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The design and the formative evaluation of an adaptive educational system based on cognitive styles☆

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Abstract

Adaptive Hypermedia Systems (AHS) can be developed to accommodate a variety of individual differences, including learning style and cognitive style. The current research is an attempt to examine some of the critical variables, which may be important in the design of an Adaptive Educational System (AES) based on student's cognitive style. Moreover, this paper describes the design issues that were considered for the development of the system that are reported in the relevant literature Throughout the development of the system, formative evaluation was an integral part of the design methodology. The results of the formative evaluation were used to improve our system in order to make the instruction more effective and efficient. Furthermore, the recommendations resulted from the formative evaluation could be seen as some points worth considering from designers of AHS.

Keywords: Evaluation methodologies; Multimedia/hypermedia systems; Teaching/learning strategies

1. Introduction

This article describes the design, the development and the formative evaluation of an Adaptive Educational System (AES) that includes accommodations for cognitive styles in order to improve students interactions and learning outcomes. Although, cognitive styles are one of the several

☆ The system interface is developed in the Greek Language, however for the purpose of this paper, Figs. 4 and 5 that illustrate screen-shots of the interface, are partially translated into the English Language. Part of this work (System Architecture and Implementation) was presented at the AH'2002 Workshop on Adaptive Systems for Web-based Education in Malaga, Spain, May 2002.

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important factors to be considered from designers and instructors of hypermedia-based courseware, little research has been done regarding the adaptation of hypermedia system to students' cognitive styles (Liu & Ginther, 1999). The current research is an attempt to examine some of the critical variables, which may be important in the design of an adaptive hypermedia system based on student's cognitive style. As a case study a Higher Education module was developed, called AES-CS (Adaptive Educational System based on Cognitive Styles).

A formative evaluation of AES-CS was carried out in order to investigate the relationship of learning behavior and cognitive style in an adaptive hypermedia environment. The purpose of the evaluation was to investigate how to improve our system in order to make the instruction more effective and efficient and also to assess its usability and appealing. This paper first discusses adaptive hypermedia technology and cognitive styles as considerable confusion appears in the literature regarding the terms cognitive style and learning style. Next, it describes the design issues that were considered for the development of the system that are reported in the relevant literature and should be taking into account from instructional designers of adaptive hypermedia. Finally, it presents the description and the results of the formative evaluation.

2. Theoretical framework

2.1. Adaptive hypermedia

The phenomenal growth of the Internet and the Web over recent years has led to an increasing interest in creating Web-based learning tools and learning environments. Hypermedia seems to be suitable for supporting the new constructivist way of active and self regulated learning. However, empirical studies have shown contradictory results about the efficiency and effectiveness of learning with hypermedia. Some studies indicate that hypermedia-based learning may contribute to enhance learning and promote cognitive flexibility when the learning environment is designed task appropriately (Spiro, Feltovich, Jacobson, & Coulson, 1991). At the same time, other studies have revealed problems for hypermedia-based learning with regards to cognitive overload and disorientation (Marchionini, 1998).

In order to overcome the problems identified, a hypermedia system should be designed in a way that can identify the user's interests, preferences and needs and give appropriate guidance throughout the learning process. Adaptive Hypermedia (AH) was introduced as one possible solution. Adaptivity is especially important for Web-based educational hypermedia, as these systems are expected to be used by several learners without assistance from a physical tutor, who usually can provide adaptivity in an actual educational environment, i.e. classroom.

Adaptive Hypermedia Systems (AHS) build a user model of the goals, preferences and knowledge of the individual user and use this model to adapt the content of pages and the links between them to the needs of that user. Since the user's goals, preferences and needs may change over time, AHS observe these changes in order to update the user's model (Brusilovsky, 1996).

AHS can be developed to accommodate various learner needs; is the ideal way to accommodate a variety of individual differences, including learning style and cognitive style (Ayersman & Minden, 1995). Numerous Adaptive Educational Systems have been implemented over the last fifteen years. INSPIRE (Papanikolaou, Grigoriadou, & Kornilakis, 2001) and CS383 (Carver, Howard, & Lavelle, 1996) are good examples of Adaptive Educational Systems with regards to learning style. Although, cognitive styles are one of the several important factors to be considered from designers and instructors of hypermedia-based courseware, little research has been done regarding the adaptation of hypermedia system to students' cognitive styles (Liu & Ginther, 1999) and this is the focus of our research.

2.2. Cognitive style and learning

There is a technical difference between the use of the terms cognitive style and learning style, although numerous authors use the terms interchangeably. Cognitive style deals with the 'form' of cognitive activity (i.e. thinking, perceiving, remembering), not its content. Learning style, on the other hand, is seen as a broader construct, which includes cognitive along with affective and physiological styles.

Cognitive style is usually described as a personality dimension, which influences attitudes, values, and social interaction. It refers to the preferred way an individual processes information. There are many different definitions of cognitive styles as different researchers emphasize on different aspects (Riding & Cheema, 1991). Witkin (1962) and Witkin, Moore, Goodenough, & Cox (1977) has done extensive work in this area and has defined two basic styles, field dependent (FD) and field independent (FI). Field dependence/independence (FD/FI) is probably the most well known division of cognitive styles (Witkin et al., 1977).

According to Witkin, field dependence–independence has important implications for an individual's cognitive behavior and for his/her interpersonal behavior. While most learners fall on a continuum between these two cognitive processing approaches, each style is defined by certain characteristics. Specifically, field independent people tend to be more autonomous in relation to the development of cognitive restructuring skills and less autonomous in relation to the development of interpersonal skills. Conversely, field dependent people tend to be more autonomous in relation to the development of high interpersonal skills and less autonomous in relation to the development of cognitive restructuring skills.

Furthermore, FD/FI dimension refers to a tendency to approach the environment in an analytical, as opposed to global, way. FI learners generally are analytical in their approach while FD learners are more global in their perceptions. Furthermore, FD learners have difficulty separating the part from the complex organization of the whole. In other words, FD individuals see things in the entire perceptual field (the forest than the trees). Additionally, FI individuals tend to be intrinsically motivated and enjoy individualized learning, while FD ones tend to be extrinsically motivated and enjoy cooperative learning.

The Group Embedded Figures Test (GEFT) (Witkin, Ottman, Raskin, & Karp, 1971) usually is used to identify the FD/FI cognitive style. In this test, subjects perceived the information, which is a series of simple figures, independently from the larger complex figure, in which the simple figures are embedded. This test describes those who tend to rely on external cues and are less able to differentiate an embedded figure from an organized field as being field dependent; and those who tent to rely on internal cues and are more able to differentiate an embedded figure from an organized field as being field independent.

Many experimental studies have showed the impact of field dependence/independence on the learning process and academic achievement. Studies have identified a number of relationships between FD/FI cognitive style and learning, including the ability to learn from social environments, types of educational reinforcement needed to enhance learning and amount of structure preferred in an educational environment (Summerville, 1999).

Studies have shown that FD are holistic and require external help while FI people are serialistic and possess internal cues to help them solve problems. FD learners are more likely to require externally defined goals and reinforcements while FI tend to develop self-defined goals and reinforcements (Witkin et al., 1977). Furthermore, FD learners appeared to benefit most from illustrative advance organizers, while FI learners preferred illustrative post organizers (Meng & Patty, 1991). An advance organizer is a bridging strategy that provides a connection between one unit and another. It also acts as a schema for the learner to make sense out of the new concept. A post organizer serves as a synopsis and supports the reconstruction of knowledge. Usually, it is available after the presentation of new information.

The amount of learner control seems to be a central variable when integrating adaptive methods in educational settings. There are several arguments in the literature for and against learner control. On the one hand, learners' motivation is increased when they control the navigation of a hypermedia environment. On the other hand, research seems to indicate that the amount of learner control depends on the pre-skills and the knowledge state of a learner (Williams, 1993). Furthermore, many studies have demonstrated student preference and improved performance using a linear structure. With regards to cognitive styles, there is evidence that FD individuals perform better using program control while FI ones prefer more learner control (Yoon, 1993).

Several problems of learning in a hypermedia environment arise from the structure of the environment itself. In an ideal Web site, the structure is evident to the user and the information is organized coherently and meaningfully. Navigational tools are essential in order to assist learners to organize the structure of the Web site as well as the connections of the various components. A coherent resource collection will allow the user to construct an accurate mental model of the topic. Research has indicated that FD learners are less likely to impose a meaningful organization on a field that lacks structure and are less able to learn conceptual material when cues are not available (Witkin et al., 1977). Furthermore, Jonassen and Wang (1993) argue that the FI learners generally prefer to impose their own structure on information rather than accommodate the structure that is implicit in the learning materials.

3. Design of AES-CS

3.1. System architecture and implementation

The earlier studies illustrate some aspects of the interaction between cognitive styles and learning strategies. Moreover, they demonstrate the importance of cognitive style on student's performance in hypermedia learning environments. This study is an attempt to examine some of the critical variables, which may be important in the design of an adaptive hypermedia system based on student's cognitive style. As a case study a Higher Education module was developed, called AES-CS (Adaptive Educational System based on Cognitive Styles), to support the course 'Multimedia Technology Systems' which is typically offered to fourth year undergraduate students in Computer Science Department at the Aristotle University of Thessaloniki, Greece.

The main characteristic of AES-CS is that it can be adapted to the cognitive style and to the level of knowledge acquired by the student. The system is organized in the form of three basic modules: the domain model, the student model, and the adaptation module (Fig. 1). These three components interact to adapt different aspects of the instructional process, i.e. adapting the content according to user's prior knowledge; adapting the presentation of contents through selection and combination of appropriate media; adapting the teaching strategies; modifying the selection of examples and links; and recommending appropriate hyperlinks.

3.1.1. Domain model

The domain model is a set of domain concepts. It serves as a basis for structuring the content of AES-CS. Each concept is structured into a set of topics. Topics represent basic pieces of knowledge for the given domain and their size depends on the domain. Topics are linked to each other thus forming a kind of semantic network. This network is actually the structure of the knowledge domain. In AES-CS each hypermedia page actually corresponds to one topic only.

3.1.2. Student model

The student model needs to be easy to construct and modify and should accurately reflect the characteristics of different students. Three different categories of information are built-in in the student model: personal profile (which includes static data, e.g. name and password), cognitive profile (which includes adaptable data like cognitive style preferences), and an overlay student knowledge profile (which illustrates student's knowledge on a subject). Table 1 shows the description of some attributes included in each category, and provides information on the possible values types of the attributes and how these can be acquired.

3.1.3. Adaptation module

To support adaptivity, AES-CS uses the 'adaptive presentation technique' (Brusilovsky, 1996) that aims to adapt the information presented to the user according to his/her cognitive style and knowledge state. Conditional text and page variants representations are used to accomplish adaptive presentation. With the conditional text technique, a page is divided into chunks. Each chunk of information is associated with a condition indicating which type of user should be presented with it. With page variants technique, two variants of the pages associated with a concept

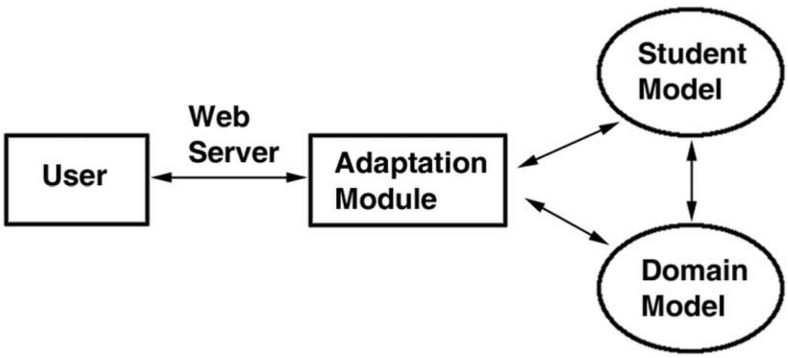

Fig. 1. System architecture.

are prepared. Each variant of the page presents information in a different style according to FD/FI dimension.

'Adaptive navigation support' is a specific adaptive hypermedia technology that aims to help users to find an appropriate path in a hypermedia-learning environment (Brusilovsky, 1996). AES-CS provides adaptive navigation support by manipulating the selection and the presentation of links through adaptive annotation and direct guidance. Adaptive annotation is the most popular form of adaptive navigation support. It was first used in ELM-ART and since it is applied in several other systems such as Interbook, KBS Hyperbook (Brusilovsky, 1999). Adaptive annotation of hyperlinks supplies the user with additional information about the content behind a hyperlink. The selection and the color of hyperlinks are adapted to the individual student by taking into account information about the learner's knowledge state and the instructional strategy. Within AES-CS, blue color is used for 'recommended' and gray color for 'not ready to be learned'. With the direct guidance, the system suggests to the student the next part of the learning material. This technique can be seen as a generalization of curriculum sequencing but within the hypermedia context it offers more options for direct guidance. Student's prior knowledge is used by the system in order to provide him/her the most suitable sequence of knowledge units to learn and to work with.

3.2. Adapting instructional strategies

In the ideal educational environment, a tutor with instructional experience on a learning domain can identify students' individual differences, with regards to cognitive styles and acquired knowledge, and thus can provide them with learning material individually selected and structured. Moreover, the interaction that takes place in a physical classroom allows tutors to experience and understand students' personal goals and preferences and thus to promote their skills. In

Table 1
The student model

Type	Item	Value	How acquired
Personal profile	Name	Free text	User
	Password	Free text	User
Cognitive profile	Cognitive style	FD or FI	User or system
	Program Control	Yes or No	User or system
	Learner Control	Yes or No	User or system
	Instructions	Yes or No	User or system
	Feedback	Yes or No	User or system
	Graphics Path Indicator	Yes or No	User or system
Knowledge profile	Concept 1	Unknown Know Learned Well- Learned	User or system
	Concept 2	-//-	-//-

order to simulate in a sense an ideal educational environment, an adaptive hypermedia system should provide learners the ability to use different instructional modes in order to accommodate their individual needs and to improve their performance. Therefore, it has to include in its design both issues of cognitive style and teaching strategy. Teaching strategy refers to the instructional material and the instructional strategy. Table 2 presents the instructional strategies adopted in AES-CS that support students according to their cognitive style, and follows a brief description of these strategies and the way they were implemented in the design of AES-CS.

Global versus analytical approach: AES-CS uses adaptive presentation techniques to provide global or analytical approach since FI learners tend to approach things analytically while FD learners tend to approach task in a global way. More specifically, conditional text and page variants representations are used to provide information from specific to general for FI learners. On the other hand, the system provides information from general to specific for FD learners.

Program control versus learner control: AES-CS provides both program and learner control option, according to theoretical assumptions in FD/FI dimension. In the case of learner control option, AES-CS provides a menu from which learner can choose to proceed the course in any order (Fig. 2). In the program control option there is no menu, but the system guides the user through the learning material via adaptive navigation support (see Fig. 3).

The use of contextual organizer: another feature that is embedded in AES-CS is the use of contextual organizers. FD learners appeared to benefit most from illustrative advance organizers, while FI learners preferred illustrative post organizers (Meng & Patty, 1991). AES-CS uses adaptive navigational support by manipulating the selection and the presentation of links in order to present and support the learner with advance or post organizer according to his/her cognitive style.

Instructions: Jonassen and Grabowski (1993) in their study summarized the research on the implications of the individual differences based on FD/FI dimension. These implications of style characteristics are considered in order to design the instructional support and the instructional environment of AES-CS. As a result, an additional frame at the bottom part of the screen is used to provide clear, explicit directions and the maximum amount of guidance to FD learner. On the other hand, the system provides minimal guidance and direction to FI learner. Specifically, the only instructions that are provided to the FI learners are those in the initial page of the course.

Table 2
Instructional strategies

Field-Dependent learners	Field-Independent learners
Provide global approach	Provide analytical approach
Provide information from general to specific	Provide information from specific to general
Program control	Learner control
Provide advance organizer	Provide post organizer
Provide maximum instructions	Provide minimal instructions
Provide maximum feedback	Provide minimal feedback
Provide structured lessons	Allow learners to develop their own structure

Feedback: According to Jonassen and Grabowski (1993), FD learners are more likely to require extensive feedback (especially informative), while FI tend to prefer only to know that an error had occurred. Therefore, the self-assessment unit provides extensive feedback to FD learner by presenting additional information on concept, relations to previous knowledge etc. On the contrary it provides minimal feedback to FI learner.

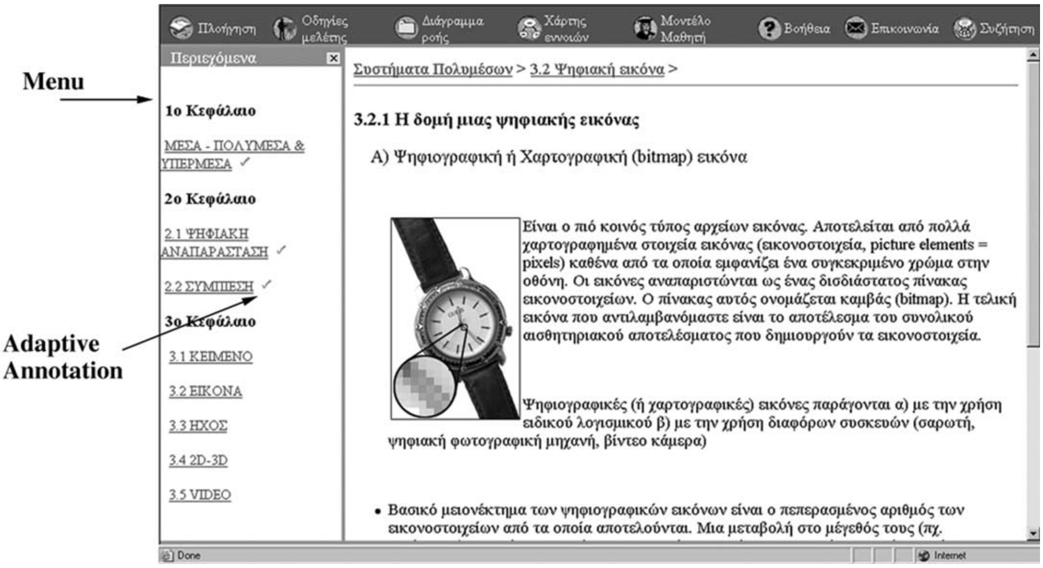

Fig. 2. System screen with the initial adaptation for Field Independence (FI) learners.

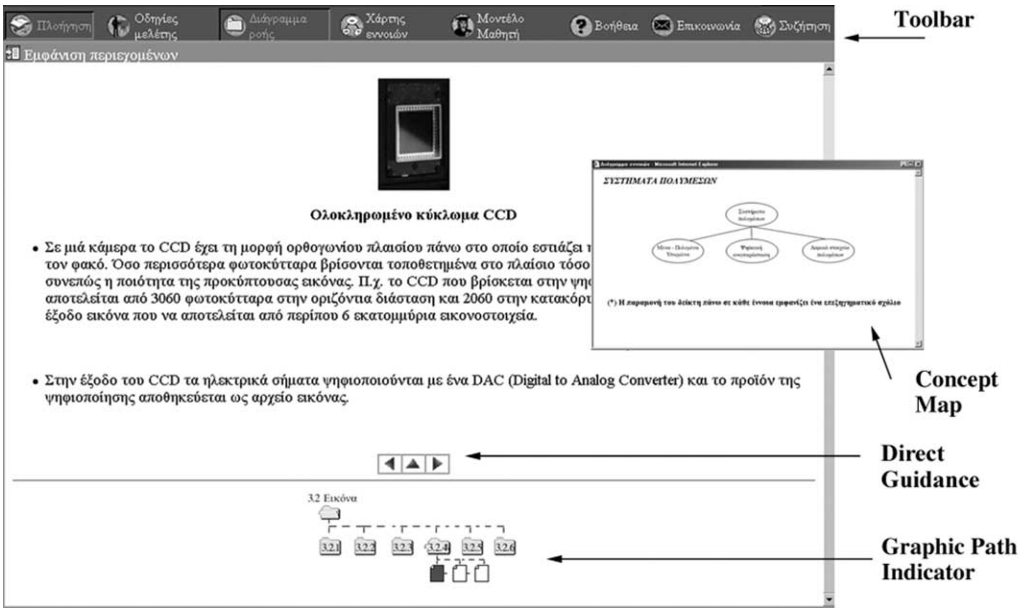

Fig. 3. System screen with the initial adaptation for Field Independence (FD) learners.

Structure: AES-CS allows FI learners to impose their own structure on information since they perform better with material that requires structure and organization. On the other hand, AES-CS provides structured lessons to FD learners since they prefer material that is organized and structured. Additionally the system supports FD learners with two navigational tools in order to help them organize the structure of the knowledge domain: concept map and graphic path indicator (Fig. 3). Concept map is a visual representation of a knowledge domain and consists of nodes representing concepts connected by directional links that define the relationships of the nodes. Concept maps may act as tools to aid study and assist to the comprehension of a domain. In AES-CS concept map is used to help FD learners understand the big picture and place detail in perspective. The graphic path indicator can orient users to the surrounding hyperspace and to the content organization, affecting both cognitive overhead and coherence. The graphic path indicator is dynamically created and presents the current, the previous and the next topic. The graphic path indicator appears at the bottom of each page and illustrates clearly the local neighborhood of a topic.

Table 3 summarizes the earlier instructional strategies that have been adopted in AES-CS to support students according to their cognitive style and outlines their implementation

Table 3
Instructional strategies and their implementation

Instructional Strategy	Implementation
Approach:	*Global Approach (FD)* From general to specific *Analytical approach (FI)* From specific to general
Control option:	*Program control (FD)* Adaptive navigational support *Learner control (FI)* A content menu
Contextual organizer:	*Advance organizer (FD)* *Post Organizer (FI)*
Study Instructions:	*Provide maximum instructions (FD)* Additional frame with instructions *Provide minimal instructions (FI)* Only the initial instructions
Feedback:	*Provide maximum feedback (FD)* Additional information *Provide minimal feedback (FI)* Basic information
Structure:	*Provide structured lessons (FD)* Graphics Path Indicator and Concept map *Allow learners to develop their own structure (FI)*

3.3. Adaptation flexibility

The initial adaptation of AES-CS to FD/FI learners was based on research results (Jonassen & Wang, 1993; Meng & Patty, 1991; Yoon, 1993) and theoretical assumptions in FD/FI dimension (Jonassen & Grabowski, 1993; Witkin et al., 1977). According to them, the system AES-CS initially supports FD/FI learners with the respectively instructional strategies (see Table 2). However, users are not just novice, intermediate or expert but range a scale of many intermediate values. Furthermore, users are not simply FD or FI learners but instead are some combination of both characteristics. Thus, a learner should use a combination of instructional strategies in order to accommodate his/her individual needs and to improve his/her performance. According to Carver, Hill, and Pooch (1999) adaptive hypermedia systems should not only model multiple dimensions of the user, but also each dimension should have as much delineation as necessary to truly model the user.

AES-CS allows users to change the initial adaptation based on their individual needs. More specifically, users can modify the status of four instructional strategies without necessary modify the status of their cognitive style. Initially, the system provides FD learners with program control, maximum instructions, maximum feedback, and structure lessons. On the other hand, the system supports FI learners with learner control, minimum instructions, minimum feedback and allows the learners to develop their own structure. Learners have the ability to change the initial stage through the student model and/or appropriate interactive features (Fig. 4). The learners may modify the control options between learner and program control, may choose minimal or maximum feedback, may request instructions and so on.

The aim of the flexibility provided is the optimization of the adaptation under basic assumption that adaptive systems need to be controllable by the user because they cannot be intelligent enough to appropriately adapt in all possible cases.

4. Formative evaluation

Throughout the development of AES-CS, formative evaluation was an integral part of the design methodology. Formative evaluation is the judgments of the strengths and weakness of instruction in its developing stages, for the purpose of revising the instruction. The major goal of formative evaluation is to improve the effectiveness and efficiency of the instruction. In AES-CS case, three types of formative evaluation were used: expert review, one-to-one evaluation and small group evaluation. Tessmer (1993) defines these evaluations types as follows:

- Expert review—experts review the instruction with or without the evaluator present. The experts can be content experts, designers or instructors.

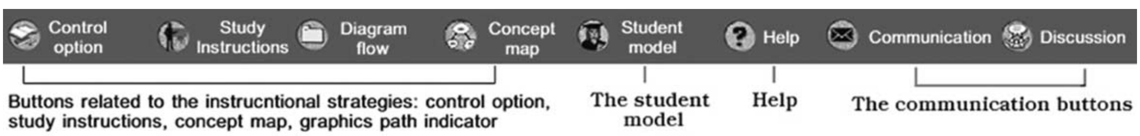

Fig. 4. The Toolbar.

- One-to-one evaluation—one learner at a time reviews the instruction with the evaluator and comments upon it.
- Small group evaluation—the evaluator tries out the instruction with a group of learners and records their performance and comments.

The current interface of AES-CS and its functionalities are the result of revisions based on the analysis of the data collected during the formative evaluation. The design of the AES-CS was revised twice: (1) after the expert review and the one-to-one evaluation and (2) after the small group evaluation. Next we will discuss the process of the formative evaluation, i.e. subjects, procedure, and results.

5. Discussion

5.1. Expert review and one-to-one evaluation

Five experts acted as evaluators in the expert review: a teaching/training expert, an instructional design expert, a subject-matter expert, an educational technologist and a subject sophisticates (i.e. a student who has successfully completed the course). In this phase, a semi-structured interview aimed at determining the reactions of experts and a debriefing session were used. During the semi-structured interview, although the subjects were prompted with questions, the main aim was to get their subjective reactions to the clarity, completeness and ease of use of the prototype courseware. The debriefing session was used to conclude the evaluation with general questions about the instruction and the design of the prototype courseware and to prompt subject's suggestions for the improvement of the courseware.

The expert review evaluation was followed by the one-to-one evaluation. Ten subjects participated in the one-to-one evaluation. They were fourth year undergraduate students studying the course Multimedia Technology Systems in Computer Science Department at the Aristotle University of Thessaloniki, Greece. In this phase, a semi-structured interview and debriefing session were used as well. Most of the subjects agreed on the user friendliness of the Web courseware. They found that it was easy to modify the initial adaptation through the student model or the appropriate interaction buttons. Additionally, they agreed that the structure of the courseware was clear and easy to understand. Although, most comments were positive, they pointed out some weakness of the software. These comments from one-to-one evaluation were compared and processed together with experts' suggestions. Some of the more significant recommendations that were implemented during the revision phase are as follows:

- Subjects agreed on the usefulness of the instructional guidance at the bottom of the screen, but they suggested that it should be included in the minimum amount of space possible with regards to the overall appearance of the screen. So, a dynamic technique has implemented which resize this frame according to the mouse position (Fig. 5).
- As it has been explained earlier, in program control option AES-CS provides adaptive navigation support by manipulating the selection and the color of hyperlinks (blue color for 'recommended' and gray color for 'not ready to be learned'). However, the user was limited

to hyperlinks recommended by the system and could not select the gray colour hyperlinks. The majority of the students did not agree with this method since they felt that they were restricted by the system. After the revision, AES-CS kept the same adaptive annotation but all the links are available to be selected by the student.
- Originally, the system uses white as background color and black for the font. However, most of the subjects suggested that they would prefer to have an option regarding the ability to adapt the background of the HTML pages. After the revision, these suggestions were implemented.

5.2. Small group evaluation

After these revisions, the final stage of formative evaluation took place, consisted of the small group evaluation in a 'real world' environment. Ten subjects took part in the small group evaluation. A lecture on 'Digital image' was used as the example learning material. The aim of this lecture is to introduce the role of digital image into the development of a multimedia application. The evaluation was conducted by collecting data about the instruction from a variety of sources, using a variety of data gathering methods and tools. The following sub-sections will describe these tools and methods used to conduct the small group evaluation.

5.2.1. Subjects

Fourth year undergraduate students studying the course Multimedia Technology Systems were asked to volunteer for the small group evaluation. The GEFT (Witkin et al., 1971) was used to classify the participants ($N = 68$) into Field Dependent (FD) and Field Independent (FI) groups. The score of the test ranged from 0 to 18. The mean score was 12.76 and the standard deviation was 4.35. According to the Gauss theory, in a normal distribution, the range from one S.D. below the mean to one S.D. above the mean contains the 68.27% of the case. Therefore, in the small

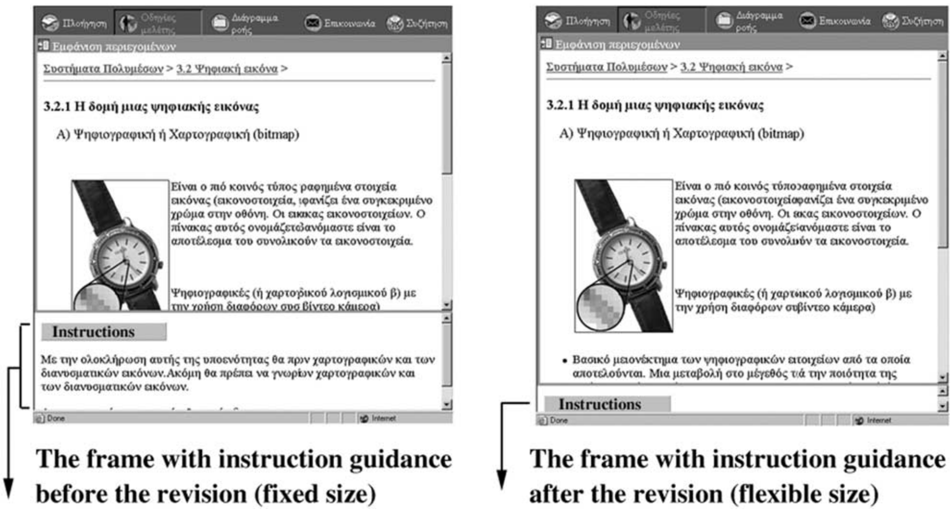

Fig. 5. The frame with instructional guidance before and after the revision.

group evaluation, the subjects were selected carefully in order to represent the target population. Ten subjects were selected according to their score: eight students with their score into the range [mean score −S.D., mean score + S.D.] that is 8–17, one student from them with the highest score (18) and one student from them with lowest score (3).

5.2.2. Procedure

A user account was created for each student to login into the system AES-CS. The initial adaptation of the system was according to the cognitive style of the students. Thus, the students with their scores ranged from 0 to 9 were classified as FD ($n=4$) and these with their scores ranged from 10 to 18 were classified as FI ($n=6$).

Before proceeding with the instruction, a pre-test was used to determine subject's prior knowledge on 'Digital image'. Then, the students received a short introduction on how to use the system and were prompted to use its various tools and instructional strategies. After that, students were login into the system by using their user account. All students were advised to work at their own pace without being given any time limit. During the instruction, the students used comment logs in order to note specific strengths or weaknesses of the system.

When all the students have finished the instruction, a post-test was used in order to measure the learning gain from the instruction. Moreover, an attitude questionnaire was given to the students aiming to determine their experience in using the system. Finally, a debriefing session was used to assess the subjective satisfaction of subjects on the instructional and interface design of AES-CS.

5.2.3. Results

The purpose of this phase of the evaluation was to investigate how to improve our system in order to make the instruction more effective and efficient. Pre-tests and post-tests having the same content in the form of open-ended items were used to measure the learning gains from the instruction. Eight open-ended items were included in each test. Since each correct answer was graded with two points, the total score for the test was within a range of 0 (0×8, none right answer) to 16 (8×2, eight right answers). Table 2 presents the means of the pre- and post-test performance scores for both the FD and FI group.

The results of the performance test indicated that subject's performance was increased after the instruction. Furthermore, FI subjects had better results than FD subjects. However, as Table 2 illustrates, the difference between the means of the pre-test and post-test showed that FD subjects were improved more than FI students. Table 3 presents the pre and post-test performance scores for every student. An interesting point here is that students with lower prior knowledge scores, demonstrated a better performance in the post-test, than students with higher prior knowledge.

Learning effectiveness and efficiency are interrelated evaluation goals, since learning and learning time are intertwined measures of instructional worth. The efficiency of the instruction is related to the time required for learners to master the objectives (Tessmer, 1993). The example learning material for the small group evaluation was prepared based on one typical lecture hour. Although the students spent enough minutes to see and to use the variety of instructional strategies and tools (concept map, graphics path indicator), they needed less than 60 min in order to complete the courseware. So, regarding the efficiency, the instruction was consider successful.

Furthermore, small group evaluation can offer useful implementation information concerning the usability and the appealing of the courseware. Usability is a measure of the ease with which a system can be learned and used. Because users principally know a system by its interface, designer's efforts at improving usability are primarily directed at improving interfaces. The usability and the appealing of the system were investigated in this study through the attitude questionnaires and the debriefing session. An analysis of the data collected showed that the subjects were satisfied with the system. In addition, they felt that the system was clear and easy to understand and after working with it they had a better understanding of the area studied. Furthermore, they felt challenged by the instruction and they stated that they wanted to use the courseware again. However, in the debriefing session they made suggestions for the improvement of the system. Some of the more significant recommendations are summarized into the following points:

- The FD subjects stated that concept map and graphic path indicator were very useful in order to organize the structure of the knowledge domain. Furthermore, they suggested that these tools should be active so to be used as an extra navigation tool. Although FI students did not use these tools in order to organize the structure of the knowledge domain, they agreed with the earlier suggestion and they felt that these tools could help them to easily navigate through the learning material thereby avoiding disorientation.
- Two of the FD students had changed many times the control option between program and learner control. In the case of learner control option, AES-CS provides a menu from which learner can choose to proceed the course in any order (see Fig. 2), while in the program control option there is no menu, but the system guides the user through the learning material via adaptive navigation support (see Fig. 3). In the debriefing session these two FD students explained that on the one hand they preferred the program control option, but on the other hand the menu helped them to understand the structure of the courseware. Moreover, they suggested that the content menu should always appear at the left frame. Therefore, the new version of AES-CS supports the users with the ability to display or not the content menu irrespectively from program or learner control.
- Another interesting finding concerns the instructions provided by the system. As it has been explained earlier, the system provides clear, explicit directions and the maximum amount of guidance to FD learner, while it provides minimal guidance and direction to FI learner. The results of the small group evaluation showed that FD students made entire use of the maximum amount of guidance while FI ask often for guidance and direction. In fact, one FI student had changed the option provided by the system so as to receive the maximum amount of guidance. Finally, in the debriefing session all students agreed on the usefulness of the flexibility to change between maximum and minimum amount of guidance and direction according to their individual needs.

Summarizing, the majority of the students were satisfied with the initial adaptation based on their cognitive style and they stated that the ability to change the initial stage through the student model or appropriate interactive features was very useful. The students indicated as very important the system flexibility to select and to use different instructional modes in order to accommodate their individual needs. Moreover, they felt challenged by the system flexibility and they were satisfied with the fact that the system was completely controllable by them.

Table 4
Performance means on pre- and post-test

	Pre-test Mean	S.D.	Post-test Mean	S.D.	Difference
FD	1.00	2.00	11.75	0.95	10.75
FI	3.67	4.41	13.50	1.22	9.83

Table 5
Performance on pre- and post-test

User	Cognitive style	Pre-test	Post-test
User1	FI	11	13
User2	FI	2	15
User3	FI	7	13
User4	FI	0	13
User5	FI	0	15
User6	FI	2	12
User7	FD	0	11
User8	FD	4	13
User9	FD	0	12
User10	FD	0	11

As mentioned earlier, most of the above suggestions were implemented during the revision of AES-CS. However, they will be further processed in order to develop more the adaptive features of AES-CS and to fully complete the design of the system. After the final revision, summative evaluation will follow to assess the effectiveness of the system with reference to other educational material used for the instruction of the particular module.

6. Conclusions and recommendations

This article describes the design and development of an Adaptive Educational System based on Cognitive Styles (AES-CS), a prototype that includes accommodations for cognitive styles in order to improve student interactions and learning outcomes. Currently, the basic architecture of the system has been implemented. The AES-CS (http://mlab.csd.auth.gr/adapt, 'guest' for login and password) has two main components: the client running in the Web browser and the server running in a PC workstation. The client is implemented as Web pages, residing in a number of linked frames. The development platform used is ASP technology using Dynamic HTML and JavaScript language that made possible to overcome HTML limitations.

Throughout the development of the AES-CS, formative evaluation was an integral part of the design methodology. The design process was driven by continuous formative evaluation. Recommendations from expert reviews, suggestions from the students and results of the small group evaluation are summarized later:

Design: the design and the development of an AES that includes accommodations for cognitive styles were effective and efficient.

Initial adaptation: the initial adaptation based on research results and theoretical assumptions in FD/FI dimension was consider successful. However, adaptive systems need to be controllable by the user because they cannot be intelligent enough to appropriately adapt in all possible cases.

Instructions: students should be able to access the maximum amount of guidance and instructions whenever they need.

Structure: the system should provide tools such as the concept map and the graphic path indicator, in order to help learners organize the structure of the knowledge domain. Furthermore, these tools should be active so to be used as an extra navigation tool.

These recommendations resulting from an empirical study, although they do not have a universal value as the design and development of a courseware always depends on the target population and the subject matter, could be seen as some points worth considering from designers of adaptive hypermedia systems. However, they will be further refined the summative evaluation of the AES-CS.

Moreover, additional research direction is the evaluation of the educational effectiveness of system's adaptation by investigating the hypothesis that the adaptivity based on student's cognitive style could be beneficial for the observed learning outcomes. An experiment by Jonassen and Wang (1993) showed that FI learners are better hypermedia processors, especially as the form of the hypermedia becomes more referential and less overtly structured. In that term, part of our further research is to examine whether or not FD learners will reach the same level of performance as FI ones when studying in AES-CS environment.

Uncited tables

Tables 4 and 5

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