Enhancing eLearning Environments with Users' Cognitive Factors: The case of EKPAIDEION

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Abstract: We are now witnessing an extensive and gradually increasing use of the World Wide Web space, proved to be a quite favourable way of communication, due to its speed, simplicity and efficiency. Distance learning (or eLearning) is considered one of the most rapidly evolving application areas of the Web that improves the traditional educational processes and methodologies of knowledge transfer. In recent years, there has been significant research and experimentation around the adaptation and personalization of the eLearning hypermedia that mainly concerns the timely delivery and adjustment of the content to user's needs and perceptual characteristics. This paper provides a new comprehensive way of reconstructing eLearning content; by creating a user profile based on specific metrics of cognitive processing parameters (such as cognitive style, cognitive processing speed efficiency and working memory factors) that have specific impact into the information space. The combination of the cognitive user profile and the 'traditional' user characteristics (e.g. age, gender, profession) could become the main personalization filter for eLearning environments. Such approach may be proved to be very useful in assisting and facilitating a student to better understand eLearning content.. In view of that, an adaptation and personalization Web-based environment, namely EKPAIDEION, has been developed. An evaluation with approximately 128 users has been conducted with the results being highly promising and encouraging, since there has been identified significant increase of learners' academic performance when interacting with our personalized eLearning environment that is matched to their cognitive styles and visual working memory span capabilities.

Keywords: Web personalization, Adaptation, eLearning, User Profile, Cognitive styles, Working memory

1. Introduction

Adapting to user context, individual characteristics and behaviour patterns is nowadays a topic of great attention in the field of Web-based and mobile learning. One of the main challenges is to design personalized interfaces and software that enable easy access to the learning content, while being sufficiently flexible to handle changes in user's context, perception and available resources.

A key technical issue in developing personalized applications is the problem of how to construct accurate and comprehensive profiles of individual users and how these can be used to identify a user and describe his behaviour. The objective of user profiling is the creation of an information base that contains the preferences, characteristics and activities of the user.

There are some noteworthy applications in the area of Web personalization that collect information with various techniques from the users, based on which they adapt the services content provided. Such systems, mostly commercial, are amongst others the Broadvision's One-To-One (www.broadvision.com), Microsoft's Firefly Passport (developed by the MIT Media Lab), the Macromedia's LikeMinds Preference Server, Apple's WebObjects, etc. Other, more research oriented systems, include ARCHIMIDES (Bogonicolos et al. 1999), WBI (Maglio & Barret 2000; Barret et al. 1997), BASAR (Thomas & Fischer 1997) and mPERSONA (Panayiotou & Samaras 2004). Significant implementations have also been developed with regards to the provision of adapted educational content to students using various adaptive hypermedia techniques. Such systems are amongst others, INSPIRE (Papanikolaou et al. 2003), ELM-ART (Weber & Specht 1997), AHA! (De Bra & Calvi 1998), Interbook (Brusilovsky et al. 1998), and so on.

This paper introduces a new model in the field of adaptive hypermedia, which integrates cognitive and mental parameters and attempts to apply them on a Web-based learning environment, extending

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the notion of user profile. Our purpose is to improve learning performance and, most importantly, to personalize Web-content to users' needs and preferences, eradicating known difficulties that occur in traditional approaches. These characteristics, which have been primarily discussed in our previous publications (Germanakos et al. 2005; Germanakos et al. 2007), have a major impact on visual attention and cognitive processing that take place throughout the whole process of accepting an object of perception (stimulus), until the comprehensive response to it.

Based on the abovementioned considerations, an adaptive Web-based environment is overviewed trying to convey the essence and the peculiarities encapsulated. This system, called EKPAIDEION is an innovative Adaptation and Personalization Web-based System that is based on the Comprehensive User Profile mentioned above, which serves as the primal personalization filtering element.

2. Theoretical Background

Web personalization is the process of customizing the content and structure of a Web site to the specific needs of each user by taking advantage of the user's navigational behaviour. Being a multi-dimensional and complicated area a universal definition has not been agreed to date. Nevertheless, most of the definitions given to personalization (Cingil et al. 2000; Blom 2000; Kim 2002) agree that the steps of the Web personalization process include: (1) the collection of Web data, (2) the modelling and categorization of these data (pre-processing phase), (3) the analysis of the collected data, and (4) the determination of the actions that should be performed.

One of the main challenges in personalization research is alleviating users' orientation difficulties, as well as making appropriate selection of knowledge resources, since the vastness of the hyperspace has made information retrieval a rather complicated task (De Bra et al. 2004). Adaptivity is a particular functionality that distinguishes between interactions of different users within the information space (Eklund & Sinclair 2000; Brusilovsky & Nejdl 2004).

A system can be classified as personalized if it is based on hypermedia, has an explicit user model representing certain characteristics of the user, has a domain model which is a set of relationships between knowledge elements in the information space, and is capable of modifying some visible or functional parts of the system, based on the information maintained in the user model (Brusilovsky & Nejdl 2004; Brusilovsky 2001; Brusilovsky 1996). In further support of the aforementioned concept of personalization, when referring to information retrieval and processing, one cannot disregard the top-down individual cognitive processes (Eysenck & Keane 2005), that significantly affect users' interactions within the hyperspace, especially when such interactions involve educational or learning, in general, goals.

Consequently, besides "traditional" demographic characteristics that commonly comprise the user model in personalized environments, we believe that a user model that incorporates individual cognitive and triggers corresponding mechanisms of adaptivity, increases the effectiveness of Web-applications that involve learning processes.

2.1 User Perceptual Preferences

This is the new component / dimension of the user profile as depicted in Fig. 1. It contains cognitive processes that could be described as user "perceptual preferences", aiming to enhance information learning efficacy.

User Perceptual Preferences could be described as a continuous mental process, which starts with the perception of an object in the user's attentional visual field, and involves a number of cognitive learning processes that lead to the actual response to that stimulus (Germanakos et al. 2005).

This model's primary parameters formulate a two-dimensional approach to the problem (Germanakos et al. 2007) outlined below:

2.1.1 Cognitive processing efficiency

The cognitive processing parameters (Demetriou & Kazi 2001) that have been included in our model are:

i. *control of processing* (refers to the processes that identify and register goal-relevant information and block out dominant or appealing but actually irrelevant information)

ii. *speed of processing* (refers to the maximum speed at which a given mental act may be efficiently executed), and

iii. *working memory span* (refers to the processes that enable a person to hold information in an active state while integrating it with other information until the current problem is solved)

iv. *visual attention* (based on the empirically validated assumption that when a person is performing a cognitive task, while watching a display, the location of his / her gaze corresponds to the symbol currently being processed in working memory and, moreover, that the eye naturally focuses on areas that are most likely to be informative).

We measure each individual's ability to perform control/speed of processing and visual attention tasks in the shortest time possible, with a specific error tolerance, while the working memory span test focuses on the visuospatial sketch pad sub-component (Baddeley 1992), since all information in the Web is mainly visual.

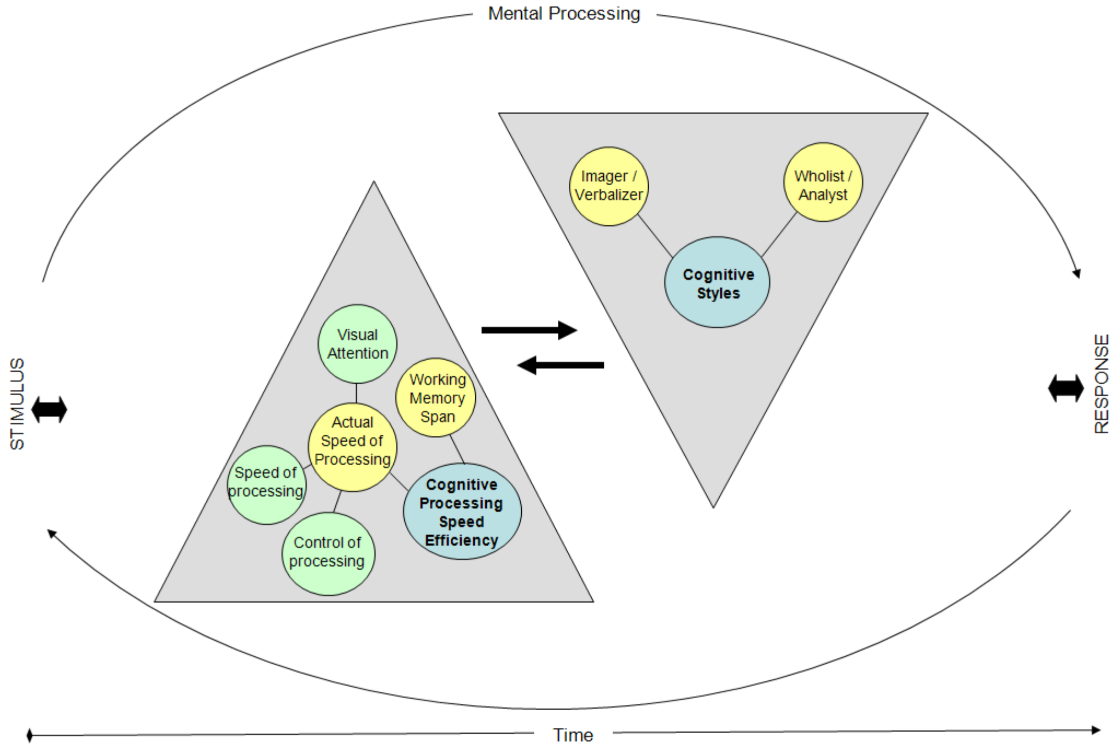

Figure 1: User Perceptual Preferences

2.1.2 Cognitive style

Cognitive styles represent an individual's typical or habitual mode of problem solving, thinking, perceiving or remembering, and "are considered to be trait-like, relatively stable characteristics of individuals, whereas learning strategies are more state-driven…" (McKay et al. 2003). Amongst the numerous proposed cognitive style typologies (Cassidy 2004) we favor Riding's Cognitive Style Analysis (Riding 2001), because we consider that its implications can be mapped on the information space more precisely, since it is consisted of two distinct scales that respond to different aspects of the Web. The imager/verbalizer axis affects the way information is presented, whilst the wholist/analyst dimension is relevant to the structure of the information and the navigational path of the user. Moreover, it is a very inclusive theory that is derived from a number of pre-existing theories that were recapitulated into these two axises.

We prefer the construct of cognitive rather than learning style because it is more stable (Sadler-Smith & Riding 1999), and to the extent that there is a correlation with hemispherical preference and EEG measurements (Glass & Riding 1999; McKayet al. 2003), the relationship between cognitive style and actual mode of information processing is strengthened. Additionally, the effect of the specific cognitive style theory on web-based learning processes has also been demonstrated by Graff (2003; 2005).

2.2 A High Level Correlation Diagram

For a better understanding of the two dimensions' implications and their relation with the information space a diagram that presents a high level correlation of these implications with selected tags of the information space (a code used in Web languages to define a format change or hypertext link) is depicted in Fig. 2. These tags (images, text, information quantity, links – learner control, and navigation support) have gone through an extensive optimization representing group of data affected after the mapping with the implications. The main reason we have selected the latter tags is due to the fact that they represent the primary subsidiaries of a Web based content. With the necessary processing and / or alteration we could provide the same content in different ways (according to a specific user's profile) but without degrading the message conveyed.

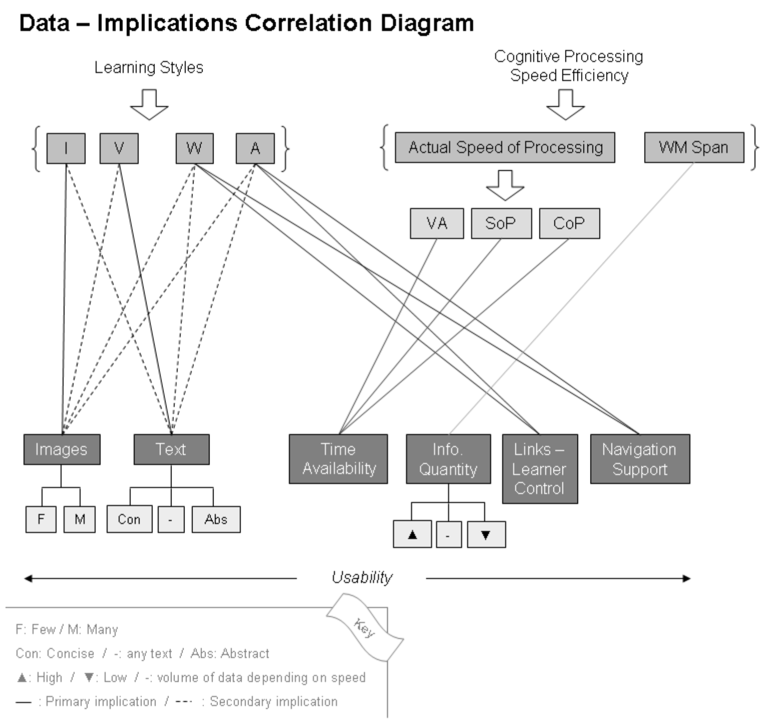

Figure 2: Data - Implications Correlation Diagram

The particular mapping is based on specific rules that are consistent to psychological theory, in order to filter the raw content and deliver the most personalized Web-based result to the user. As it can be observed from the diagram above almost each profiling dimension has primary (solid line) and secondary (dashed line) implications on the information space altering dynamically the weighting of each factor on the creation of the environment.

A user might be identified that:	**Tags affected accordingly:**
a) He is Verbalizer (V) – Wholist (W) with regards to the Learning Style.	a) Images (few images displayed), Text (any text could be delivered).
b) He has an Actual Cognitive Processing Speed Efficiency of 1000 msec.	b) Medium interaction time availability (since his cognitive processing speed efficiency is moderate).
c) He has fair Working Memory Span (weighting 5/7).	c) Info Quantity (less info since his has medium working memory).
	d) Links – Learner Control (less learner control because he is Wholist).

Figure 3: A practical example of the Data – Implications Correlation Diagram

According to theory, with regards to learning styles for example, the number of images (few or many) to be displayed has a primary implication on imagers, while text (more concise or abstract) has a secondary implication. The analytic preference has a main effect on the links (learner control and navigation support tag). Moreover, actual speed of processing parameters (visual attention, speed of processing, and control of processing) as well as working memory span primarily affect time availability during interaction process and information quantity respectively (see an example in Fig. 3).

At this point it should be mentioned that in case of internal correlation conflicts primary implications take over secondary ones.

3. The EKPAIDEION System

Based on the abovementioned considerations, an adaptive Web-based environment is overviewed trying to convey the essence and the peculiarities encapsulated. The current system, EKPAIDEION[2] (see Fig. 4), is a Web-based and mobile Web application. It is further detached into a number of interrelated components, each one representing a stand alone Web system briefly presented below (the technology used to build each Web system is ASP .Net):

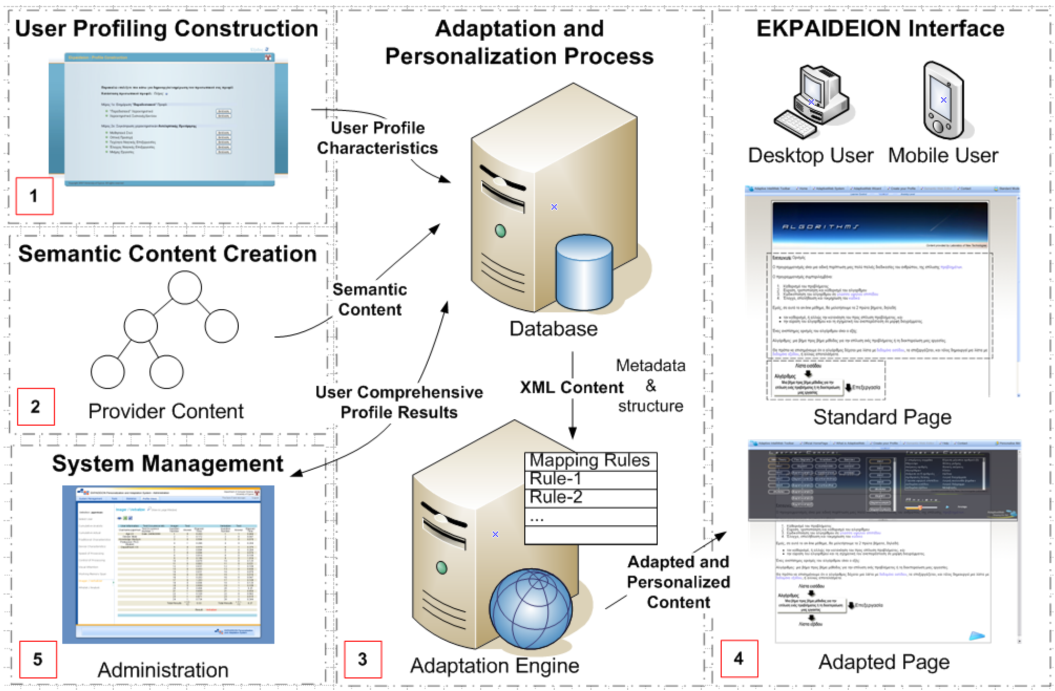

Figure 4: EKPAIDEION System Architecture

3.1 User Profiling Construction

To get personalized and adapted content, users have to create their comprehensive profile through the "User Profiling Construction" component. At this point the users have to give their "Traditional" and Device / Channel Characteristics and further complete a number of real-time tests (attention and cognitive processing efficiency grabbing psychometric tools) for generating their cumulative profile. Furthermore, our main concern is to ensure openness and interoperability within and between the system's components. Using XML for implementing the users' profile seems to be the best way to achieve this since it enables the extendibility we need and enhances functionality and integration among systems' components.

We have designed a Web Service (a software system designed to support interoperable Machine to Machine interaction over a network) for retrieving the users' comprehensive profile. Depending on the needs of a third party system that interacts with our system through this middleware; calculations are made and are finally exported in XML.

3.2 Content Authoring and Adaptation Process

Another major issue in Web Personalization and Adaptation is the personalized content architecture, how it is authored and processed. The content provider has to create his / her own content by defining objects that will be embodied in a given content.

The content structure has to be "well-formatted" and the objects have to be "well-defined" (based on given semantic tags) by the editor in order to give the best results to the end-user. The technology that will be used for creating the personalized content is a more expressive semantic Web language

[2] Source: http://www3.cs.ucy.ac.cy/ekpaideion/site/index.html

like OWL or RDF used for describing data and to focus on the relation between them. The author of the page uploads the content on the system's database, which will be mapped after with the system's "Mapping Rules". The system's "Mapping Rules" are functions that run on the EKPAIDEION server and comprise the main body of the adaptation and personalization procedure of the provider's content, according to the user's comprehensive profile. In this section, all the system's components interact with each other in order to create and give personalized and adapted content to the end user.

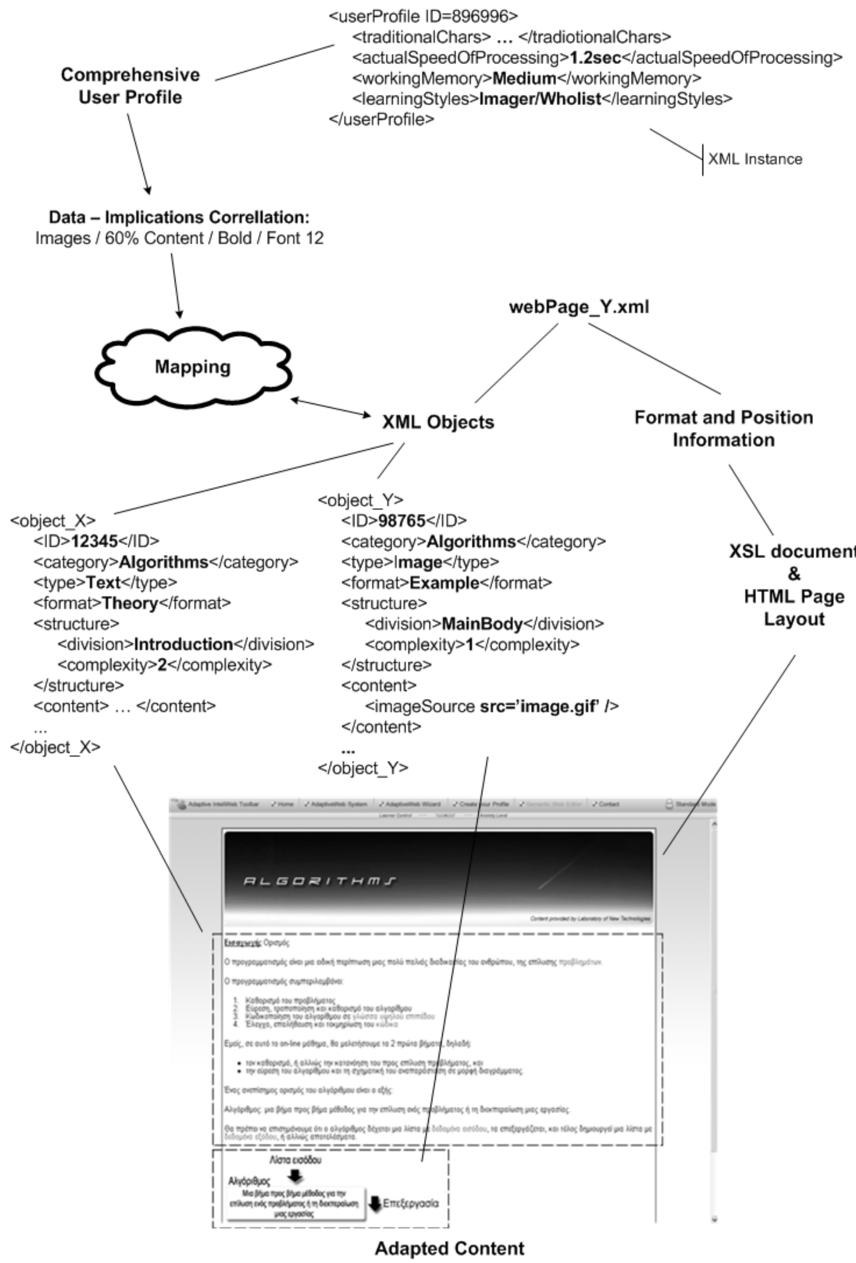

Figure 5: The Adaptation Process

For experimental purposes, we have currently authored an e-learning multimedia environment with a predefined content for adaptation and personalization. This environment includes a course named "Introduction to Algorithms" and is a first year e-learning course environment that aims to provide students with analytic thinking and top-down methodology techniques for further development of constructive solutions to given problems.

To get a better insight of the adaptation process and how data flows, we hereafter depict how the personalized content (the "Introduction to Algorithms" predefined environment) interacts with the Comprehensive User Profile, using specific mapping rules.

Fig. 5 shows the whole adaptation process. The system's adaptation engine initially retrieves the actual profile characteristics of the user and then interprets the profile to conclude what implications the user's characteristics have in the information space; what adaptation techniques to use on the content. Every Web-page is detached into standalone objects, each one having special characteristics (i.e. image diagram for Imagers or text object for Verbalizers).

At this point the system has all the information necessary for adapting the content; the data - implications correlation diagram based on the user's comprehensive profile and the content description of the particular Web-page. The next step is to map the implications with the Web-page's content, for assembling the final version of the provider's content. The content adapts according to the users' preferences. The new, adapted content loads then onto the users' device.

Furthermore, Fig. 6 shows the mapping process (concerning the cognitive style) using our example; explained in pseudo code.

```
Algorithm : Mapping Process Phase
Input: User's data-implications correlation diagram (contentAmount, fontSize, fontWeight,
learningStyles), WebObjects, XSL document, HTML layout
Output: Generate an Adapted and Personalized Web-page
Execute these steps (top-down):
  1) For each structure division (Introduction, MainBody, Conclusion)
         Filter out the implication's contentAmount of the WebObjects in ascending order based on
  their complexity (<complexity>);
  2) For each remained object, make a further filtering based on the object's <type> tag
         if (learningStyle1 = Imager)
             Add image objects;
         elseif (learningStyle1 = Wholist)
             Add text objects;
         if (object has NavigationSupport Tag){
             var wordDefinitionObject = retrieveWordDefinitions(objectID)
             var navigationSupportType;
             if (learningStyle2 = Analyst)
                 getNavigationSupportType(objectID);
                 Show description in popup up window;
             elseif (learningStyle2 = Wholist OR learningStyle2 = Intermediate)
                 getNavigationSupportType(objectID);
                 Show description in tooltip on mouseover;
         }
  3) Format each object based on the fontSize and fontWeight and the XSL (eXtensive Stylesheet)
  4) Position each object in the right structure division based on the HTML layout document
```

Figure 6: Mapping Process Example (pseudo code)

So far, we have presented how adaptation of the actual raw content of the Web-page is achieved matching the comprehensive user profile with the content description XML document using specific mapping rules. The next step is to elaborate on how the system's auxiliary tools (navigation support and learner control) are affected and altered through the adaptation and personalization process described below.

3.3 Viewing the Adapted Content - The EKPAIDEIONWeb Environment

The last component of the architecture is the EKPAIDEION User Interface, namely EKPAIDEIONWeb, which is a Web application used for displaying the raw or personalized and adapted content on the user's device. The main concept of this component is to provide a framework where all personalized Web sites can be navigated. Using this interface the users navigate through the provider's content. Based on their profile further support is provided to them with the use of a slide-in panel at the top of the screen, containing all navigation support and learner control attributes adjusted accordingly.

Users log in the system providing their username and password to see adapted content. The corresponding profile loads onto the server and in proportion with their cumulative characteristics the content of the provider maps with the "Mapping Rules", as described before.

Based on theory (Sadler-Smith & Riding 1999), Analysts have a more analytic way of think; thus the navigation support provided (analytic description of definitions) is in popup windows, so they can manage the entire lesson, along with its definitions by themselves. In the learner control support (that is, the slide-in help panel from the top of the page) is a linkable sitemap of the whole e-learning lesson, plus the entire lesson's definitions in alphabetic order and an anxiety bar for changing their current anxiety level.

On the other hand, Wholists tend to have a wholistic approach of learning (Sadler-Smith & Riding 1999); thus the navigation support and learner control support is more restricted and is specifically provided for guidance. The analytic description of a definition is only shown in a tooltip when they move their mouse over it and the learner control shows them only the current chapter's pages they learn and lets them navigate only to the next and the previous visited pages.

4. Evaluation

The evaluation of the system was conducted empirically by applying an approach derived from experimental psychology methodology. Users of the e-learning environment embedded on the system took online educational courses and their level of comprehension of the content was assessed afterwards.

In general, learners were grouped according to whether they would receive a personalized to the aforementioned human factors online course, or a mismatched to their preferences environment. Thus, the two main categories of users were “matched” and “mismatched”. At a first level, an experiment to assess the effect of cognitive style as a personalization factor has shown that performance is indeed increased through adaptive techniques (Tsianos et al. 2008).

In this paper, we present results of an experiment that was mainly focused on working memory and interaction with cognitive style.

4.1 Materials

Cognitive style: Since we used Riding's inclusive theory of cognitive styles, we consequently integrated in our system the electronic version of the corresponding psychometric tool (Riding's Cognitive Style Analysis).

Working memory: Due to the visual nature of our educational approach, we used a tool that measures visual working memory span-VWMS (Demetriou et al. 2002).

4.2 Sampling and Procedure

The total number of participants was 128, with a mean age of 21 years; approximately 65% were female and 35% male. All of them were students at the University of Cyprus, and their participation was voluntary. The course that was taught was about algorithms in computer science, and learners' experience on the subject was controlled by the fact that all participants came either from social science departments or were first year students.

At first, users logged into the system and completed the psychometrical procedures that involved the abovementioned materials, in order to classify them according to their cognitive style and their VWMS. Having already assessed the role of cognitive style, all users received a course that was adapted on their style preference, but not on their VWMS; half of those with low VWMS were taught in a matched way (segmented content) and the other half in a mismatched way (full content). Those with medium or high VWMS served as control group that do not require special manipulation of the content.

What we expected to see was that mismatched low VWMS would perform worse that the control group, thus underpinning the significance of personalization. Matched low VWMS (receiving segmented content that is) on the other hand would perform better than their mismatched counterparts or equally well to the control group.

As soon as participants completed the online course, a memory/comprehension exam test had to be taken immediately after. Score on this test was the dependent variable that would demonstrate differences in information comprehension and the positive, if any, effect of personalization.

4.3 Results

Personalization on the basis of VWMS was proven significant in increasing low VWMS learners' performance. As expected, these learners did perform worse than those with medium or high working memory when receiving the same (full) content. However, when the provided content was segmented, there was an increase of performance. More specifically, mismatched low VWMS learners had a mean score of 52.36%, matched low VWMS learners 56.33%, while the control group 62.94%.

A 3X3X3 univariate analysis of variance was performed on the data in order to calculate the statistical significance of these differences and possible interactions with cognitive style; the independent variables were matched/mismatched/control group, imager/intermediate/verbalizer cognitive style and wholist/intemerdiate/analyst, with score on the exam test as the dependent variable.

Table 1 demonstrates that the differences in the performance attributed to the VWMS are significant, while an interaction of VWMS and the imager/verbalizer dimension of cognitive style was observed.

Table 1: Univariate analysis of variance of differences in learners' performance according to the group they belong and interactions of cognitive style with VWMS

Tests of Between-Subjects Effects - Dependent Variable: Score %

Source	df	F	Sig.
Corrected Model	23	**1.751**	**.030**
Intercept	1	607.889	.000
MatchedWM	2	**4.315**	**.016**
ImagerVerbalizer	2	.613	.543
WholistAnalyst	2	1.704	.187
MatchedWM * ImagerVerbalizer	4	1.283	.282
MatchedWM * WholistAnalyst	4	.964	.431
ImagerVerbalizer * WholistAnalyst	4	.222	.926
MatchedWM * ImagerVerbalizer * WholistAnalyst	5	**2.775**	**.022**
Error	104		
Total	128		
Corrected Total	127		

a R Squared = .279 (Adjusted R Squared = .120)

Table 2: Post hoc test on differences in performance according to the VWMS factor

Multiple Comparisons - Dependent Variable: Score %

	(I) Matched WM	(J) Matched WM	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Tukey HSD	Matched	Mismatched	3.97	4.999	.708	-7.92	15.86
		Control	-6.61	3.993	.228	-16.10	2.89
	Mismatched	Matched	-3.97	4.999	.708	-15.86	7.92
		Control	**-10.58(*)**	3.920	**.022**	-19.90	-1.26
	Control	Matched	6.61	3.993	.228	-2.89	16.10
		Mismatched	**10.58(*)**	3.920	**.022**	1.26	19.90

Based on observed means.
* The mean difference is significant at the .05 level.

Post hoc analysis of VWMS differences has shown that mismatched learners differ significantly from the control group, while matched learners do not. However, the latter do not reach statistical significance in their scores from the mismatched learners, thus enabling us to conclude that performance is indeed increased, but not at the levels of the control group (see table 2).

As it concerns the interaction observed between VWMS and cognitive style, it seems that in the case of mismatched VWMS, significant differences in performance in relation to cognitive style took place (see Fig. 7). For some reason, intermediate users with no specific verbal or visual preference perform much worse when they receive full content. Imagers come next, while verbalizers are not equally burdened by the amount of the content.

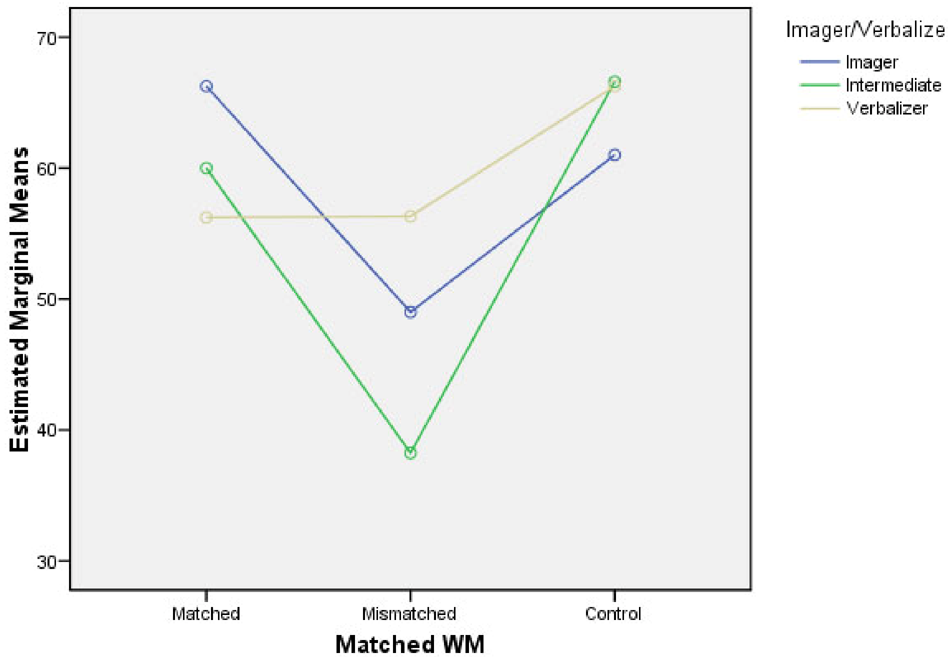

Figure 7: Plot of means illustrating the interaction between VWMS and cognitive style

To sum up, we may support that:

- Working memory, and more specifically visual working memory span, is significant in users' interactions with an educational system.
- Personalization on this factor by segmenting the educational content has a positive effect on users' performance.
- There is an interaction observed between cognitive style and VWMS. It seems that personalization on cognitive style somehow alleviates the effect of cognitive overload in the case of imagers and mostly verbalizers, (cognitive style as a standalone factor was proven quite significant in our previous work) but those without a specific preference (intermediates) are very susceptible to VWMS differences.

To that end, it is our estimation that working memory and cognitive style are important factors in e-learning applications; therefore, our future work will focus on these dimensions by incorporating more elaborate personalization techniques and by conducting further empirical evaluation.

5. Conclusions and Future Work

The basic objective of this paper was to make a reference to concepts and techniques coming from the research area of Web personalization, all of which focus upon the user. It has been attempted to approach the theoretical considerations and technological parameters that can provide the most comprehensive user profile, under a common filtering element (User Perceptual Preferences), supporting the provision of the most apt and optimized user-centred Web-based result.

Our two-dimensional model (based on which we developed the EKPAIDEION system) seems to cover a wide area of human factors that are proven significant in computer mediated learning procedures, and may provide a basis for meaningful personalization. Cognitive style is certainly of high importance, cognitive processing efficiency and working memory have an impact on the Web environment for optimization of academic performance.

The initial evaluative results were really encouraging for the future of the current work since we found that in many cases there is high positive correlation of matched conditions with academic performance, and a noteworthy interaction between the two dimensions of our model (cognitive style and VWMS), clearly observed. This fact demonstrates the effectiveness of incorporating human factors in Web-based personalized environments. There are of course limitations in our approach, mainly due to the nature of the Web content that often limits radically differentiated adaptation, and the psychometric challenges of measuring a wide spectrum of human cognition.

Future and emerging trends include a more detail analysis of the current model as well as the relationship between its different sub-dimensions; further investigation of constraints and challenges arise from the implementation of such issues on mobile devices and channels; study on the structure of the metadata coming from the providers' side, aiming to construct a Web-based personalization architecture that will serve as an automatic filter adapting the received content based on a comprehensive user profile; as well as the use of an eye-tracker gadget to clarify the role of visual attention in Web-based communication environments.

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