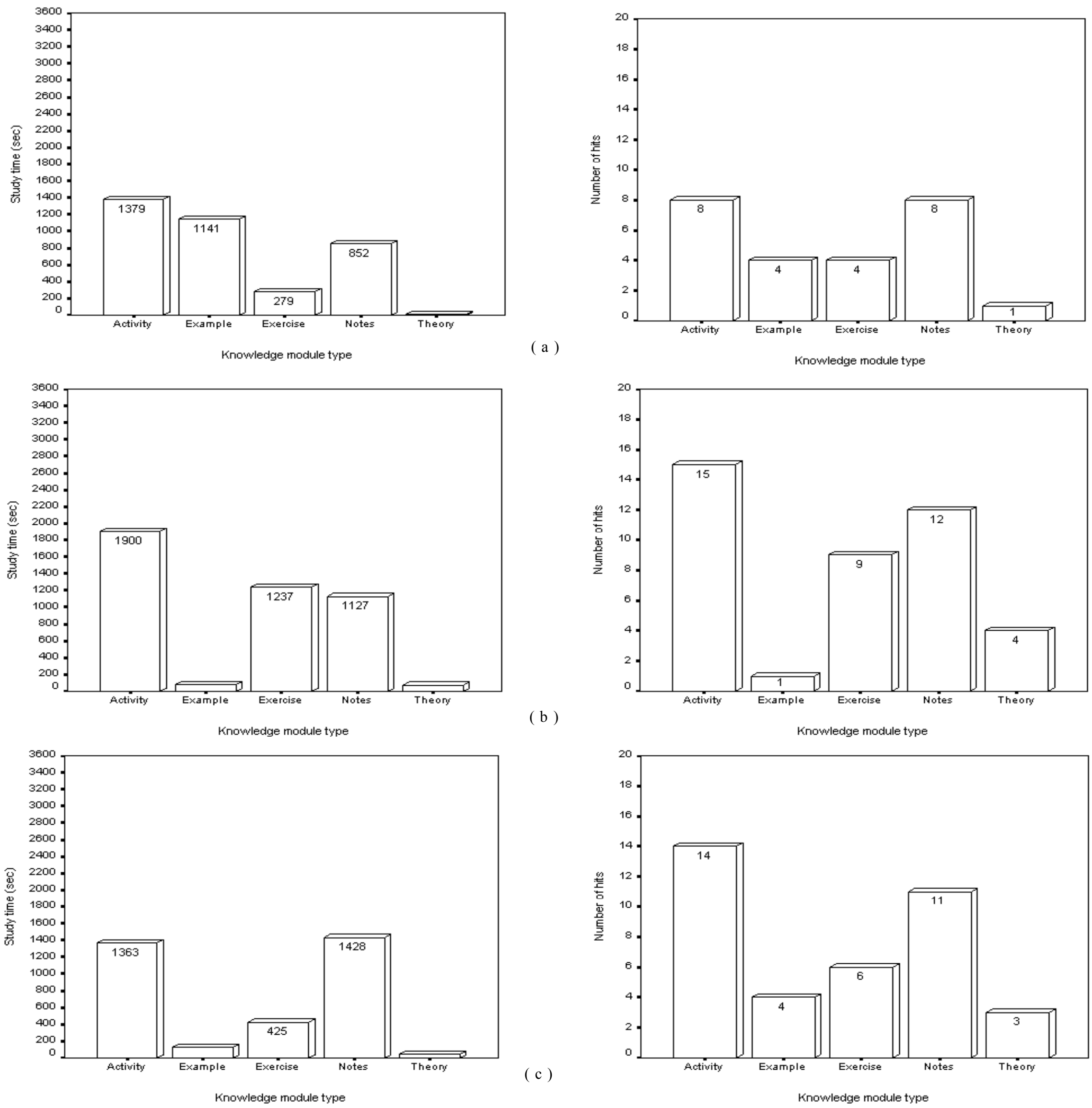


Figure 10. Total study time and number of hits on the knowledge modules of educational material pages of the Use level of performance that three different participants (a), (b), (c), characterized as "Activists", studied.

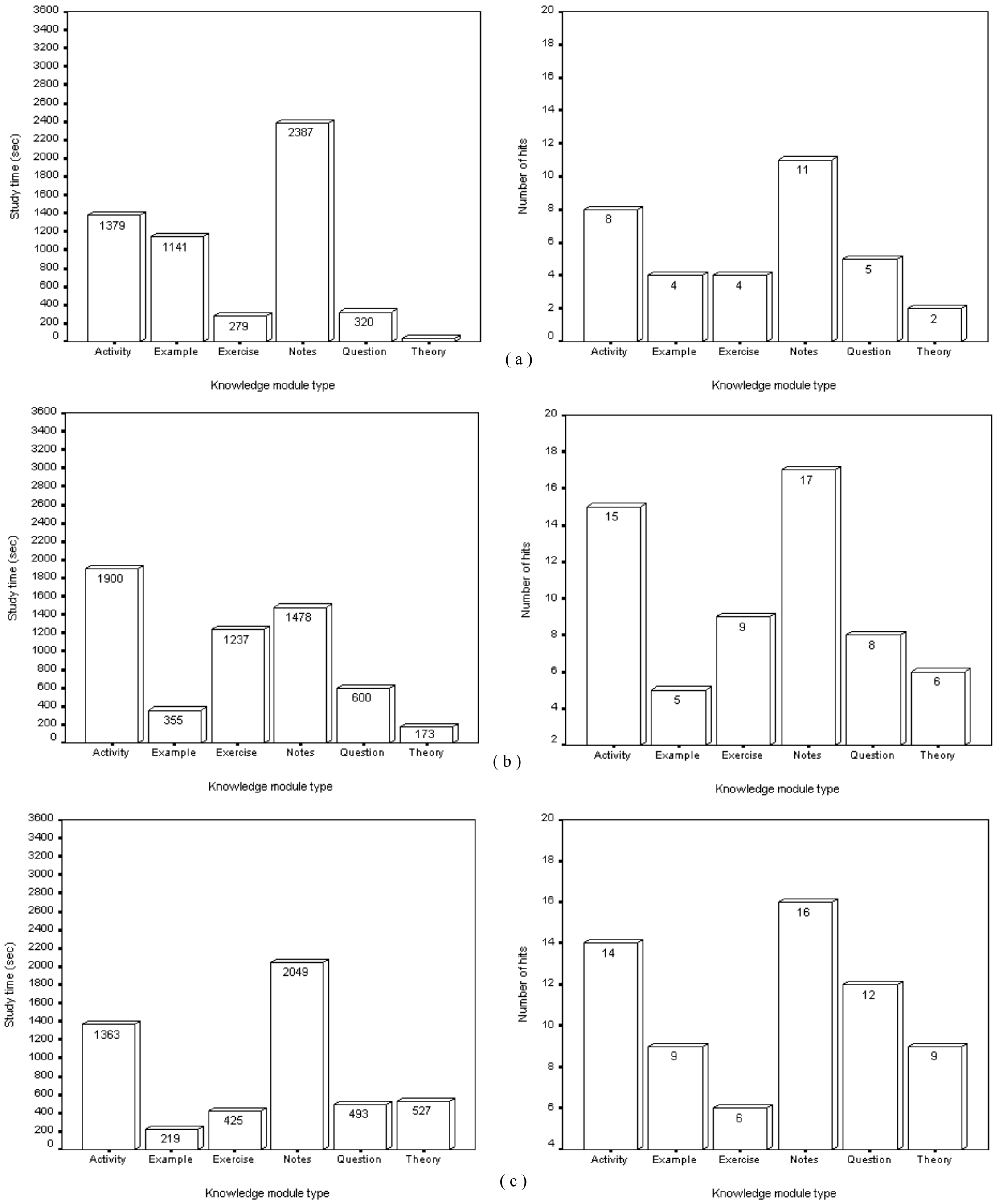
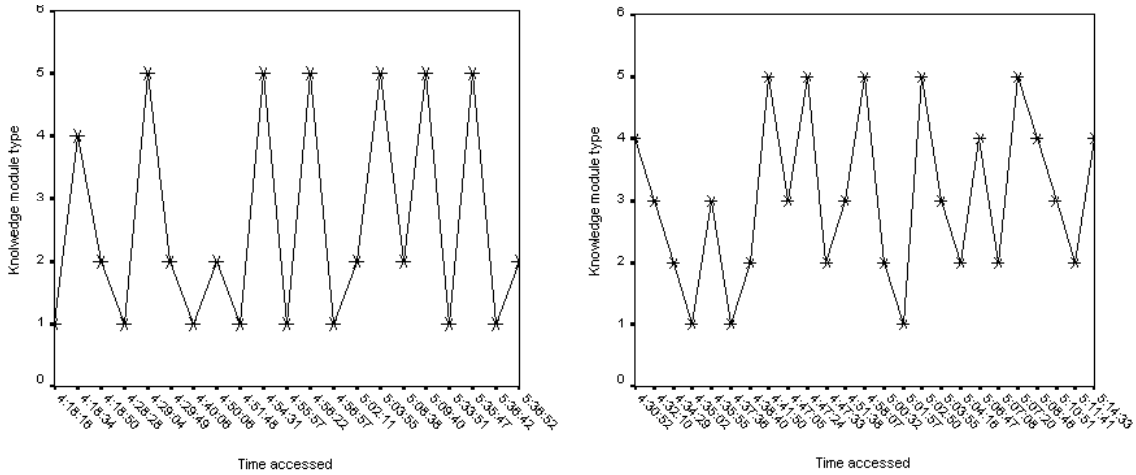


Figure 11. Total study time and number of hits on knowledge modules of the educational material pages that three different participants (a), (b), (c) characterized as "Activists" studied during the experiment (including educational material pages of the Use and Remember levels of performance).

In Figure 12 (a) the navigation pattern of an Activist (learner (b) in Figures 10 and 11) is provided in an educational material page of the Use level. The particular learner seems to work mainly with the activity and the exercise included in the page and less with the theory and the examples. Thus, following his navigation trace in this Figure, we observe that he accessed eight times the knowledge module "Activity" in steps 1 (time slot 4:18:16), 4 (time slot 4:28:28), 7 (time slot 4:40:06), 9, 11, 13, 18, and 20. Among these steps, he visited six times the knowledge module “Exercise” in steps 3 (time slot 4:18:50), 6 (time slot 4:29:49), 8, 14, 16 and 21, and the tool “Personal Notes” in order to submit his answers of the Exercise and Activity to the system (in steps 5-time slot 4:29:04, 10-time slot 4:54:31, 12, 15, 17, 19).



(a) (b)

Figure 12. Comparison of the navigation patterns of an Activist (a) and a Theorist (b) within the same educational material page of the Use level of performance. Note that in the y-axis appear {1: Activity, 2: Exercise, 3: Example, 4: Hints from Theory, 5: Keeping notes}.

Correspondingly, in Figure 12 (b), the navigation pattern of a participant characterized as Theorist is provided in the same page as in Figure 12 (a). Note that, the educational material pages of the Use level of performance for Theorists comprise of “Hints from Theory” (appears “opened” on the top of the page while the rest appear as links), an “Example”, an “Exercise”, and an “Activity”. Following her navigation trace, we observe that:

- she starts from the theory, i.e. the “Hints from Theory” module (1st step at time slot 4:30:52),
- then she works mainly with the “Exercise” (step 3–time slot 4:34:29, step 7-time slot 4:38:40, step 11, step 14, step 18, step 20, step 24) and
- in the middle she studies the ”Example” (step 2–time slot 4:32:10, step 5–time slot 4:35:55, step 9, step 12, step 17, step 23), and
- almost at the end of her study, she returns to study the “Hints from Theory” module (in steps 19-time slot 5:06:47, 22-time slot 5:08:48, 25-time slot 5:14:33).

So, this learner, as a Theorist, seems to start from the theory and end with it, but in the middle she also studies the available example in order to deal with the provided exercise. Moreover, she seems to overlook the proposed activity.

Comparing both navigation patterns, i.e. of the Activist and Theorist participants, we notice that they concentrate on different types of knowledge modules and they use them in a different order with the common aim of accomplishing the tasks (submission of questions, exercises, activities) proposed by the scenario of the experiment (same for all participants). Thus, although the Activist spent most of his time in dealing with the activity, the Theorist tries to answer the provided exercise which is of lower interactivity level compared to the activity. Moreover, the Theorist studies the provided modules "Example" and "Hints from Theory" while the Activist just once gets advices from the "Hints from Theory" module.

Lastly, the questionnaire of Honey and Mumford, which consists of 80 questions and needs about 15 minutes to complete it, was submitted by half of the participants while the others selected on their own their dominant learning style. Moreover, 16 out of the 23 participants didn't change their learning style during their interaction with the system even though they had the option to select another learning style category, check how this information affects the presentation of the educational material in the Content Area and finally choose the one that best matches their preferred way to study.

The above data and their interpretation provide useful indications on the studying attitude of specific learners who were considered representative of the learning style categories considered. However, we should point out that the task of interpreting such data is a very complicated and ambiguous task and in no case unique. This experience was very interesting and constructive, and inspired us to reconsider several issues concerning the processing and interpretation of such complicated data as well as the reliability of the data. Thus, the exploitation of AI methods that take real cases as input data and extract, as output, useful information about the relations that underlie among them, which usually are not so obvious, should be investigated towards the construction of useful tools for the task of processing log file data. Also, another aspect that we should consider is the reliability of the data. Data gathered from learners using the system in real working conditions under longer periods of time are considered more appropriate for the aim of inferring learners' studying attitudes through their observable behaviour. Of course the problem of the availability of the appropriate conditions for performing such a study is an issue that usually restricts the process of gathering data in experiments performed under controllable conditions.

Section A: Learners' opinions about several aspects of the adaptation framework of INSPIRE				
	Not at all	A Little	Enough	Very Much
Questions about INSPIRE's domain model				
Do you think that the concepts' organization in outcome concepts followed by their prerequisites and related facilitated your study?	None	2	16	5
Does the structure of the educational material on different levels of performance (Navigation Area), Remember, Use, Find, support the accomplishment of the learning outcomes posed?	None	4	9	10
Does the multiple knowledge modules on each outcome concept (theory, exercises, examples, activities, etc.) support you to understand and use the concept?	None	2	13	8
Does the presentation of multiple knowledge modules on each concept (theory, exercises, examples, activities, etc.) through links, in the Content Area, facilitate your study?	None	4	11	8
Questions about INSPIRE's adaptive functionality				
Do you think that the navigation path through the content, proposed by INSPIRE, facilitated your study?	3	9	6	5
Do you think that the content presentation, as a study proposal providing several types of educational material in a specific order, facilitates your study?	None	5	14	4
Do you think that providing gradually the main concepts of the learning goal facilitates your orientation in the lesson contents and supports knowledge consolidation?	None	4	16	3
			Yes	No
In every lesson, the structure of the lesson contents is presented graphically through multiple icons. Is this information useful?			21	2
At the same time, you have the option to select the material that you prefer to study next. Is this option useful?			23	None
Questions about INSPIRE's adaptable functionality				
	Not at all	A Little	Enough	Very Much
Do you think that the option the system provides you, to select the lesson contents in an unknown to you domain is useful?	2	5	6	10
Do you think that the option the system provides you to select the lesson contents in a domain that you consider already known is useful?	None	3	10	10
			Useful	Indifferent
Do you think that the information about your knowledge level on the different concepts of the learning goal and your learning style is useful?			17	5
Do you think that the option to update your model is a useful tool or it bothers you with another role?			18	5

Section B: Learner's preferences of different learning modes for undergraduate and postgraduate studies		
	Undergraduate Studies	Postgraduate Studies
Classroom-based	3	2
Distance Learning through INSPIRE	4	6
Mixed model, classroom-based with access to INSPIRE	16	14

T*able III.* This table summarizes, in different sections, learners' answers to the different questions included in the usage scenario. It is separated in sections according to the topic of the questions. Each row contains a question and a column that shows the number of learners that responded with a specific answer.

7. Conclusions and Further Research

AEH systems extending the benefits derived from the instructional use of the Web, incorporate the idea of offering learners personalized support and/or instruction. In this paper INSPIRE, an AEH system, is presented, focusing on its adaptive and adaptable features. The proposed system aims to facilitate learners during their study, adopting a pedagogical framework inspired from theories of the areas of Instructional design and Learning styles. This framework guided the system's design and development unifying several processes that mainly affect system's adaptation and enhancing the educational perspective of the system.

The modeling approach adopted for the learner model and the domain knowledge of INSPIRE mainly supports its adaptive and adaptable behavior. The learner model stores information about learner's interaction with the content in a multi-layer structure reflecting the adopted domain knowledge model and facilitating the communication among the different modules of the system as it always stores the current state of the learner. Moreover, the hierarchical representation of the domain knowledge in three levels of knowledge abstraction, i.e. learning goals, concepts, and educational material, facilitates the re-use of the different elements of the domain under different instructional conditions, supports the implementation of multiple instructional strategies and provides the base for structuring the learner model. Lastly, the representation of the educational material follows an international standard for representing descriptive information about learning objects, the ARIADNE recommendation, which facilitates the re-usability and inter-change of educational resources among technology-supported learning environments.

INSPIRE's adaptive functionality follows the knowledge level of the learner and his/her progress during the interaction with the system. However, another aspect that differentiates system's response to learners is their learning style. In the proposed approach, a combination of different adaptation technologies is used to implement system's adaptive functionality. A combination of curriculum sequencing, formulating the lessons contents, and adaptive navigation support technologies, providing orientation and navigation support, has been adopted in order to balance between navigation freedom and guidance. Thus, the outcome concepts of a learning goal are presented gradually enriching the domain presented to the learner and the system uses visual cues in order to inform the learner about system's curriculum sequencing decisions. Additionally, using the adaptive presentation technique, multiple representations of the same concepts, i.e. knowledge modules, are combined differently, following alternative instructional strategies for the sequencing and presentation of the educational material, each one focusing on a different perspective of the concept. Specific instructional strategies are tailored to different learning style categories. In the current implementation of the system, learners' learning style is approached through the categorization proposed by Honey and Mumford (1992). The learning style of each individual learner is recognized through the submission of a specially designed questionnaire (Honey and Mumford, 1992), or it is declared by the learner based on the general characteristics of the particular model of learning styles.

INSPIRE also supports end-learner modifiability using the learner model as a means of communication with the learner. To this end, the learner model is "open" to learners to inspect its contents, be informed on system's internal functionality and modify their characteristics. Learners' estimations about their knowledge level and learning style have a direct impact on system's adaptive behavior. Lastly, learners have the option to deactivate system's adaptive behavior and select the domain concepts they need to study. In this case, the provided educational material for each concept is organized around specific instructional objectives following the domain model.

An experiment that focused on the adaptation functionality of INSPIRE has been conducted with undergraduate students of the Department of Informatics and Telecommunications of the University of Athens, attending the course on Computer Architecture. This experiment provided us with direct information from learners about their attitudes towards INSPIRE's adaptation framework and their interaction with the system. Most learners appreciate the combination of the adaptation technologies adopted in INSPIRE and the support offered by the system. However, they all seem to prefer to have control over system functionality. With regards to the data stored in the log files recording participants' interaction with INSPIRE, this provided us valuable indications of the study attitude of participants belonging to different learning style categories.

Finally, further research is on progress with regards to the information stored in the learner model and the way this can be exploited by the tutor for the evaluation of the provided educational material and for monitoring learners' progress and attitude while studying. Moreover, we plan to use data coming from observation of learners' studying attitude during their interaction with the system in order to enhance the dynamic adaptation of the system to learners' changing needs. To this end, it would be beneficial to gather more data from learners using the system in real working conditions under longer periods of time and to perform a thorough study of their navigation patterns and attitudes. In the task of interpreting log file data, apart from human observation, methods from the area of AI will be investigated in order to support the extraction of useful information about the relations that underlie among such data.

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Table of Contents

Figure legends

Figure 1. The introductory page of the concept "The Role of Cache Memory". INSPIRE's main screen is divided into three areas: (i) the Navigation Area shows the contents of the lessons in a hypertext form as links; (ii) the Content Area presents the pages of educational material that the learner selects from the Navigation Area; (iii) the Toolbar contains several tools/icons (Glossary: link to a glossary of terms, Notes: link to this page notepad, Favorites: link to the educational material pages the learner has marked as favorites, Communication: communication capabilities, such as e-mail, chat, discussion lists and bulletin boards, Help: information on system functionality, Learner Model: link to a page where the learner can inspect and modify his/her model, Lesson: link to a page where the learner can deactivate the dynamic lesson generation process and select the contents of the next lesson).

Figure 2. The structure of the domain knowledge of INSPIRE.

Figure 3. Lesson contents that include the concepts of the first layer of the learning goal "Cache Memory" (cf. with Table II). In the Navigation Area, the first outcome concept "The role of cache memory" has been expanded (only one outcome concept can be expanded in the Navigation Area at each time). The English translation of the lesson contents is shown on the right.

Figure 4. The structure of Learner Model. The nodes at each layer hold specific information about the learner: (i) the root node stores general information, (ii) nodes of the 2nd and 3rd layers store information about the knowledge level and the studying attitude of the learner on the selected learning goals and their concepts, respectively, and (iii) nodes of the 4th layer store information about the studying attitude of the learner in relation with the educational material of the selected goals.

Figure 5. The Navigation Area for a particular learner in two different timeslots (colored icons are marked with a bullet for clarity). Lesson 1: The lesson contents include the concepts of the first layer: "The role of cache memory" and "Mapping techniques". The learner is proposed to study the prerequisite concepts and the educational material of the first level of performance (Remember) for the concept "The role of cache memory". Lesson

2: the lesson contents include the concepts of both the first and second layer. The learner is proposed to study the educational material of the second level of performance (Use) for the concept “Placement operation”.

Figure 6. The knowledge modules of the educational material page entitled “Address mapping between main and cache memory” of the outcome concept “Mapping techniques” are presented to an Activist following an activity-oriented approach. This is an educational material page of the Use level of performance that includes: (1) Activity using computer simulation; (2) link to an application Example; (3) link to Hints from Theory; and (4) link to an Exercise. English translation of the lesson contents is provided on the left hand side.

Figure 7. The knowledge modules of the educational material page entitled “Address mapping between main and cache memory” of the outcome concept “Mapping techniques” are presented to a Reflector following an example-oriented approach. This is an educational material page of the Use level of performance that includes: (1) Application Example; (2) link to Hints from Theory; (3) link to an Exercise; (4) link to an Activity using computer simulation. English translation of the lesson contents is provided on the left hand side.

Figure 8. Learner’s opportunities to intervene in the Lesson Generation Process.

Figure 9. Externalization of the learner model. The system informs learner of his/her knowledge level on the concepts s/he is currently studying, as well as on his/her learning style. Details of the different categories of learning styles and of the way his/her knowledge level on each concept was evaluated are available through the Information icon.

Figure 10. Total study time and number of hits on the knowledge modules of educational material pages of the Use level of performance that three different participants (a), (b), (c), characterized as “Activists”, studied.

Figure 11. Total study time and number of hits on knowledge modules of the educational material pages that three different participants (a), (b), (c) characterized as “Activists”

studied during the experiment (including educational material pages of the Use and Remember levels of performance).

Figure 12. Comparison of the navigation patterns of an Activist (a) and a Theorist (b) within the same educational material page of the Use level of performance. Note that in the y-axis appear {1: Activity, 2: Exercise, 3: Example, 4: Hints from Theory, 5: Keeping notes}.

Table captions

Table I. Comparison of AH systems, where ANS: Adaptive Navigation Support; AP: Adaptive Presentation, CS: Curriculum Sequencing, PSS: Problem Solving Support

Table II. The conceptual structure of the learning goal "Describe the role of cache memory and its basic operations". Each row contains an outcome concept followed by its prerequisite and related concepts. The order of the outcome concepts corresponds to their order of appearance in the lesson contents (Navigation Area). The layer in which each outcome concept belongs is also presented.

Table III. This table summarizes, in different sections, learners' answers to the different questions included in the usage scenario. It is separated in sections according to the topic of the questions. Each row contains a question and a column that shows the number of learners that responded with a specific answer.

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