British Journal of Educational Technology Vol 34 No 4 2003 ■■–■■

Adaptive web-based learning: accommodating individual differences through system's adaptation

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Abstract

The idea of developing educational hypermedia systems for the Web is very challenging, and demands the synergy of computer science and instructional science. The paper builds on theories from instructional design and learning styles to develop a design rational and guidelines for adaptive web-based learning systems that use individual differences as a basis of system's adaptation. Various examples are provided to illustrate how instructional manipulations with regards to content adaptation and presentation, and adaptive navigation support, as well as the overall degree of system adaptation are guided by educational experiences geared towards individual differences.

Introduction

The appearance and spread of educational technology, and particularly of computer-based systems, is beginning to transform the processes of teaching and learning in higher education. Along this line, individualised learning provides students the capability to select the mode of delivery and timing of module material. A primary principle of individualised learning is that no single instructional strategy is best for all students. As a consequence students will be able to achieve learning goals more efficiently when pedagogical procedures are adapted to their *individual differences* (Federico, 2000). Among other considerations, an important step in the design of instruction and its methodologies is the identification of student needs and learning preferences. Investigations of student learning preferences have shown that among the variables that influence the success of learning, e.g. gender, age group, prior experience and discipline of study, learning styles are considered particularly important (Ford and Chen, 2000).

Published by Blackwell Publishing Ltd., 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.

Among a range of categorisations of learning styles, Curry (1987) organised the various learning styles into three categories or models

(i) *Instructional and environmental learning preferences*: this model refers to the individual's choice of the environment within which they learn. It is expected that these preferences are likely to change and are influenced by the learning context.
(ii) *Information processing style*: this model, whilst not directly interacting with the learning environment, is capable of adaptation through learning experience and the development of learning strategies.
(iii) *Personality related learning preferences*: this is considered as an underlying and relatively permanent personality characteristic.

Sadler-Smith (1996) extended Curry's models to include

(iv) *Learning strategies*: these are similar to a plan of action adopted in learning through study and experience, and
(v) *Cognitive strategy*: this is considered as a plan of action adopted in organising and processing information.

An attempt to integrate the many conceptualisations of learning styles has been made by Riding and Cheema (1991), and led to the development of a two-dimensional model of cognitive style. In their model, one dimension is conceptualised as Wholist-Analytic and the other as Verbaliser-Imager. Riding and Sadler-Smith (1992) have suggested that the Field-dependence/Field-independence dimension (Witkin *et al*, 1977) is a label used within the Wholist-Analytic cognitive style family (p. 324), with the Field-dependents lying within the Wholist category. Another effort has been made by Honey and Mumford (1992). Honey and Mumford, based on Kolb's theory of experiential learning (Kolb, 1984), suggested four types of learners: *Activists*, *Pragmatists*, *Reflectors*, and *Theorists*. Also, several attempts have been made, such as those proposed by Smith and Kolb (1996) and Sadler-Smith and Riding (1999) with the aim to assess students' learning styles.

Assessing students' learning styles provides awareness of their particular preferences, which can be used to design, develop, and deliver educational material or resources to maximally motivate and stimulate students' acquisition of subject matter in an attempt to individualise instruction (Kaplan and Kies, 1995). Understanding learning styles can improve the planning, producing, and implementing of educational experiences, so they are more appropriately tailored to students' expectations, in order to enhance their learning, retention and retrieval (Federico, 2000).

The emergence of the Web as an instructional medium has led to the design of student-centred systems with the aim to enhance the learning experience (Lin and Hsieh, 2001). It is expected that enhancement of the effectiveness can be achieved by recognising students' learning needs, the diversification of learning styles, preferences with respect to specific learning processes, as well as interests in specific learning modules that cover their knowledge deficit. All these are important attributes that characterise each student and form a kind of student model that incorporates student's individual

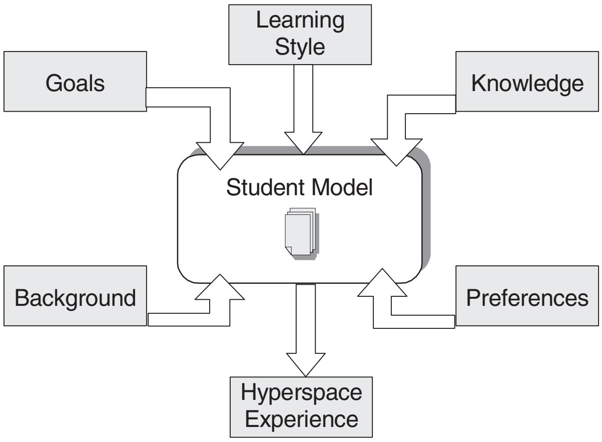

Figure 1: Generic student model that incorporates individual differences

differences (Figure 1). Although, it has been proved empirically that individual differences have implications for the degree of success or failure experienced by students (Ford and Ford, 1992; Ford and Chen, 2000), further research is necessary to fully explore their impact on the quality of learning attained within computer-based learning environments (Ford and Chen, 2001). Actually, the main problems in exploiting such information in a Web-based learning environment is to determine which attributes should be used (are worth modelling) and how (what can be done differently for students with different styles) (Brusilovsky, 2001).

This paper examines the use of individual differences as a basis of adaptation in web-based learning systems. In particular it focuses on the use of learning styles, as these emphasise the fact that individuals perceive and process information in very different ways (McLoughlin, 1999). The paper starts by providing an overview of concepts and techniques used in adaptive web-based learning systems, as well as an example of adaptation. Then it discusses implications of individual differences for the design of a Web-based learning system and presents guidelines for designing system that accommodate individual differences through system's adaptation. An example of adaptation to individual differences is given and the paper ends with conclusions.

Individual differences in adaptive wed-based learning systems

Adaptive web-based learning maintains the appropriate context for interaction between the student and the system accommodating a diversity of student characteristics, needs and abilities. Several web-based systems have taken into account individual differences to adapt the content, the presentation, and the problem solving and navigation support (see Brusilovsky, 2001 for a recent review). In this context, learning takes place progressively by making students actively participate in instructional decisions, and supporting them individually to assess their personal learning goals; this is indeed a challenging task that demands the synergy of computer science and instructional science.

Adaptive web-based learning systems combine two opposed approaches to computer assisted learning systems: the more directive *tutor-centred* style of traditional Intelligent Tutoring Systems and the more flexible *student-centred* browsing approach of hypermedia systems (Eklund and Zeilinger, 1996). In this context, *adaptation* is defined as the concept of making adjustments in an educational environment in order to accommodate individual differences. Several levels of adaptation can be distinguished, depending on who takes the initiative to the adaptation: the learner or the system (Kay, 2001). Thus, a critical point in designing adaptive 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 *student control*.

Table 1 summarises several adaptive web-based learning systems along four dimensions: the individual student characteristics used to guide the adaptation, the level of system control in providing adaptation, the level of student control that relates to system adaptability, and the adopted teaching/learning approach or theory.

An example of adaptation

This section offers a point of view that has been implemented in the context of a web-based learning system for learning Computer Architecture (Papanikolaou *et al*, 2003). The user interface provides students with a complete view of the structure of the domain knowledge, and direct access to learning resources and systems' functionality. The main screen of the system consists of three areas (Figure 2):

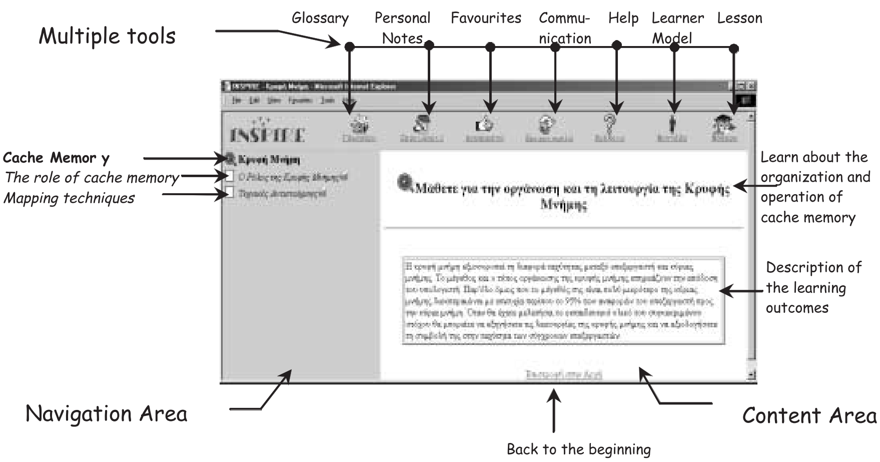

Figure 2: Main screen

Table 1: Individual differences as a basis of adaptation in web-based learning systems (ANS: Adaptive Navigation Support; AP: Adaptive Presentation, CS: Curriculum Sequencing, PSS: Problem Solving Support)

System	*Application/Title*	*Student Attributes*	*System Control*	*Student Control*	*Teaching/Learning Approaches*
DCG Vassileva (1997; 1998)	Domain Independent	Knowledge level; Learning goal; Personal traits; preferences	LCS	Direct manipulation of learning goal, personal traits and preferences	Generic Task Model (Van Marcke, 1992)
ELM-ART II Weber and Specht (1997)	Programming in Lisp	Knowledge level; Preferences	PPS; ANS; CS	Direct manipulation of student model	Example-based programming
Interbook Brusilovsky *et al* (1998)	Domain Independent	Knowledge level	CS; ANS	N/A	N/A
KBS Hyperbook Henze *et al* (1999)	Introduction to Programming using Java	Knowledge level; Learning goals	ANS	Direct manipulation of learning goal	Project-based learning
AST Specht *et al* (1997)	Introductory Statistics	Knowledge level; Learning style preferences	CS; ANS	Introductory questionnaire about preferred type of material, teaching strategy, level of detail for texts	Multiple teaching strategies: Learning by example, reading texts, doing
CS383 Carver *et al* (1996)	Computer Systems	Learning style (Felder and Silverman, 1988)	AP	Introductory questionnaire to initiate adaptation	Media selection based on learners' learning style
Arthur Gilbert and Han (1999)	Computer Science Programming	Learning style preferences	CS	N/A	Multiple instructional styles: visual-interactive, auditory-text, auditory-lecture, text style
INSPIRE Papanikolaou *et al* (2003)	Computer Architecture	Knowledge level; Learning style (Honey and Mumford, 1992)	AP; CS; ANS	Direct manipulation of learning goal, student model. Direct control of adaptation	Domain model based on Component Display Theory, Elaboration Theory content presentation based on learners' learning style

- In the *Navigation Area* a structural navigation form of links has been adopted to outline the structure of the lesson contents and support student-controlled navigation;
- The *Content Area* presents pages of educational material that the students select from the Navigation Area;
- The *Toolbar* includes several tools offering students easy access to various facilities; access to the lesson contents and to the updates of their student model.

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

- *Curriculum sequencing* allows the gradual presentation of the outcome concepts for a learning goal based on student's progress;
- *Adaptive Navigation Support* helps students navigate in the lesson contents according to their progress;
- *Adaptive Presentation* offers individualised content depending on the learning style of the student.

Our approach builds on ideas from two instructional theories and the learning style theory in order to formulate a comprehensive instructional framework (Papanikolaou *et al*, 2003) that provides guidelines for structuring the domain knowledge and developing the tailed educational content. The instructional material of each lesson, generated for a particular learning goal, is organised around specific key/outcome concepts which are determined by the teacher-expert following the Elaboration Theory (Reigeluth and Stein, 1983). The educational material provided for each outcome concept, is organised in different levels of performance which students should achieve in order to master the concept. In defining the various levels of student's performance, the Component Display Theory—CDT, (Merrill, 1983), was adopted which organises material into three different levels: (*i*) *Remember*, this level is associated with the ability of students to recall the provided theory and specific instances presenting a concept, (*ii*) *Use*, this level relates to the ability of students to apply theory to specific case(s), and (*iii*) *Find*, this level is associated with the ability of students to propose and solve original problems.

Moreover, the instructional strategies adopted for the presentation of the educational material of the outcomes concepts follow students' learning style. Thus individualised content for the Remember, Use and Find levels is provided following the relevant learning style, i.e. Activist, Reflector, Theorist, and Pragmatist, as proposed by Honey and Mumford (1992). The selection of the appropriate instructional strategies for the different learning style categories (Table 2) reflects tendencies of each category in approaching information and is in accordance to related work (Stoyanov *et al*, 1999). In particular, two of the key aspects of the learning styles described by Honey and Mumford (1992) form the orthogonal dimensions, bi-polar dimensions presented in Figure 3. One dimension is concerned with the preference of the different learning style categories for concrete experiences and for linking the educational material with real-life experiences whilst the second one is concerned with the challenge/safety

Table 2: Instructional strategies adopted for different learning style

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

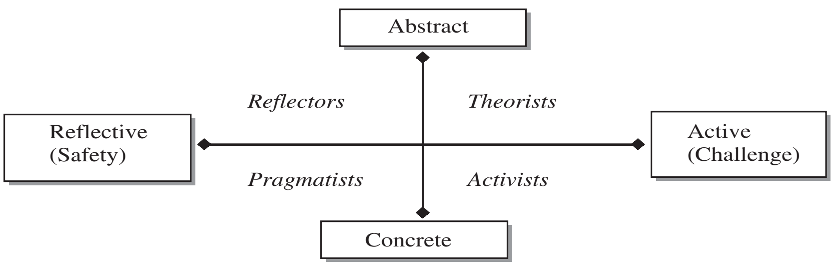

Figure 3: Key aspects of the Honey-Mumford learning styles used for adaptive presentation

dichotomy. Thus, the association of instructional strategies with the different learning style categories, as described in Table 2, has been mainly inspired by the graph illustrated in Figure 3.

With regards to providing navigation support, the system adopts the idea of restricting the domain knowledge at the beginning of the interaction—an approach appropriate for novices (Bransford *et al*, 1999)—and enriching it, progressively, following learner progress. This approach of guided learning is also beneficial to Field Dependent students who usually experience problems when they are offer several options. The Field dependent/independent learning style model inspired several navigation support techniques used in our approach. Figure 4 relates navigation support with the levels of student/system control (cf. with Table 6 as will be explained below).

Development of guidelines

Design rational

The proposed approach is guided by the following design considerations focusing on accommodating student needs: (a) organise educational content; (b) provide individualised content; (c) provide navigation support; and (d) offer various levels of student

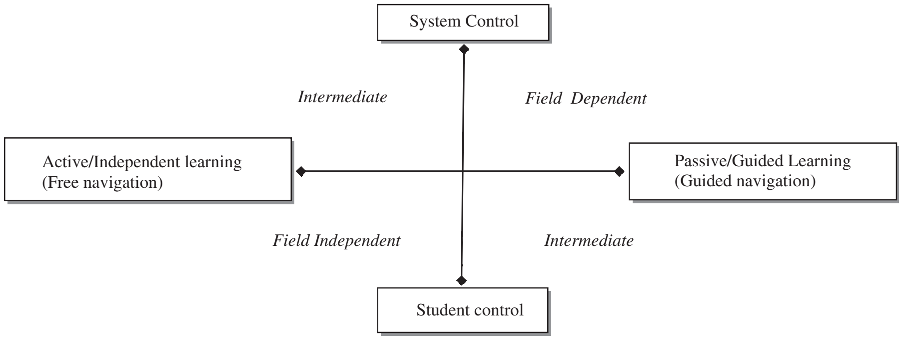

Figure 4: Key aspects of the Field dependent/independent learning used for navigation support

control. The key adaptive features reflecting these considerations are summarised in Tables 3–6, where purpose and appropriate examples are also given.

An Example of implementation

There is no single approach to introduce adaptation in order to accommodate individual differences. In this section, we provide an example for implementing the guidelines proposed previously. Figure 5 illustrates an example of organisation of educational content highlighting at the same time features of navigation support. The figure 5 focuses on the navigation area of Figure 2, giving a detailed account of our approach to the organisation of educational material of a learning goal and the various visuals cues offered to students, eg, the measuring cup metaphor to inform students about their progress (when progress with regards to a specific outcome concept is inadequate an empty measuring cup appears; the cup becomes half full and then full following student's progress), or the open book metaphor to access the material of prerequisite concepts.

As far as the implementation of the instructional strategies is concerned, 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 hyperlinks. In Figure 6, the theory about a concept at the Remember level of performance can be presented following an inquisitory or expository instructional strategy. Inquisitory presentation is tailored to Theorists who like to discover concepts and are getting motivated when using their prior knowledge and imagination: the presentation starts with a question, which appears at the top of the page, then examples and theory for answering that question are given. When expository presentation is used, the same question appears at the bottom of the page, as a self-assessment question, aiming at motivating learners to reflect on concepts already studied (Figure 7). Accordingly, an educational material page at the *Use* level of performance is constituted by hints from theory, examples, exercises and activities (if all exist). Thus, if the instructional strategy is exercised-based (the student is encouraged to start practicing and use the examples and the theory as aids

Table 3: Key features of our approach to the organisation of educational content

Feature	*Purpose*	*Example*
A lesson is generated for a particular learning goal and is organised around specific outcome concepts	Follow guidelines of Elaboration Theory (Reigeluth and Stein, 1983)	Each outcome concept is associated with specific learning outcomes as well as with prerequisites and related concepts.
Outcome concepts of a learning goal are organized into a hierarchical structure/ menu	Follow guidelines of Elaboration Theory (Reigeluth and Stein, 1983) Provide explicit structure to Field Dependent students (Chen and Macredie, 2002)	At the first layer the simplest and more fundamental concepts are included, providing an overview of the learning goal, and then, subsequent layers add detail to a part or aspect of the learning goal.
Educational material provided for each outcome concept is organised in different levels of performance which students should achieve in order to cover the concept	Adopt the approach proposed in the Component Display Theory—CDT (Merrill, 1983)	Material is organised in three levels: (*i*) *Remember*, material that targets the ability of students to recall the provided theory and specific instances presenting a concept, (*ii*) *Use*, material that aims to strengthen the ability of students to apply theory to specific case(s), and (*iii*) *Find*, material that aims at enhancing students ability to propose and solve original problems.
The educational material pages developed for each outcome concept include a variety of knowledge modules that support students to achieve the three levels of performance of the Component Display Theory	Following CDT prescriptions, each level of performance should include presentation, practice and test items (Merrill, 1983)	Text presentations (definitions, descriptions, conclusions), examples (concrete instantiations of concepts, analogies), exercises, activities using computer simulations, definitions in the glossary, etc.

Table 4: Key features of our approach to individualising the content

Feature	*Purpose*	*Example*
Personalise the delivery and presentation of the content based on the learning style	Match dominant learning preferences with appropriate educational material (Honey and Mumford, 1992) The order and manner a topic is treated can produce very different learning experiences (Wenger, 1987)	The concepts of a learning goal are presented gradually and specific educational material pages are recommended
Provide multiple types of educational material	Stimulate learning style growth and collaboration (Kolb, 1984)	Highlight different perspectives of the concepts depending on the instructional strategy adopted
Adopt multiple instructional strategies to present the same educational content	Avoid rewriting the same content tailored to each learning style category (McLoughlin, 1999; Gilbert and Han, 1999) Supports students in their effort to master the different concepts covered in the module and their interrelationships by adopting specific strategies provided by instructional design theories (Hoffman, 1997)	Use a variety of learning resources that different in their interactivity level and format so that they can be reused for students with different preferences and from different instructional strategies

Table 5: Key features of our approach to provide navigation support

Feature	*Purpose*	*Example*
Propose material to study next depending on student knowledge level	Direct guidance helps passive Field Dependent students avoid experiencing lack of comprehension (Chen, 2002)	Adaptively annotate or hide links of outcome/prerequisite concepts
Support student's navigation through the domain using adaptive link annotation, and link hiding based on students knowledge level	Allow students decide the learning strategies by themselves (Ford and Chen, 2001) May help to support the needs of Field Dependent students (Chen, 2002)	Prerequisite-based annotation provides information on the background relevant to the outcome concept
Provide visual cues/ graphic visualisations	Keep students informed about their progress (Weber and Brusilovsky, 2001) Avoid "lost in hyperspace" feeling (Nielsen, 1993), usually experienced by Field Dependent students (Chen, 2002)	Use combination of flashlight and filling of measuring cup metaphors to provide qualitative representation of the progres of the student on each particular concept Use a history-based mechanism so that as each page is accessed a check mark appears next to the link

for solving the exercise), as in the case of the Pragmatist shown in Figure 8, then the knowledge module "exercise" appears on the top of the page followed by the rest of the modules. For the Theorist of Figure 9 the instructional strategy is theory-based, thus the knowledge module "Hints of theory" appears on the top of the page whilst the rest of the modules appear below. That way the student is encouraged to start thinking the theory and reading application examples that concentrate on the manner the particular concept is used. Next, the student 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 (if such activities are available) in order to accomplish certain tasks.

Conclusions

In this paper, we presented an approach that builds on using individual differences as the basis for adaptation in hypermedia systems. In this way, lessons are based on combinations of educational material modules, and are tailored to students with different learning styles aiming to maximise the benefit gained from style awareness.

Compared with other approaches, the proposed guidelines support designing several levels of adaptation, ranging from full system-control to full student-control, and

Table 6: Key features of our approach to provide several levels of student control

Feature	*Purpose*	*Example*
Students initialises or updates their learning style/knowledge level	Teaching students how to learn, and how to monitor their own learning styles is crucial to academic success (McLoughlin, 1999) Students reflect on their performance on each particular page of the course (Weber and Brusilovsky, 2001)	Students may submit the Honey-Mumford questionnaire and, automatically, their learning style is classified into {Activist, Reflector, Theorist, Pragmatist} using the method of Honey and Mumford (1992) Students may intervene/ guide personalisation decisions with regards to lesson generation
High/low level of system control	Field Dependent students benefit from high level of system control and Field Independent students enjoy learning when there is low level of system control (Chen and Macredie, 2002)	System provides guidance through the contents by annotating/hiding links; thus providing a structured lesson Students that prefer free navigation are allowed to access any page they like and develop their own structure
Externalize the student model	Student is able to access the model, interact with it and change it, intervening to system's instructional decisions (Hartley *et al*, 1995) Externalizing the information that the model maintains for the studying attitude of the student provides tutors with a tool for monitoring students' progress, and evaluating the educational material (Hartley *et al*, 1995)	Students deactivate adaptive features of the system, i.e. adaptive presentation, content sequencing Changing their knowledge level on the different concepts of the learning goal, students plan the content and delivery of a lesson Changing their learning style on the student model, students may plan the presentation of the educational material accordingly
Students may take full instructional control over the system	Students should be provided with a view of the internal workings of the system and of the influence of their actions on system's functions (Höök *et al*, 1998)	Students have the option to deactivate the dynamic lesson generation process and select the lesson contents, e.g. the outcome concepts, in case that they just want to revise specific concepts of the domain

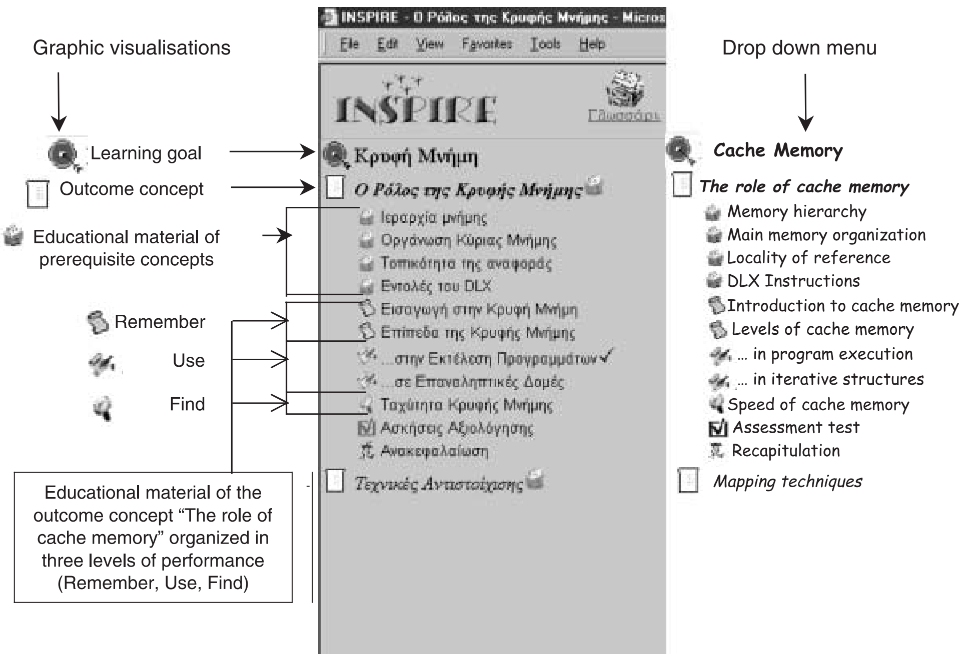

Figure 5: Organisation of material for the learning goal and the various graphics visualisations

combine instructional design theories 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, and exploiting individual traits (eg students' dominant learning style); planning the lessons content, delivery and presentation, and providing the appropriate navigation support to learners.

With regards to the exploitation of the learning style, many questions are still open in the context of adaptive web-based learning systems: questions related to the way students with different learning styles work with assessment tests, activities, etc, their navigation traces, the common characteristics of students with similar style, the way students of a particular learning style select and use educational resources that are considered beneficial for their style, and so on. Towards these directions further research is needed to exploit the information stored in the student model in order to inform students on adaptation decisions, and tutors on the effectiveness of the provided material and for monitoring learners' progress and attitude while studying. Empirical studies are also needed to evaluate the educational effectiveness of the adaptations and their implications on usability considerations. The way a student uses the educational material in conjunction with his/her progress may provide valuable information denoting how successful is the association of particular types of educational material

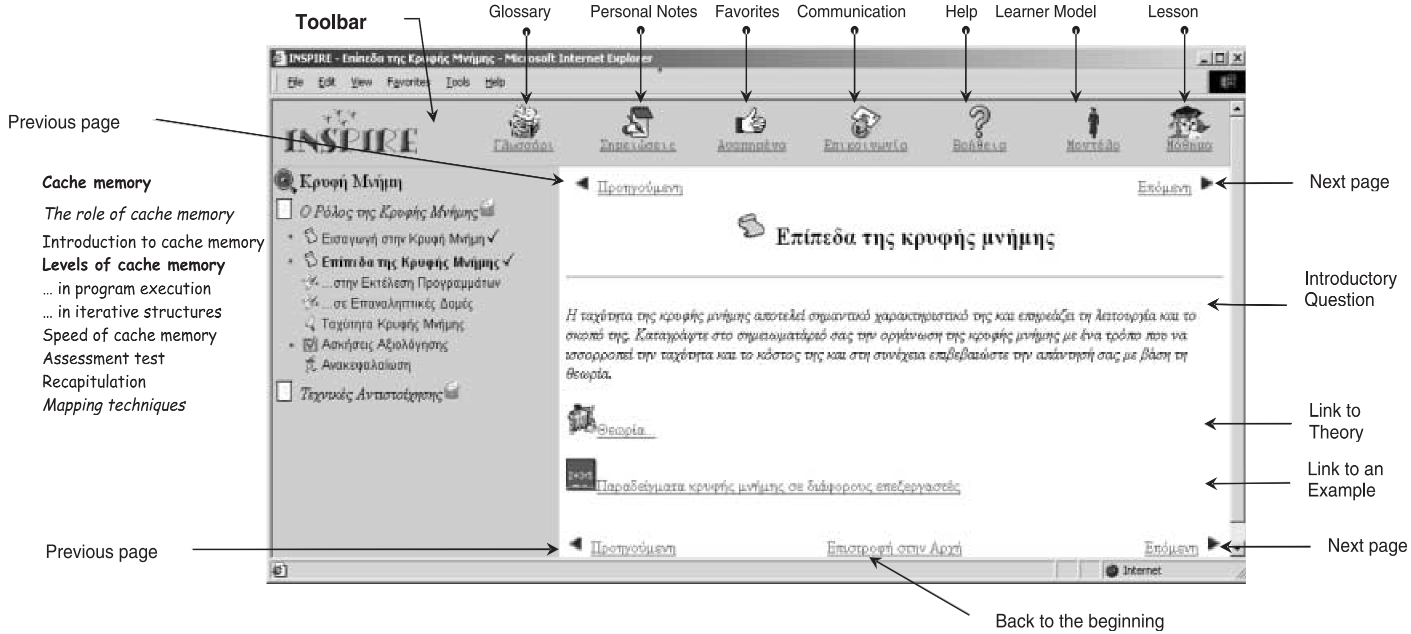

Figure 6: Educational material page about the "Levels of cache memory" as presented to a Theorist following an inquisitory strategy. This is an educational material page of the Remember level of performance that includes: (1) Introductory Question; (2) link to Theory; (3) link to an Example. Coloured icons of educational material pages are marked with a bullet for clarity

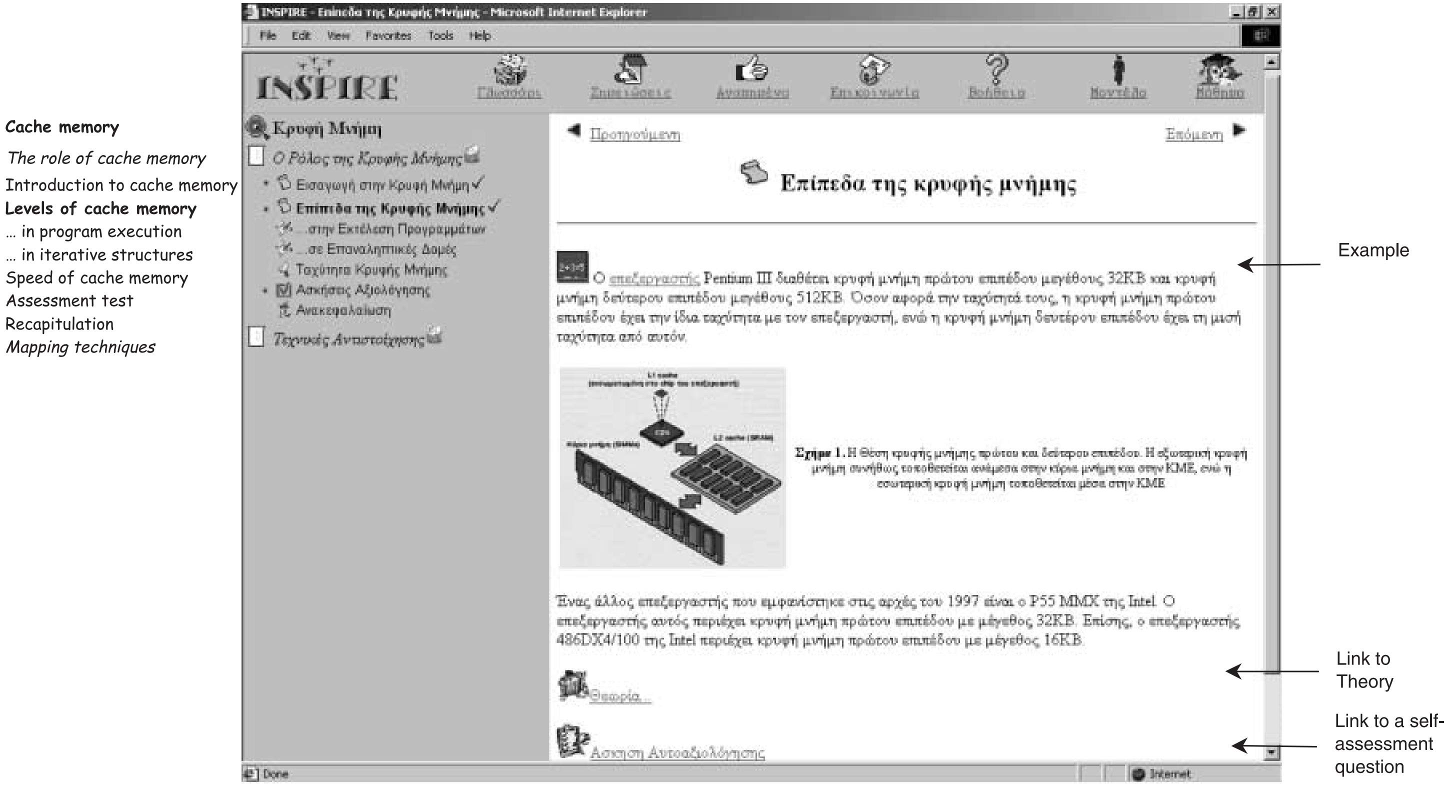

Figure 7: Educational material about the "Levels of cache memory" as presented to a Pragmatist following an expository strategy based on examples. This is an educational material page of the Remember level of performance that includes: (1) Example; (2) link to Theory; (3)link to a self-assessment question

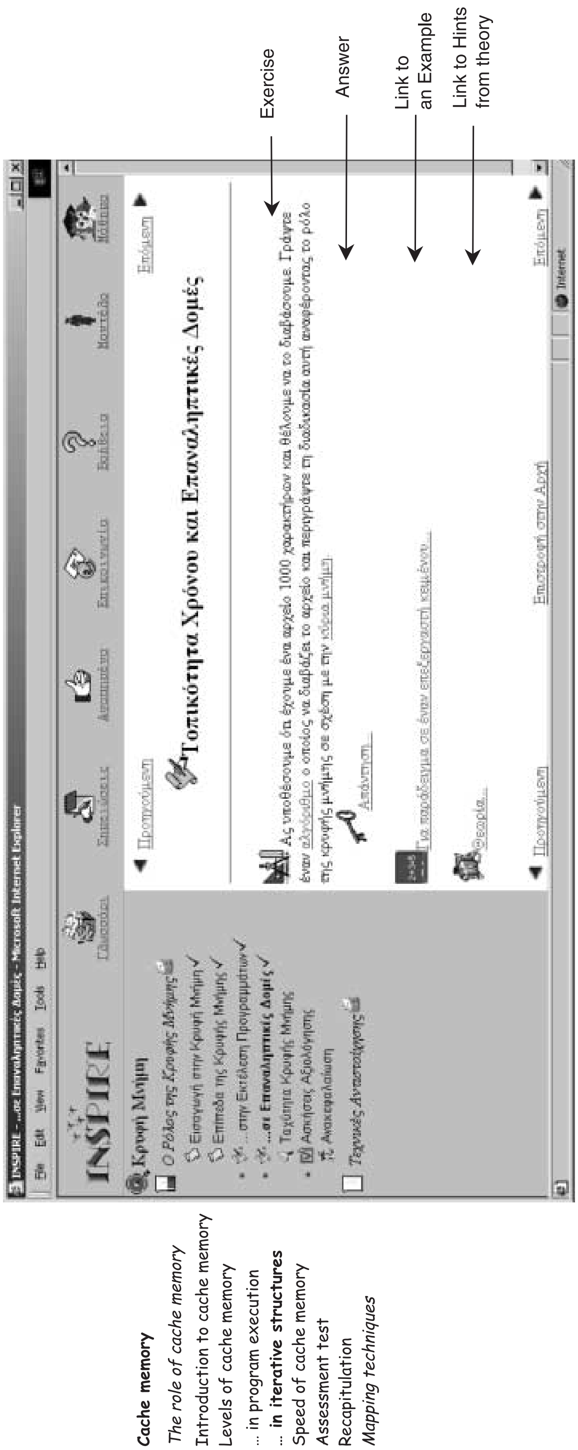

Figure 8: Educational material about the "Locality of time in iterative structures" as presented to a Pragmatist following an exercise-based strategy. This is an educational material page of the Use level of performance that includes: (1) Exercise and link to the answer; (2) link to an application Example; (3) link to Hints from Theory

Figure 9: Educational material page about the "Locality of time in iterative structures" as presented to a Theorist following a theory-based strategy. This is an educational material page of the Use level of performance that includes: (1) Hints from Theory; (2) link to an application Example; (3) link to an Exercise

with the particular learner. Furthermore, this information can also be used for the dynamic adaptation of the educational material during learner's interaction with the system.

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