Towards new forms of knowledge communication: the adaptive dimension of a web-based learning environment

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Abstract

Adaptive Educational Hypermedia Systems aim to increase the functionality of hypermedia by making it personalised to individual learners. The adaptive dimension of these systems mainly supports knowledge communication between the system and the learner by adapting the content or the appearance of hypermedia to the knowledge level, goals and other characteristics of each learner. The main objectives are to protect learners from cognitive overload and disorientation by supporting them to find the most relevant content and path in the hyperspace. In the approach presented in this paper, learners' knowledge level and individual traits are used as valuable information to represent learners' current state and personalise the educational system accordingly, in order to facilitate learners to achieve their personal learning goals and objectives. Learners' knowledge level is approached through a qualitative model of the level of performance that learners exhibit with respect to the concepts they study and is used to adapt the lesson contents and the navigation support. Learners' individual traits and especially their learning style represent the way learners perceive and process information, and are exploited to adapt the presentation of the educational material of a lesson. The proposed approach has been implemented through various adaptation technologies and incorporated into a prototype hypermedia system. Finally, a pilot study has been conducted to investigate system's educational effectiveness.

Keywords: Multimedia/hypermedia systems; Distance education and telelearning; Navigation; Teaching/learning strategies

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1. Introduction

The Internet and the World Wide Web in particular offer an innovative instructional delivery system that connects learners with educational resources. The hypermedia form of the educational material in a Web-based educational system makes learning a task-driven process, where learners are motivated to explore alternative navigational paths through the domain knowledge and different resources around the globe. However, the structure of the presented domain and the content are usually presented in the same way, and without taking into account learners' goal of browsing, their experience, their prior knowledge, etc. This is an issue that needs further consideration, especially in Web-based instruction, where learners' population is usually characterised by considerable heterogeneity with respect to background knowledge, age, experiences, cultural backgrounds, professions, motivations and goals, and learners take the main responsibility of their own learning.

Novel forms of co-operation and communication between hypermedia learning environments and learners could support the communication of knowledge between the system and the learner with the final aim to improve the learning effectiveness and efficiency. Towards this direction, a new generation of Educational Hypermedia (EH) systems has been proposed recently, called Adaptive Educational Hypermedia Systems (AEHSs) (Brusilovsky, 1996, 1999). AEHSs possess the ability to make intelligent decisions about the interactions that take place during learning and aim to support learners without being directive. AEHSs increase the functionality of conventional hypermedia combining free browsing with personalisation and can support all the continuum of learning modes, from pure system-controlled to full learner-controlled (Brusilovsky, 1995). To this end, AEHSs build a model of the goals, preferences and knowledge of each individual learner and use this model throughout the interaction with them for adapting the content and the navigation to the needs of the particular learner (Brusilovsky, 1996). However, in order to exploit this information, it is also necessary to determine which instructional strategies are suitable for learners with a particular profile and how these strategies would be supported by the knowledge representation of the system.

In this paper, we present an approach to adaptive hypermedia learning environments design and illustrate how learners' knowledge level and individual traits can be exploited to guide the adaptive dimension of a hypermedia system. Based on the goal that the learner selects from a set of meaningful learning goals that are proposed by the system, a sequence of lessons that accommodates his/her knowledge level and learning style, and follow his/her progress is generated to support learners in the accomplishment of their goals.

The paper is organised as follows. The notion of adaptivity in the context of existing AEHSs is considered in Section 2. Several adaptive and intelligent technologies used to implement adaptation in AEHSs are presented, and examples of AEHSs that employ these technologies are discussed. Sections 3, 4 and 5 cover the aspects of the adaptive dimension of an adaptive hypermedia system used to illustrate our approach. Section 3 presents a general overview of the user interface of our prototype system whilst Section 4 describes the adaptive functionality and the way it has been implemented. Issues concerning the representation of the domain knowledge and the instructional design adopted are described, and the ways these two aspects of the system support the adaptive functionality are presented. The contents of the learner model and the educational metadata used for the representation of the educational material in the AEHS both influence and support the adaptive functionality, and are outlined in Section 5. In Section 6, results from a pilot study, evaluating the quality of the educational material and the adopted instructional design, are reported. The paper ends, in Section 7, with conclusions.

2. Adaptivity in educational hypermedia systems

Adaptivity in educational hypermedia systems may be at the content level or at the link level (Eklund & Brusilovsky, 1999). Content level adaptivity is the dynamic generation of content based on the learner model, whilst link level adaptivity assumes a static content and alters the appearance or prominence of the links connecting elements of this hyperspace (Eklund & Brusilovsky, 1999).

In Web-based AEHSs, several adaptive and intelligent technologies have been applied to introduce adaptation (Brusilovsky, 1999), such as:

curriculum sequencing, where the system provides the learner with the most suitable, individually planned, sequence of knowledge units to learn and of learning tasks to work with;
problem-solving support, where the main aim is to help learners with solving an educational problem;
adaptive presentation, where the content of a hypermedia page is adapted to the learner, i.e. pages of educational material are adaptively generated or assembled from different pieces for each learner; and
adaptive navigation support, where the system helps learners to find the most relevant path in the hyperspace, i.e. it supports learners' orientation and navigation by adapting the appearance of visible links to the particular learner.

In practice, AEHSs use combinations of the above-mentioned technologies in order to enrich their adaptive functionality and enhance the support offered to learners. For example, ELM-ART II (Weber & Specht, 1997) is an AEHS that supports learners studying the LISP programming language. It provides adaptive navigation and problem-solving support. The knowledge base of the system contains knowledge about problem-solving in Lisp as well as the Lisp conceptual network that represents all important concepts used in the course and their interrelationships. Adaptive navigation support is provided through several techniques, such as adaptive annotation, direct guidance and adaptive sorting. Adaptive annotation provides adaptive guidance through the course and uses visual cues to show the type and educational state of each link of the course contents. Coloured balls are used to annotate the links (the text of the links is outlined with different styles to aid colour-blind users), i.e. red ball (not ready to study); yellow ball (problem has been solved correctly, or already visited, or nodes' subordinated pages have been visited or learned); green ball (ready to study and recommended); orange ball (page known to the learner; not all of the subordinated pages of the node have been visited or learned). In addition, direct guidance (called individual curriculum sequencing by the authors) is provided by advising the learner on how to proceed with the course. Learner's knowledge and evaluation skills (defined as the skills needed to decide whether programs function correctly and find errors in the code) are assessed through the submission of tests. ELM-ART II also supports example-based programming; it encourages learners to re-use the code of previously analysed examples when solving a new problem. It can predict learner's way of solving a particular problem and find the most relevant example from the individual learner's history. It adaptively sorts these examples, according to their relevance, so that the links that are most similar to the problem that the learner is currently working on are presented first (adaptive sorting technique).

InterBook (Brusilovsky, Eklund, & Schwarz, 1998; Eklund & Brusilovsky, 1999) is a system for authoring and delivering adaptive electronic textbooks on the Web. It is an environment through which structured textbooks can be presented on the Web augmented with the adaptive navigation support functionality providing individualised assistance to each learner. InterBook uses a structured domain model represented as a network, which has nodes corresponding to domain concepts and links reflecting several kinds of relationships among the concepts. Interbook uses adaptive annotation and direct guidance in order to provide adaptive navigation support. Coloured icons and different fonts are used to provide adaptive annotation. Wherever a link appears on Interbook pages (in the table of contents, in the glossary, or on a regular page), its font and the colour of the bullets associated with it represent the status of the node behind the link. For example, green bullet and bold font mean "ready and recommended", i.e. the node has not been learned yet, but is ready to be learned, red bullet and italic font mean "not ready to be learned", etc. A checkmark is placed next to already visited nodes. The same mechanism can be used to distinguish among the different levels of learner knowledge on concepts of the domain: no annotation means "unknown", small size checkmark means "learning started", medium size checkmark means "learned" and big size checkmark means "well-learned". In InterBook, learners have the option to allow the system to propose them which unit should study next by pressing the "Teach me" button. In this case, the system selects the most suitable unit among those ready to be learned providing direct guidance. Learners' knowledge on the different concepts of the domain is estimated by their interactions/actions, i.e. page visits, problem solving, quiz answering.

The Dynamic Course Generation (DCG) system (Vassileva, 1997) generates individualised courses according to learner's goals and previous knowledge, and dynamically adapts the course according to learner's progress. It performs advanced sequencing of content based on the learning goal that learners select. The DCG represents the domain concept structure separated from the teaching materials. The concept structure is used as a road map to generate a plan of the course, i.e. a sequence of concepts and relations that have to be taught during the course. The teaching material is kept in HTML files and a graphical editor allows the creation of concepts, connecting them with various types of semantic relations. Learner's knowledge is mainly determined by the tests s/he submits to the system. In case a learner fails the tests, the system tries to present additional teaching material, and if that is not possible, it requests the "planner" to form a new course plan based on learner model.

MANIC (Stern & Woolf, 2000) is a Web-based instructional system, which provides lecture-based material. Each course consists of slides, designed by the instructor of the course, and audio from the lecture. The slides are dynamically constructed based on learner knowledge and learning style. The domain is organised as a semantic network of topics and adaptation is accomplished through concepts which appear as keywords on the slides. Each concept is associated with a collection of related content objects (either pieces of text or pictures), which describe the particular concept. MANIC implements adaptive presentation through a kind of *stretchtext* (Boyle &

Encarnacion, 1994), which allows certain parts of the page to be opened or closed, i.e. it allows a keyword or phrase to be clicked on by the learner and this way to show up supplementary information about that phrase including graphics and/or text. Furthermore, in order for MANIC to decide which is the most appropriate content object for a concept and how this should be presented, it takes into account learner's preferences of several features of the available content objects as well as where the content object is going to appear on the screen. Thus, the learner's learning style is approached through his/her preferences with respect to the type of media (graphic, text), the type of instruction (explanation, example, description, definition, analogy) and the level of abstractness (abstract, concrete) of the content objects, as well as through his/her ordering preferences of the different types of content objects, for instance, examples should appear first, followed by abstract textual descriptions.

Arthur is a Web-based system (Gilbert & Han, 1999) that provides adaptive instruction based on the learning style of the learners. In this system, several styles of instruction are provided to learners, such as visual-interactive, auditory-text, auditory-lecture and text style. The course content is divided into small sections, named concepts, corresponding to basic units of instruction or to fundamental concepts that must be covered within the course. Multiple types of educational material and assessment tests have been developed for each particular section and each one is tailored to an instruction style, such as interactive Java applets, streaming video, streaming audio and video of previously recorded classroom lectures, text-based explanations. During instruction, the system adapts the instructional style according to the learner's performance in the tests s/he submits. For example, in case the learner scores 70% in a quiz of a concept, then s/he will be provided with material on the same concept but of an alternative instructional style; otherwise, if the learner passes the quiz, then the instructional style currently used is supposed to match the learner's learning style.

Adaptive Courseware Environment (ACE; Specht & Oppermann, 1998) is a Web-based tutoring framework. Within ACE several adaptation technologies have been implemented, such as adaptive navigation support and adaptive sequencing, term used by the authors for a combination of curriculum sequencing and adaptive presentation technologies. In this system, adaptation is based on the pedagogical background of adaptive instruction and the psychology of learning. Learner's knowledge, interests and preferences of the learning material (language, media, interface settings) are used as a source of adaptation. The domain model is built on a conceptual network of learning units which are sections containing other units or concepts. The model is enriched by the use of multiple types of learning materials, such as text (introduction, several levels of text, summary), examples, demonstrations, interactive playgrounds, and tests. Several teaching strategies are adopted, resulting from alternative sequencing of the learning materials. ACE implements two techniques of adaptive navigation support: adaptive annotation and incremental linking of hyperlinks. The adaptive annotation technique is based on the knowledge of the learner and on specified relations among the units to be learned. Coloured balls are used to represent the different states of the concepts, such as ''recommended'', ''not recommended'', etc. A hook annotates concepts that learners have visited. By applying incremental linking of hyperlinks, the system, based on learner's knowledge, disables hyperlinks for ''not ready to be learned units'', restricting the learner's navigation space. Following the adaptive sequencing technique, ACE proposes: (1) a sequencing of the learning units, providing an optimal path based on learner's current knowledge, and (2) a sequencing of learning materials that follows a particular teaching strategy, based on learner's interests and learning material preferences. In ACE, learner's learning material preferences are determined by taking into account his/her learning style preferences as these are inferred from an introductory questionnaire that collects information on learner's preferred learning strategy (learning by example, reading texts or learning by doing). The dynamic adaptation of the teaching strategy is based on information coming from monitoring learner requests on learning materials, as well as on the success of the currently used strategy. The latter is mainly determined by learner's performance in the final tests; repeated occurrences of high performance raise the preference value of a strategy and when a threshold is exceeded, this strategy is considered as default for the particular learner.

Most of the previously-described Web-based systems provide adaptive navigation support, which is one of the most popular technologies in current adaptive hypermedia systems. Adaptive presentation, especially curriculum sequencing, and problem-solving support, both coming from the area of Intelligent Tutoring Systems, are not extensively provided. The domain knowledge in most of these systems is represented through a set or a network of concepts, i.e. elementary pieces of knowledge for the given domain, and the content is provided through interconnected hypermedia pages. All systems maintain a learner model for each individual learner, which usually represents learner knowledge level on the concepts of the domain and preferences of different types of educational material and their order of appearance, or screen design preferences. The knowledge level is usually determined by learner's navigation through the domain or by the percentage of the right over wrong answers to assessment questions.

Users' individual traits (Brusilovsky, 1999), refer to features that define a user as an individual, such as personality factors, cognitive factors, learning styles, have not attracted considerable attention as a source of adaptation yet. These are traditionally extracted not by a simple interview, but by specially designed psychological tests (Brusilovsky, 1999). The main problem in exploiting such information is to determine which features should be used (are worth modelling) and how (what can be done differently for learners with different styles). Learner's learning style in MANIC is used to select the appropriate type of educational material provided as supplementary information for a concept, and to specify where to place the material on each page. In this system learning style is approached through learner's preferences of several features of the educational material as they are inferred from his/her previous selections. In Arthur, learner's learning style is considered as the style of instruction that helps learners exhibit satisfactory performance. The alternative styles of instruction used in Arthur differ in the media they use. Thus, their implementation demands the development of multiple types of educational material using different media for each particular section of the course. In ACE, the learning style of each learner is approached through his/her preferred learning strategy (learning by example, reading texts or learning by doing) as the learner declares it in an introductory questionnaire. Learner's learning style preferences are used to select the appropriate teaching strategy for that particular learner and they are dynamically adapted based on learner's actions and on the success of the current strategy. In ACE, the alternative teaching strategies adopted mainly differ in the sequence of the learning materials that they propose.

In INSPIRE (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2002), the prototype AEHS used to illustrate our approach, a combination of instructional design theories with the learning styles theory is adopted, in an attempt to propose an adaptation framework that is educationally effective and technologically feasible. This framework mainly affects the domain knowledge representation of the system, as well as several aspects of the instructional process.

Based on learners' knowledge level and individual traits, individualised Web-content is generated and presented to learners. Specially, learners' individual traits are approached through the learning style of the learner following the categorisation proposed by Honey and Mumford (1992), and are used to determine the appropriate instructional strategy for presenting the content (adaptive presentation technology). Also instructional decisions for selecting lessons' content (curriculum sequencing) and for annotating hyperlinks in the domain hyperspace (adaptive navigation support) are based on the knowledge level of the learner and his/her progress (level of performance) as it is assessed through the submission of tests that include questions of multiple types.

3. Overview

INSPIRE is a prototype AEHS designed to support Web-based instruction as well as traditional classroom-based teaching as a supplementary resource (Papanikolaou et al., 2002). The system adopts the idea of restricting the domain knowledge at the beginning of the interaction—an approach appropriate for novices (Bransford, Brown, & Cocking, 1999)—and enriching it, progressively, following learner progress. Based on the notion of the learning goals, (Vassileva, 1997), that the learner chooses to pursue, the system generates lessons that correspond to specific learning outcomes accommodating learner's knowledge level and learning style.

User interface in INSPIRE provides learners with a complete view of the structure of the domain knowledge, and with direct access to learning resources and to system's functionality. To this end, the main screen of INSPIRE is divided into three different areas, as shown in Fig. 1.

1. The *Navigation Area* includes the contents of the lessons in a hypertext form as links. A structural navigation form of links, (Nielsen, 2000), has been adopted to outline the structure of the lesson contents and to support learner-controlled navigation;

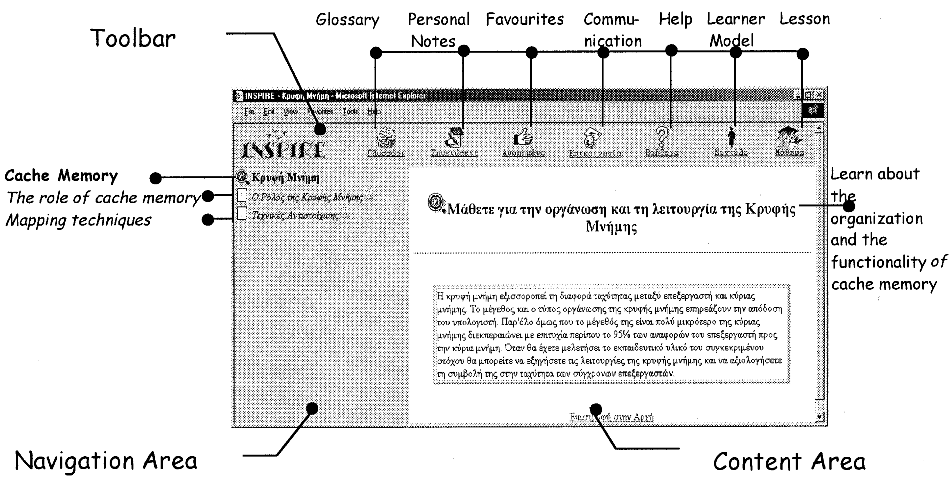

Fig. 1. INSPIRE's main screen is divided into three areas: (A) Navigation Area: the contents of the lesson are provided as links, (B) Content Area: presents the contents of the page that the learner selected and (C) Toolbar: several tools are provided.

2. The *Content Area* presents the pages of educational material that the learner selects from the Navigation Area;
3. The *Toolbar* includes several tools that offer learners: (1) *easy access to* various facilities, such as glossary of terms, personal notes, favourite pages, communication means (e-mail, forums, chat), help on system functionalities/facilities; (2) access to the lesson contents and to their learner model, which is stored and updated by the system during interaction.

INSPIRE's adaptive functionality is reflected to the personalisation of the Navigation and Content Areas and is implemented through the following technologies:

Curriculum sequencing, that allows the gradual presentation of the outcome concepts for the learning goal that the learner studies, by making use of information about the learner's progress;

Adaptive Navigation Support, that helps learners navigate in the lesson contents by annotating the links in the Navigation Area, according to learners' progress;

Adaptive Presentation, that supports various alternative forms of presentation of the educational material pages in the Content Area according to the learning style of the learner, as this is initialised by the appropriate questionnaire (Honey & Mumford, 1992), or by the learner.

4. Adaptive dimension

In our approach, lesson generation is based on the learning goals that learners select from a set of meaningful learning goals, i.e. the hypermedia system plans the lesson content and delivers the appropriate educational material, supporting learners to accomplish their goals. Moreover, the presentation of the educational material of each lesson is adapted to the learner's learning style, and a navigation route through the lesson contents is proposed based on his/her knowledge level. In this section, we explain the way lessons in the hypermedia system are structured to support instructional decisions. We, then, proceed by describing the technologies used to implement adaptive behaviour.

4.1. Structuring a lesson

The structure of each lesson is organised in three hierarchical levels of knowledge abstraction: *learning goals, concepts* and *educational material* (Papanikolaou, Magoulas, & Grigoriadou, 2000). A learning goal corresponds to a topic of the domain knowledge that the learner can recognise and select for studying. Each goal is associated with a subset of concepts of the domain knowledge, which formulates a conceptual structure that represents all the concepts of the goal and their interrelationships. The concepts of a learning goal are assigned qualitative characterisations, such as *outcome concepts, prerequisite concepts* and *related concepts,* where the outcome concepts are the most fundamental ones to the accomplishment of the goal. Prerequisite and related concepts are associated with each of the outcome concepts. The educational material that presents the concepts of a learning goal consists of various types of *knowledge modules*. The knowledge modules constitute multiple external representations of the concepts, such as theory presentations (definitions, descriptions, conclusions), examples (concrete instantiations of concepts, analogies), exercises, activities using computer simulation, definitions in the glossary, etc.

The structure of the generated lessons is visualised in the Navigation Area (see Fig. 2). The lesson contents are organised hierarchically into: learning goal, outcome concepts (the icon on the right of the outcome's name in the Navigation Area provides access to its prerequisites) and educational material associated with each outcome and its prerequisites (if it exists). The educational material of an outcome concept is further organised in three different levels (annotated by different icons as will be explained in Section 4.4) that correspond to three levels of learner's performance. In defining the three levels of learner's performance, the approach proposed in (Merrill, 1983) was adopted: (1) *Remember,* this level is associated with the ability of learners to recall the provided theory and specific instances presenting a concept, (2) *Use,* this level relates to the ability of learners to apply theory to specific case(s), and (3) *Find,* this level is associated with the ability of learners to propose and solve original problems. Combinations of various types of knowledge modules (theory presentations, examples, exercises, activities using computer simulation, etc.) constitute the pages of the educational material that correspond to each of the three levels of performance for each particular concept. Accordingly, brief presentations are provided for the prerequisite concepts of each outcome. Prerequisite concepts are accessible through hyperlinks located in the Navigation Area (see Fig. 2—links to the educational material of prerequisite concepts), or in the introductory page of the outcome concept (see Fig. 3—links to prerequisite concepts). Definitions of the related concepts of each outcome become available

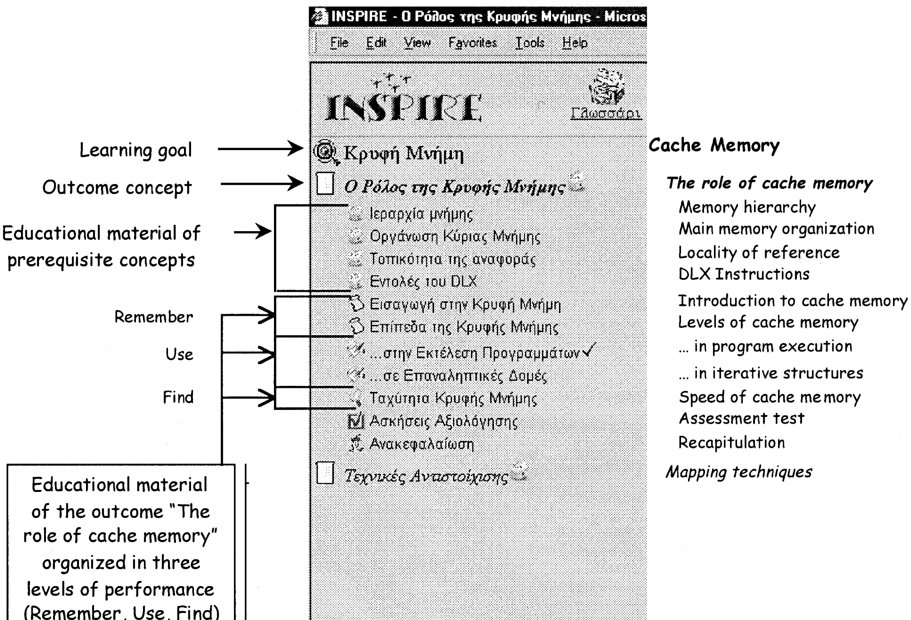

Fig. 2. In the Navigation Area, the contents of the first lesson generated for the learning goal "Cache Memory" are shown. The first outcome concept "The role of cache memory" appears expanded, as each time only one of the outcome concepts can be in expanded form in the Navigation Area. Descriptions of the components of the Navigation Area are provided on the left-hand side, while the English translation of the lesson contents is given on the right-hand side.

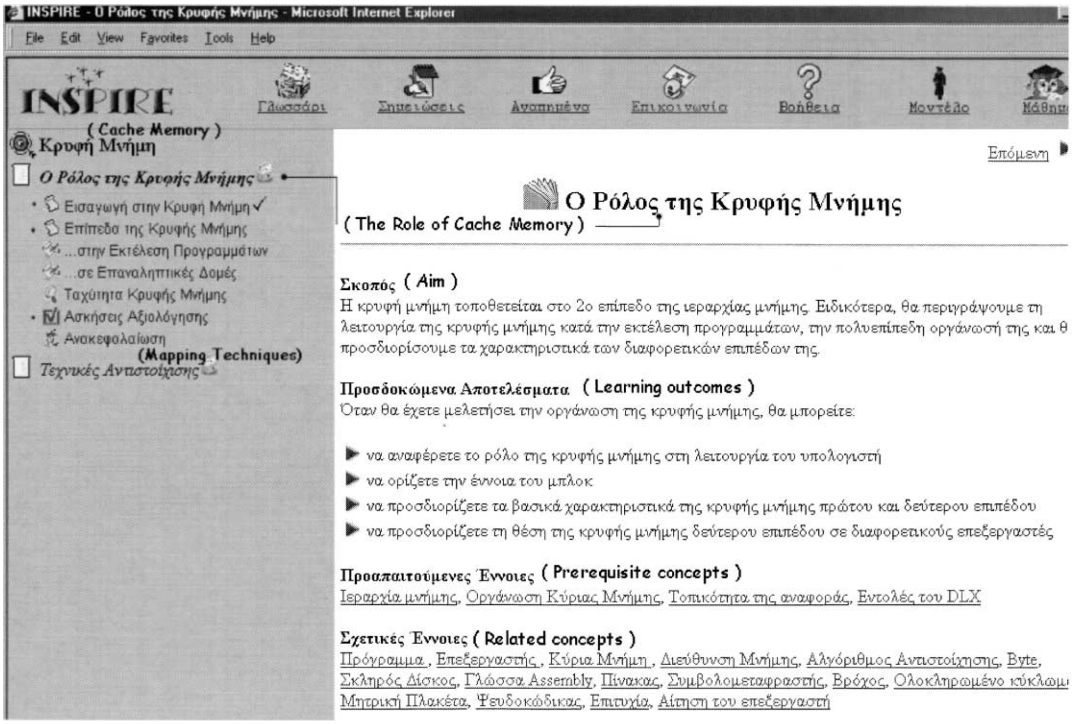

Fig. 3. The introductory page for the outcome concept "The role of cache memory". The page includes: aims of the presentation, learning outcomes and links to prerequisite and related concepts.

when learners click on the hyperlinks of the related concepts located on the introductory page of each outcome concept (see Fig. 3—links to related concepts).

4.2. *Curriculum sequencing*

The technology of curriculum sequencing is used in order to generate a sequence of lessons that gradually guide the learner to accomplish specific concept-related learning outcomes, and finally meet the selected learning goal. To this end, the system follows several instructional strategies for planning the content and the delivery of the educational material of each lesson for a particular learner, based on his/her progress.

4.2.1. *Planning the content of a lesson*

The concepts of a learning goal in INSPIRE, are presented gradually following the internal structure of the outcome concepts. The outcome concepts of a learning goal are organised in a *layered structure* following a simple-to-complex sequence (Reigeluth & Stein, 1983), according to which at the first layer the simplest and more fundamental concepts are included, providing an overview of the learning goal, and then, subsequent layers of outcome concepts add complexity, or detail to a part or aspect of the learning goal.

The content planning process, i.e. the selection of the concepts to be included in the lessons generated for a learning goal, follows the layered structure of the outcome concepts taking into account the knowledge level of the learner. As a consequence, the layer of the outcome concepts that is included in each lesson is determined by the learner's knowledge level on the outcome concepts of the previous layers. Thus, learners should successfully pass the assessment tests provided for the concepts of the current layer in order to proceed to the next one. The knowledge level of the learners on the different concepts of a lesson is evaluated using the assessment tests that learners submit to the system, and classified into categories: {Inadequate, Almost Adequate, Adequate, Advanced}, as discussed in Section 5.1.

Furthermore, several strategies are used in order to determine the concepts of the selected layer that the learner should study next. These instructional decisions are mainly based on the knowledge level of the learner as well as on the relative importance of each concept with respect to the currently studied learning goal (outcome or prerequisite concept).

Strategy A. The knowledge level of the learner has been evaluated as {Inadequate} on a number of outcome concepts. Then, these outcome concepts and their prerequisite concepts are recommended to the learner: the leamer is suggested to start studying the prerequisite concepts of the outcome concepts independently of his/her knowledge level on those concepts, and then to proceed with the outcome concepts (prerequisite concepts appear in the Navigation Area just above the educational material of an outcome concept).

Strategy B. The knowledge level of the learner has been evaluated as {Almost Adequate} or {Adequate} on a number of outcome concepts and {Advanced} on several of their prerequisite concepts. Then, these outcome concepts, and the rest of their prerequisite concepts are recommended to the learner. As learner's knowledge of the outcome concepts reaches a level of sufficiency, s/he is suggested to start studying only those of the prerequisite concepts that s/he does not already know and then proceed to study the outcome concepts.

Note that in the current implementation of the system, related concepts are always available to the learner. In addition, the concepts of each subsequent layer enrich those of the previous layers, i.e. the content of each subsequent lesson also includes contents of previous lessons, aiming at augmenting gradually the domain space presented to the learner.

For example, in Fig. 4 the Navigation Area of INSPIRE is shown in three different timeslots. The left part of Fig. 4 (Lesson 1) shows the contents of the Navigation area for a learner who just selected to study the learning goal "Describe the role of cache memory and its basic operations" or briefly called "Cache memory", and s/he is a novice. Thus, the system presents the concepts of the first layer, i.e. the outcome concepts "The role of cache memory" and "Mapping techniques", on which his/her knowledge level is considered as "Inadequate". Then, following Strategy A, the generated lesson includes the two outcomes and all of their prerequisites. As the learner progresses, his/her knowledge level is evaluated as {Adequate} on both outcome concepts (after performing well in the assessment tests). Then, in the next generated lesson the concepts of the second layer ("Basic operations" and "Placement") will enrich those of the first one, as shown in Fig. 4 (Lesson 3).

4.2.2. Planning the delivery of the educational material

This process selects the appropriate educational material for the concepts of a lesson (as these have been determined by the content planning process described earlier) by taking into account

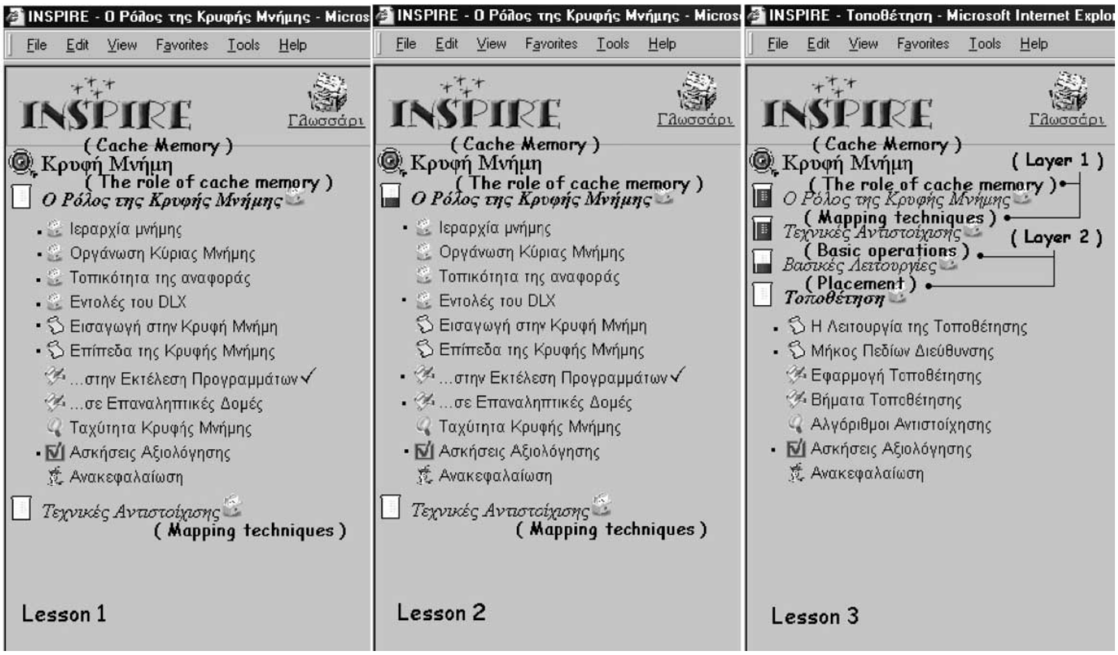

Fig. 4. INSPIRE's Navigation Area in three different timeslots (to improve the clarity of the screenshot the coloured icons are marked with a bullet) for a particular learner. Lesson 1: The lesson contents include the concepts of the first layer for the outcome concept "The role of cache memory". The learner is proposed to study the prerequisite concepts and the educational material of the first level of performance. Lesson 2: the lesson contents include the concepts of the first layer for the outcome concept "The role of cache memory". In this case, the learner is proposed to study several of the prerequisite concepts (those marked with a bullet), and the educational material of the second level of performance.

the knowledge level of the learner on those concepts. Multiple strategies can be used for planning the educational material of a lesson. For example, three of the strategies used in the selection of the educational material for a generated lesson are:

Strategy 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 those of their prerequisite concepts that have been included in the lesson contents, is proposed to the learner.

Strategy D. The knowledge level of the learner has been evaluated as {Almost Adequate} on a number of outcome concepts included in the lesson contents. Then, educational material of the *Use* level of performance for these outcome concepts as well as material for those of their prerequisite concepts that have been included in the lesson contents are proposed to the learner.

Strategy E. The knowledge level of the learner has been evaluated as {Adequate} on a number of outcome concepts included in the lesson contents. Then, educational material of the *Find* level of performance for these outcome concepts, as well as material for those of their prerequisite concepts that have been 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 the concepts included in the lesson, visual cues are used to point out pages that the learner is recommended to study next. This way, we provide individual navigation advice following learners' knowledge level without restricting the provided educational material and limiting learners' freedom to browsing.

Next, we provide an example following the curriculum sequencing procedure and the way its output is visualised in the Navigation Area of INSPIRE. The left part of Fig. 4 (Lesson 1) shows the contents of the Navigation Area for a learner who is considered a novice with respect to the current learning goal. The knowledge level of the learner on both outcome concepts, i.e. "The role of cache memory" and "Mapping techniques", is characterised as "Inadequate". Thus, following Strategy C, the system proposes the learner to study the educational material of the *Remember* level of performance for the two outcome concepts, the material of their prerequisite concepts, and the assessment test, which is always proposed independently of learner's knowledge level. Note that in Fig. 4 (Lesson 1), where the educational material of the outcome "The role of cache memory" is fully expanded, coloured icons (marked also with a bullet) are used to annotate the proposed educational material (the material for the Remember level of performance is also shown in Fig. 2 translated in English). The next time slot (Fig. 4—Lesson 2) shows the state of the learner soon after the submission of a test. His/her knowledge level has been evaluated {Almost Adequate} on the outcome "The role of cache memory" and {Advanced} on its prerequisite concepts "Main memory organisation" and "Locality of reference". Then, the system implements Strategy D for the outcome "The role of cache memory" and Strategy C for the outcome "Mapping techniques". Thus, the system proposes educational material of the *Use* level of performance for the first outcome concept and the material of two of the prerequisite concepts, i.e. of the concepts "Memory hierarchy" and "DLX instructions" (see Fig. 4—Lesson 2, where the educational material of the outcome "The role of cache memory" is fully expanded; English translation is provided in Fig. 2). The system also proposes the learner to study the educational material of the *Remember* level of performance for the outcome concept "Mapping techniques", and the material of its prerequisite concepts (note that in Fig. 4—Lesson 2 the concept "Mapping techniques" is "closed", as only one outcome concept is possible to appear in expanded form in the Navigation Area).

4.3. Adaptive presentation: planning the presentation of the educational material pages

The presentation of the educational material pages, in the Content Area, differentiates depending on the learning style of the learner. As presented in Section 4.1, the educational material pages of the outcome concepts contain various types of knowledge modules, such as theory presentations, examples, exercises, activities using computer simulation, etc. Although all learners are provided with the same knowledge modules, the method and order of their presentation on each page of educational material is adapted to the learner's learning style. In INSPIRE, the different knowledge modules are either embedded in the page, or appear as links with a specified order, depending on the learning style of the learner. Thus, through the adaptive presentation technology, the same knowledge modules can be reused in different instructional strategies that focus on highlighting different aspects of the concepts. This approach alleviates the problem of rewriting the same content for each learning style category.

Table 1
Instructional strategies adopted for presenting the educational material pages to learners with different learning styles (Activist, Reflector, Theorist, Pragmatist) at the Remember and Use levels of performance. The sequencing of the knowledge modules used in each level of performance (appear in parentheses) differentiates depending on the learning style of the learner

	Remember	Use
Activist	Inquisitory presentation (Question, Example, Theory)	Activity-based (Activity, Example, Theory, Exercise)
Reflector	Expository presentation (Theory, Example, Quetion)	Example-based (Example, Theory, Exercise, Activity)
Theorist	Inquisitory presentation (Question, Theory, Example)	Theory-based (Theory, Example, Exercise, Activity)
Pragmatist	Expository presentation (Example, Theory, Question)	Exercise-based (Exercise, Example, Theory, Activity)

In more detail, various types of knowledge modules, such as questions, theory presentations (definitions, descriptions, conclusions) and examples constitute an educational material page at the *Remember* level of performance. Changing the order and method of presentation of the modules on an educational material page results in the implementation of alternative instructional strategies (see Table 1). For example, at the Remember level of performance, the theory of a concept can be presented following an inquisitory or expository instructional strategy. Inquisitory presentation starts with a question, which appears at the top of the educational material page, aiming to motivate the learner to use his/her prior knowledge and imagination, the examples and the necessary theory (they better appear as links) for answering that question (see Fig. 5). When expository presentation is used, the same question appears at the bottom of the educational material page, as a self-assessment question, with the aim to motivate the learner to reflect

Fig. 5. Inquisitory presentation of theory of the outcome concept ‘‘The role of cache memory’’ at the Remember level of performance. The knowledge modules that comprise the page of the educational material entitled ‘‘Introduction of cache memory’’ are: (1) Introductory Question; (2) link to an Example which can be an analogy of everyday life, a real paradigm of the concept, or a computer simulation that visualises the theory; (3) link to the Theory presenting the concept.

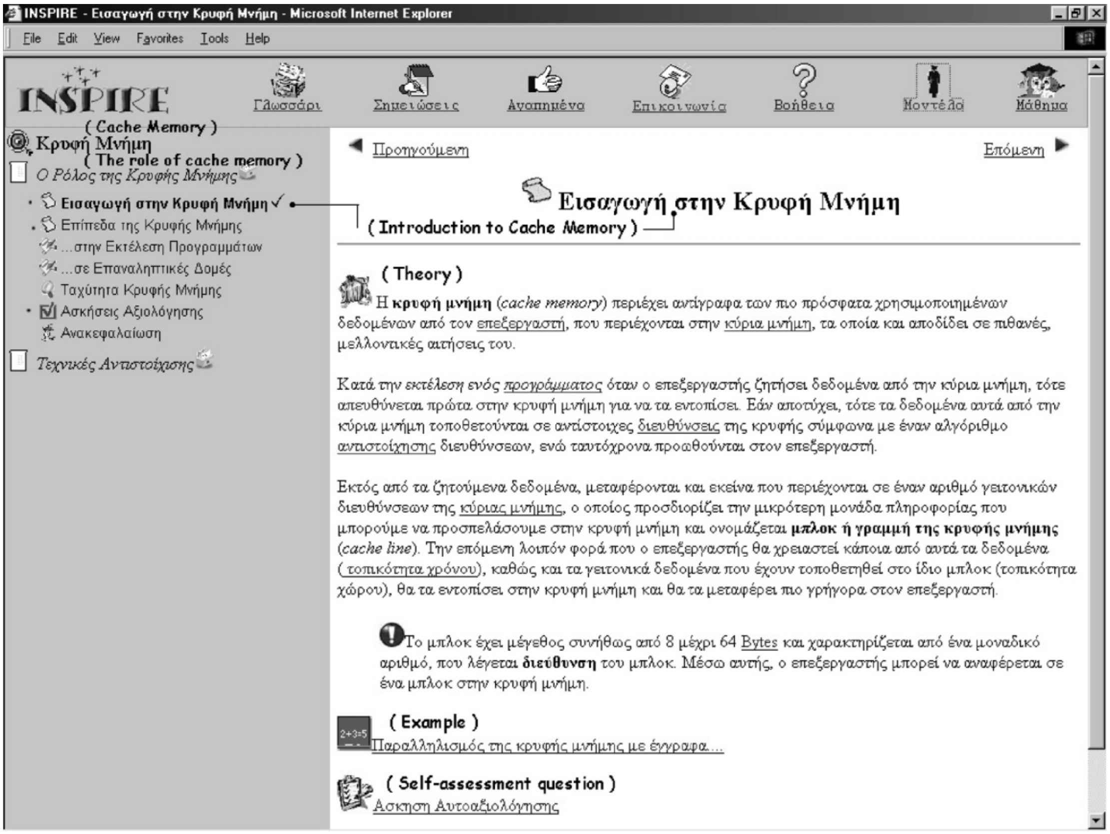

Fig. 6. Expository presentation of theory of the outcome concept ''The role of cache memory'' at the Remember level of performance. The knowledge modules that comprise the page of educational material entitled ''Introduction to cache memory'' are: (1) Theory covering the concept; (2) link to an Example which is an analogy of everyday life, a real paradigm of the concept, or a simulation that visualises the theory; (3) link to a Self Assessment Question.

on what s/he has already studied (see Fig. 6). The arrangement of the provided examples and theory may also differentiate depending on the strategy so as to stimulate the learner to start studying the theory of the concept or specific instances of it (cf. Figs. 5 and 6). Accordingly, an educational material page at the *Use* level of performance is constituted by hints from theory, examples, exercises and activities using computer simulations. Thus, if the instructional strategy is activity-based then the knowledge module ''Activity'' appears on the top of the page followed by the rest of the modules, which appear as links (see Fig. 7). In this case the learner is encouraged to start experimenting and use the examples and the theory as aids for dealing with the challenging task of the activity. When the adopted instructional strategy is example-based, then the knowledge module ''Example'' appears on the top of the page whilst the rest of the modules appear below as links (see Fig. 8). Thus, the learner is encouraged to start reading application examples of the concept and hints from the theory, which provide the necessary information on the way the particular concept is used. Next, the learner is supposed to apply this information to solving some exercises (these have the same degree of difficulty as the examples provided), and to performing activities using computer simulation in order to accomplish certain tasks.

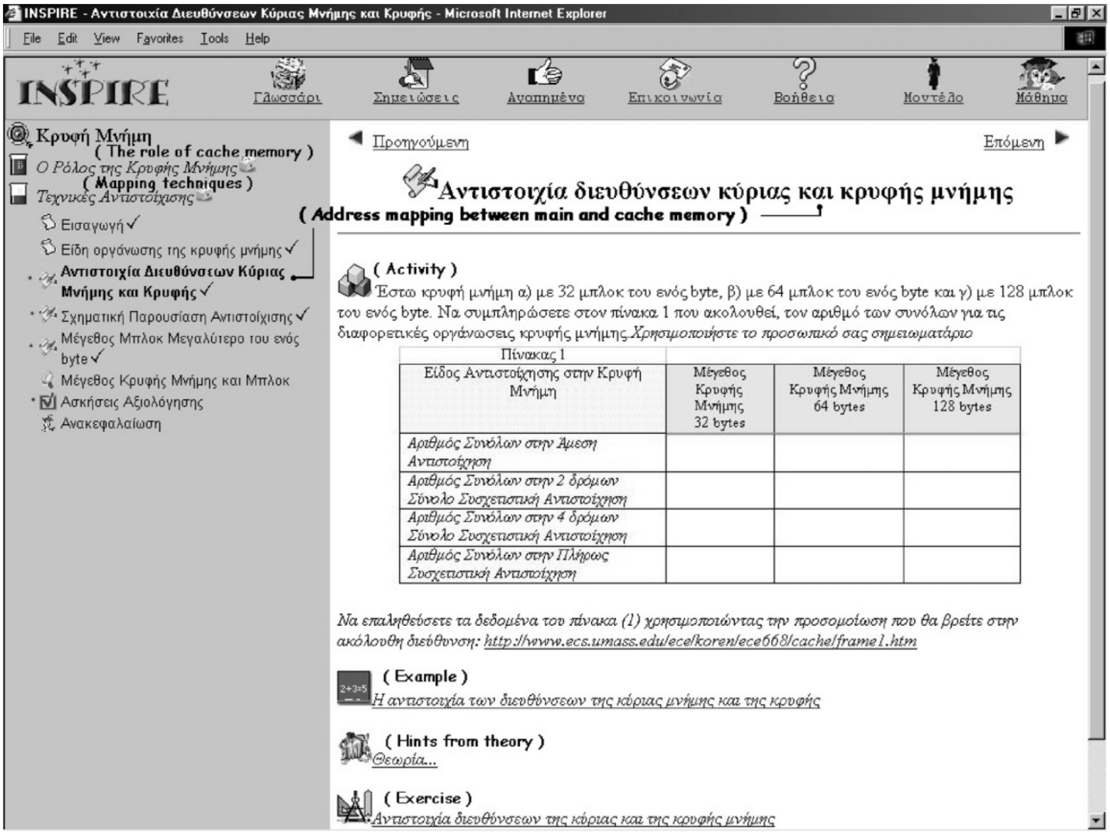

Fig. 7. Presentation of the educational material for an Activist: knowledge modules that comprise the page of educational material entitled ‘‘Address mapping between main and cache memory’’ of the outcome concept ‘‘Mapping techniques’’. (1) Activity that uses computer simulation; (2) link to an application Example; (3) link to hints from the Theory; and (4) link to an Exercise.

The selection of the most appropriate instructional strategy for presenting the educational material pages to each individual learner is mainly determined by his/her learning style. The main objectives are to enhance learning by matching the dominant learning preferences of the learners with the appropriate sequencing of educational material and to stimulate learning style growth and collaboration by providing them with knowledge modules of multiple types. Learners are motivated to pass through the provided educational material exploiting their own capabilities and developing new ones (Kolb, 1984). At the current implementation of the system learners are classified according to their dominant learning style following the learning style model proposed by Honey and Mumford (1992). This model based on Kolb’s theory of experiential learning (Kolb, 1984), describes four types of learners: *Activists, Pragmatists, Reflectors, Theorists*. This approach to learning styles focuses on learners’ behaviour and beliefs in the workplace, and, thus, it was considered promising for a Web-based course, where the target group is usually professionals with a common interest on the particular subject of the course they attend.

The selection of the appropriate instructional strategies for the different learning style categories (see Table 1) reflects some tendencies of each category in approaching information and is

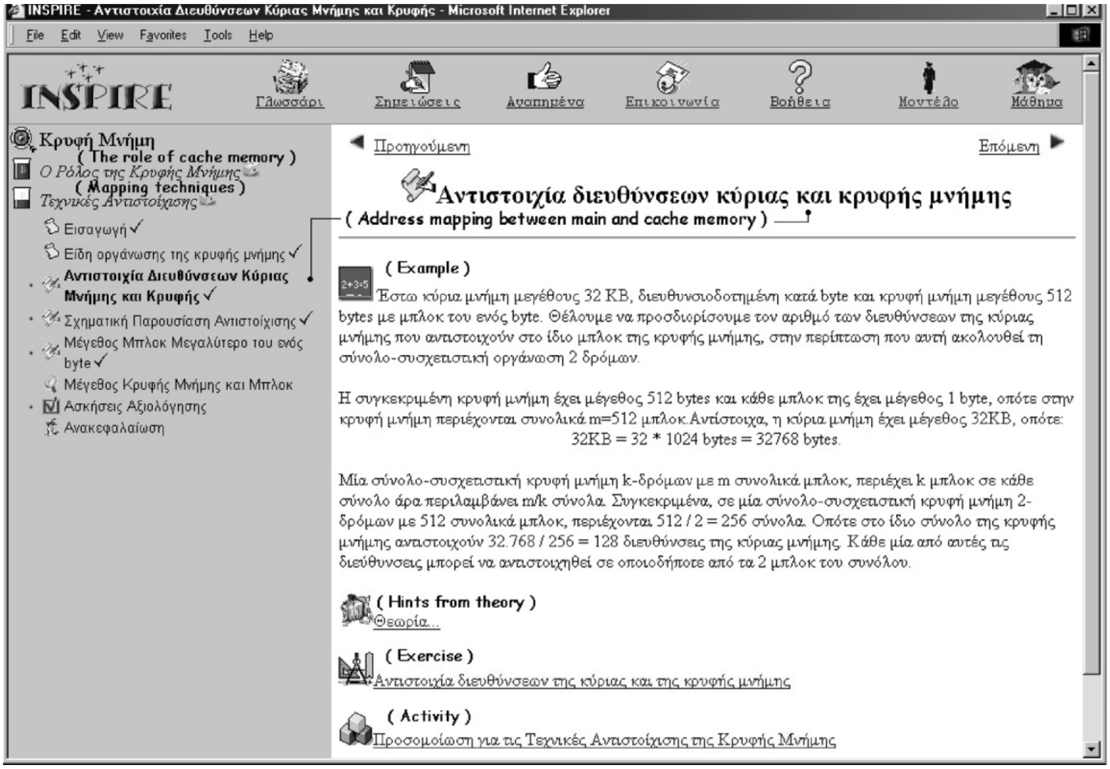

Fig. 8. Presentation of the educational material for a Reflector: knowledge modules that comprise the page of educational material entitled ‘‘Address mapping between main and cache memory’’ of the outcome concept ‘‘Mapping techniques’’. (1) Application Example; (2) link to hints from the Theory; (3) link to an Exercise; (4) link to an Activity that uses computer simulation.

in accordance to related work proposed in the literature (Groat & Musson, 1995; Stoyanov, Aroyo, & Kommers, 1999). Furthermore, empirical investigations of learners’ preferences have been realised during the first stages of the formative evaluation of INSPIRE aiming to provide direct information from learners about their studying attitudes in relation to the material (see Section 6 for more details). Thus, the presentation of the educational material to Activists, who are more motivated by experimentation and are attracted to challenging tasks, focuses on activities. To this end, the inquisitory presentation of theory is adopted for the Remember level of performance and the activity-based strategy is employed for the Use level of performance. Accordingly, for Reflectors who prefer to collect and analyse data before acting, the instructional strategy adopted is the expository presentation of theory for the Remember level of performance and the example-based strategy for the Use level of performance.

For example, Fig. 7 shows a screenshot of INSPIRE illustrating an educational material page as viewed by an Activist. The learner is a novice and is currently studying the educational material ‘‘Address mapping between main and cache memory’’ of the outcome concept ‘Mapping techniques’’. The instructional strategy suggests that the learner should start with an activity, i.e. run an experiment following a specified educational scenario that uses a computer simulation. The learner undertakes an active role and through experimentation constructs his/her own internal representations for the concept s/he studies. In case the learner needs more help, an example and hints from the theory are available. Also, an exercise is provided offering additional opportunities for practicing. When a Reflector is using the system (see Fig. 8), INSPIRE proposes to start reading an example, continue with hints from the theory and then try to solve an exercise. Finally, an activity using a computer simulation is provided with the aim to visualise the presented concepts and stimulate the learner, through an educational scenario, to get an active role, experiment with the already acquired information, or just test his/her knowledge.

4.4. *Adaptive navigation support*

Learner's orientation and navigation in the content is supported by using graphical icons to point out the structure of the lesson (see Fig. 1—Navigation Area), and by changing the appearance of the links in the lesson contents in the Navigation Area in order to:

- propose a navigation route according to learner's progress;
- inform learners of their level of performance on the different concepts of the current learning goal;
- denote the current educational material page and the already visited pages.

The structure of each generated lesson (presented in Section 4.1) is visualised in the Navigation Area using different icons. These icons aim to support the learner's expectations about the interface and are used to point out the structure of the domain, i.e. the learning goal, the outcome concepts and the educational material. Especially, the learner can access material of the prerequisite concepts of an outcome by clicking on the special icon placed next to the outcome concept in the Navigation Area. That causes the hyperlinks of the educational material of the prerequisite concepts to appear in the Navigation Area below the corresponding outcome concept (cf. Fig. 3—Navigation Area, and the educational material of the outcome concept "The role of cache memory" in Fig. 4—Lesson 1, Lesson 2). Alternatively, the prerequisite as well as the related concepts of an outcome can be accessed through hyperlinks, which are embedded in the introductory page of the outcome concept (see under the headings "Prerequisite concepts" and "Related concepts" on the bottom of the page in the Content Area of Fig. 3). The educational material provided for each outcome concept is organised in three levels, which correspond to the Remember, Use, and Find levels of learners' performance, as mentioned in Section 4.1. The different icons, which appear next to the hyperlinks of the educational material pages of the outcomes in the Navigation Area, identify the level of the corresponding, page i.e. a "page icon" denotes the *Remember* level of performance, a "page with a pencil icon" denotes the *Use* level of performance and a "lens icon" denotes the *Find* level of performance (Fig. 2—Navigation Area).

The navigation route in the lesson contents reflects the concepts and the educational material that the system recommends the learner to study next, following the curriculum sequencing process presented in Section 4.2. In the Navigation Area, as presented in Section 4.2.2, the system provides all the available educational material for the presented concepts by adopting an adaptive annotation technique that uses visual cues in order to recommend learners what material they should study next. To this end, a "flashlight" metaphor is employed: two state icons are associated with the links of the educational material pages of the outcome and prerequisite concepts (see Fig. 4: Lessons 1,2 and 3); coloured icons appear next to the links of the pages that are recommended to be studied but still not learned, while black and white icons appear next to the rest of the links.

Furthermore, additional information about the current knowledge level of the learner, i.e. his/her level of performance on the different outcome concepts augments the appearance of the concepts in the Navigation Area. In particular, the filling of a measuring cup is adopted as a visual metaphor to denote the learner's progress (see in Fig. 4—Lesson 3 the different icons associated with the outcome concepts).

A history-based mechanism has also been developed to support learners' orientation in the domain space; thus, a check mark appears next to a page link (see Fig. 3—Navigation Area) after visit, whilst the link to the current page appears boldfaced and italicised.

For example, in Fig. 4—Lesson 2, INSPIRE distinguishes the educational material that is recommended by means of coloured icons. Thus, as shown in Fig. 4, INSPIRE "colours" only the icons of the educational material associated with the *Use* level of performance of the outcome concept "The role of cache memory", as well as its prerequisite concepts "Memory Hierarchy" and "DLX instructions" (in Fig. 4, coloured icons are marked with a bullet). A half-filled cup, placed next to the outcome concept, denotes that learner's knowledge level on this outcome concept has been evaluated as {Almost Adequate}. With regards to the second outcome concept, "Mapping techniques", the learner has been evaluated as having an {Inadequate} knowledge level; thus, an empty cup is placed next to the concept. Should the learner click on the outcome concept "Mapping techniques", links to the corresponding educational material will appear. The educational material of the *Remember* level of performance of this concept and that of its prerequisite concepts will be associated with coloured icons.

5. Implementation issues

The adaptive behaviour of a hypermedia system following our approach is mainly based on the domain knowledge representation, and is guided by the learner model, which reflects specific features of the learner. The learner model stores the "current state" of the learner, and is updated during interaction. Below we briefly present issues related to the learner model, the representation of the educational material and the technology used for dynamic page generation in the context of our prototype system.

5.1. Learner model

The learner model represents the knowledge of the system about the learner. It reflects several characteristics of the learners and supports the communication between learner and system. In our approach, the learner model includes general information about the learner, his/her dominant learning style and his/her "current state" (knowledge level on the different concepts of the learning goals that s/he studies, performance on assessment tests, the type of the knowledge modules s/he has accessed and the time spent studying them, etc.).

In particular, the knowledge level of the learners on the different concepts of the learning goal that they study is evaluated using the assessment tests that learners submit to the system.

Assessment tests are part of the educational material of each outcome concept and include various types of questions assessing learner's level of performance on the outcome concept and its prerequisite concepts. The knowledge level of the learner on the outcome concepts of the selected goals takes values in the set {Inadequate, Almost Adequate, Adequate, Advanced} using the evaluation method proposed in (Magoulas, Papanikolaou, & Grigoriadou, 2001). A detailed account of this technique is provided in (Grigoriadou, Kornilakis, Papanikolaou, & Magoulas, 2002).

In the current implementation of the system the learning style is initialised through the submission of the questionnaire developed by Honey and Mumford (1992). Thus, the first time learners log on the system, they submit the questionnaire and, automatically, their learning style is determined using the procedure defined in Honey and Mumford (1992); their learning style is stored in the individual learner's model. Alternatively, the learning style can be directly initialised or updated by the learner, 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.

Finally, information stored in the learner model with regards to the current state of the learner is a valuable resource for the tutor in order to monitor learners' progress and studying attitude, and to evaluate the educational material. A quantitative evaluation of learners' preferences of the educational material, in terms of time learners spent on it, their performance, their requests to the system for help on specific pages, etc., would provide the tutor with useful information about the quality of the educational material.

5.2. *Metadata specifications*

Currently, the educational material that has been developed to support and test the adaptive functionality addresses the learning goal ''Describe the role of cache memory and its basic operations'' which is based on the chapter *Computer Memory* of the University level course ''Computer Architecture'' offered by the Department of Informatics and Telecommunications of the University of Athens.

Metadata specify the attributes that fully and adequately describe educational material pages. The description of the educational material pages in INSPIRE is based on the ARIADNE recommendation for educational metadata. In Table 2, the metadata description of a page is presented using three types of descriptors (ARIADNE, 2000): (1) *pedagogical attributes,* (2) *semantics* of the resource, and (3) *general information* about the resource.

Following the previous description: (1) the *level of performance* to which each page corresponds, i.e. Remember, Use, Find, is related to the values of the pedagogical attributes' field {*Difficulty_Level*}, (2) the *concepts* that are presented in a page are defined in the fields {*Main_Concepts, Other_Concepts)* of the semantics of the resource, and (3) the *learning goal* that each page it is related to is defined in the field {*Sub-discipline*} of the semantics of the resource.

5.3. *Platform*

The current implementation of the prototype system is using an IIS Web server running on Windows NT. The learner model and the educational metadata describing the educational material are stored in a SQL Server database that communicates with the Web server through the use of the ActiveX Data Objects (ADO) technology. The implementation of the adaptive functionality of

Table 2
A sample of the metadata information of the educational material page {Ed 12 }. The page is entitled "Introduction to cache memory" and covers the outcome concept "The role of cache memory" that belongs to the learning goal "Cache Memory"

General information	Semantics of the resource	Pedagogical attributes
Identifier: Ed12 *Title:* "Introduction to cache memory" *Authors:* 'M. Grigoriadou' *Date:* '09/01/2000′ *Language:* 'GR' *Publisher:* 'Dept. of Informatics & Telecommunications, University of Athens' *Sources:* 'Computer Architecture', Henessy & Patterson, 1996, 2nd Ed.	*Discipline:* 'Computer Architecture' *Sub-discipline:* 'Cache Memory' *Main Concept:* 'The role of cache memory' *Main Concept Synonyms:* *Other Concepts:*	*End User Type:* 'Learner' *Doc. Format:* 'Text' *Usage Remarks:* *Didactical Context:* 'University level' *Course Level*: 'GR, University level, 2nd year' *Difficulty Level:* 'Remember' *Semantic Density:* 'High' *Pedagogical Duration:* 20

INSPIRE is based on the Active Server Pages (ASP) technology, which allows the dynamic generation of pages.

6. Pilot Study

This section describes a pilot study conducted as first part of the formative evaluation of the prototype system. Formative evaluation helps to improve several aspects of a system as part of an iterative process. The main goal of this study is to investigate the strong and weak aspects of the system from the point of view of the learner. Thus, our approach is mainly qualitative and focuses on:

- the quality of the educational material and learners' preferences of the different types of knowledge modules provided;
- the instructional design adopted, which provides the framework for structuring the domain and developing the educational material of the system; and
- the way the instructional design of the hypermedia system reflects to the interface.

The first two aspects of the system are very important and reflect the educational perspective of a hypermedia system, as educational material plays an important role in the educational effectiveness of a learning environment (Grigoriadou & Papanikolaou, 2000). Moreover, getting the interface right is crucial in learning situations so as to reflect effectively the instructional design of the system and to prevent needless squandering of the learner's resources. Thus, this form of evaluation serves as a first step towards the evaluation of the adaptive functionality of the system that it is partly based on these aspects.

6.1. Test plan

The test plan (Nielsen, 1993) describes the main aspects of the pilot study: (1) goal; (2) place, time and duration; (3) necessary equipment, both software and hardware; (4) who would serve as experimenters, organising and co-ordinating the pilot study and to what extent they are allowed to help users; (5) who should participate in the study (test group) and what tasks participants are going to perform; (6) what data should be collected and how they should be analysed. The earlier-mentioned aspects are presented later in more detail.

The goal of the pilot study was to provide us with: (1) direct information from learners, i.e. INSPIRE's intended-users, with regards to their opinions for the quality of the educational material, the instructional and the interface design; (2) real data of the way learners utilise the system.

The pilot study took place in the main laboratory of the Department of Informatics and Telecommunications soon after the final exams of the autumn semester (academic year 2000–2001) and lasted 2 hours. All the computers used in the experiment were connected to the Internet and participants accessed INSPIRE through a common web browser. At the beginning of the experiment all the computers were on without a particular software program running. Access to INSPIRE from University's network machines is faster than normal access from home through a modem. Nevertheless, we did not consider that as a problem because the main goal of this study was to evaluate participants' satisfaction of the instructional design and educational material.

As experimenters served two of the team working for the design and development of INSPIRE. According to Nielsen (1993), experimenters must have extensive knowledge of the application under consideration and its functionality. Knowledge about the system is necessary for the experimenters to understand what the learners are doing, as they perform tasks with the system, and make reasonable inferences about the functionality of the system. However, one problem that may arise is a possible lack of objectivity that may lead the experimenters to intervene in the experiment helping participants a lot, or explaining common weaknesses of the system instead of acknowledging them. In order to deal with these problems and at the same time make participants feel comfortable, one of the experimenters made a brief introduction to the main functionality of the system and the scope of the pilot study. Then the role of the experimenters was restricted to making notes of the problems participants encountered during interaction with the system and, only in a "crisis" situation, to briefly answering queries giving hints.

The test group consisted of 10 undergraduate students (second year students) of the Department who had already studied the handouts of the module "Computer Architecture" and had taken the exams of the module. INSPIRE's intended users are adults studying at a distance, as well as University students to whom access to INSPIRE is provided as a supplementary resource. Thus, the test group covered a main category of the system's intended users and was considered adequate for the particular study, since participants had the appropriate background and experience.

Students were asked to participate in an additional examination in order to improve their total mark of the module by 20%. This actually was proposed for motivational reasons, but it caused several inconveniences as some of the participants focussed their attention on the computer assessments. As a consequence, their study of the provided educational material was mainly guided by the questions of the tests. Participants worked independently, one on each computer, and studied the learning goal "Describe the role of cache memory and its basic operations". At the end of the study, they should submit assessment tests that were included in the system. All the tasks that participants had to perform were listed in a usage scenario (Carroll & Rosson, 1990), which they followed at their own pace in order to ensure that they would experience the full functionality of the system's instructional design during the experiment. Several questions, both closed and open, were embedded in the different steps of the usage scenario, reflecting likes and dislikes, problems identified, suggestions, etc. (a sample is shown in Table 3). At the end of the experiment, participants submitted the questionnaire of Honey and Mumford in order to evaluate their learning style.

6.2. *Results*

Data collected from this pilot study included participants' answers to questions embedded in the scenario and log files of interactions with the system during the experiment. Participants' preferences of the different types of educational material were provided and their subjective satisfaction with the quality and plurality of the educational material were estimated through their answers. In addition, the effectiveness of the adopted instructional design was investigated based on participants' subjective estimation of the support that the system offers throughout their study.

At the beginning of the experiment, participants answered the questions shown in Section A of Table 3 to express their own preference with respect to the different instructional strategies that formulate the presentation of the educational material for the theory of a concept and its application (the Remember and Use levels of performance). The learning experiences that they prefer, such as studying theory, working on activities, experimenting, observing a task/process being executed, etc., seem to differentiate a lot and their answers do not exhibit a clear trend to a particular strategy. Furthermore, different learning preferences and studying attitudes were detected from their comments to the open questions with regards to the usefulness of the provided educational material. Some of the participants were delighted by the inquisitory presentation of the theory while others found little use for the questions introducing the concepts at the top of the educational material page. These latter students said that they preferred the expository presentation of the theory which ends with self-assessment questions. Some of the participants found the idea of working with activities on computer simulations very interesting and motivating, while others found that the provided examples helped them to understand and use the presented concepts. Moreover, asking participants about their attitude towards studying with the traditional classroom-based way or through INSPIRE, they seem to prefer a mixed mode of learning for their undergraduate studies while for their postgraduate studies half of them prefer distance learning through INSPIRE, mainly due to time constraints as shown in Section B of Table 3.

In Section C of Table 3, participants' responses with regards to the quality and plurality of the educational material that corresponds to the different levels of performance are summarised. Note that most of the students found that the provided material sufficiently covered the learning goal. However they reported that giving more examples would be beneficial.

Participants also gave their opinion, using a four-point scale, on the instructional design, the educational material structure and the multiple representations of the outcome concepts provided through various types of knowledge modules. The acquired data are presented in Section D of Table 3 and show participants' overall satisfaction with the design. In Section E of Table 3, responses are exhibited that show participants' satisfaction with the support provided by the system during their study and navigation through the domain. Participants made positive comments (responding to open questions about their opinion on the adopted structure of the domain)

Table 3
The different sections of the table summarise participants' responses to different questions of the usage scenario. Each row presents an open question and each column shows the number of participants that gave the specific answer

Section A: Participants' preferences of the different instructional strategies adopted for the presentation of the educational material of the *Remember* and *Use* levels of performance.

Give your own priorities to the strategies adopted for the presentation of the theory of a concept (Remember)

	1st	2nd	3rd
Expository Presentation	2	2	6
Inquisitory Presentation	5	2	3
Theory Presentation based on real examples and analogies	2	6	2

Give your own priorities to the strategies adopted for the application of a concept (Use)

	1st	2nd	3rd
Example-based	3	4	3
Exercise-based	4	1	5
Activity-based	3	5	2

Section B: Participants' preferences of the different learning modes of undergraduate and postgraduate studies

	Undergraduate studies	Postgraduate studies
Classroom-based	2	None
Distance Learning through INSPIRE	None	5
Mixed model, classroom-based with access to INSPIRE	8	5

(*continued on next page*)

Table 3 (*continued*)

Section C: Participants' opinions of the quality and plurality of the educational material				
	Satisfactory	More theory	More examples	More examples and exercises
Suggest the type of educational material that should be added or removed from the theory presentation (Remember level)	6	None	4	None
Suggest the type of educational material that should complement the application of theory and its use in novel problems (Use level)	6	None	3	1

Section D: Participants' opinions about several aspects of the instructional material (courseware) design: conceptual structure, educational material structure, use of multiple external representations (knowledge modules)				
	Not at all	A little	Enough	Very much
Do you think that the organisation of the concepts in outcomes followed by their prerequisites is logical and well structured?	None	None	1	9
Does the structure of the educational material in different levels of performance, in the Navigation Area, support the accomplishment of the learning outcomes posed?	None	None	6	3
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	None	3	5

Section E: Participants' subjective satisfaction with the support that the system provides to them				
	Not at all	A little	Enough	Very much
Does the proposed design facilitate your study?	None	None	None	10
Does the proposed design facilitate your navigation through the domain knowledge?	None	1	None	9

with regards to the structure of the content, and noted that the provided educational material is easier to study, understand and find specific information within it when compared with the handouts of the module. Also, they reported that the usage of multiple types of knowledge modules in the educational material provides them with the opportunity to approach the main concepts of the goal through various perspectives.

A number of open questions included in the scenario were focussed on interface design issues and how instructional design reflects on system's interface. The main aspects of the interface considered were the presentation of the educational material pages in the Content Area, as well as the accuracy and the perceptibility of the icons' notation that are used to present the lesson contents in the Navigation Area and the different types of knowledge modules comprising an educational material page. Specifically, with regards to the presentation of the educational material pages in the Content Area, participants commented that despite the fact that studying in front of a screen is very fatiguing when done for an extended period of time, the idea of structuring a page in multiple areas is considered very helpful. In addition, they noted that the representation of multiple types of knowledge modules as hyperlinks, each one opening a different window, minimises the text presented on a page, facilitates their study and at the same time provides them with the initiative of selecting the educational material to study next. Participants' comments on the icons associated with the different types of knowledge modules of a page of educational material, and on those used to point out the lesson structure in the Navigation Area (denoting the learning goal, the outcomes and the educational material), inspired several improvements.

Lastly, participants characterised the metaphor of the filling cup, used to denote learner's knowledge level on the outcome concepts, perceptible. Although, as experimenters noticed, the "flashlight" metaphor used to point out the educational material pages that learners should study next did not attract participants attention as it was expected to.

7. Conclusions

Adaptive educational hypermedia systems aim to formulate an environment that facilitates learners to achieve their personal learning goals and objectives. To this end, educational hypermedia reflect some characteristics of the learner in the learner model and apply this model to adapt various visible aspects of the system to individual learners.

The approach proposed in this paper integrates theories of instructional design with learning styles to develop a framework that is educationally effective and technologically feasible. Learners' knowledge level is approached through a qualitative model of the level of performance that learners exhibit with respect to the concepts they study and is used to adapt the lesson contents and the navigation support. Three levels of learners' performance were identified, and multiple educational material modules were developed for each of these levels in a prototype system implementation to illustrate our approach.

Learners' individual traits, especially learning style, represent the way learners perceive and process information, and are also exploited in our approach to adapt the presentation of the educational material of a lesson.

Thus, lessons are based on combinations of educational material modules, and are tailored to learners with different learning styles aiming to maximise the benefit gained from style awareness.

The proposed approach has been implemented through various adaptation technologies and incorporated into a prototype hypermedia system. A pilot study that focussed on the quality of the educational material and on the instructional design of the system has been conducted with undergraduate students of the Department of Informatics and Telecommunications of the University of Athens, attending the course on Computer Architecture. Participants' reactions are encouraging as their comments led to several improvements of the user interface of the system and corroborated the assumption that different instructional strategies should be applied to different learners.

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