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# ADAPTING mLEARNING ENVIRONMENTS ON LEARNERS' COGNITIVE STYLES AND VISUAL WORKING MEMORY SPAN

Panagiotis Germanakos
*University of Nicosia, Cyprus*, pgerman@cs.ucy.ac.cy

Mario Belk
*University of Cyprus*, belk@cs.ucy.ac.cy

Zacharias Lekkas
*National & Kapodistrian University of Athens, Hellas*, zlekkas@gmail.com

Constantinos Mourlas
*National & Kapodistrian University of Athens, Hellas*, mourlas@media.uoa.gr

Georgia Kleanthous
*University of Cyprus*, georgia.kleanthous@gmail.com

***See next page for additional authors***

**Authors**
Panagiotis Germanakos, Mario Belk, Zacharias Lekkas, Constantinos Mourlas, Georgia Kleanthous, and George Samaras

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*Panagiotis Germanakos, University of Nicosia, Cyprus & University of Cyprus, pgerman@cs.ucy.ac.cy*

*Mario Belk, University of Cyprus, belk@cs.ucy.ac.cy*

*Nikos Tsianos, National & Kapodistrian University of Athens, Hellas, ntsianos@media.uoa.gr;*

*Zacharias Lekkas, National & Kapodistrian University of Athens, Hellas, zlekkas@gmail.com*

*Constantinos Mourlas, National & Kapodistrian University of Athens, Hellas, mourlas@media.uoa.gr*

*Georgia Kleanthous, University of Cyprus, georgia.kleanthous@gmail.com*

*George Samaras, University of Cyprus, cssamara@cs.ucy.ac.cy*

## Abstract

*The research that is described in this paper focuses on incorporating theories of individual differences in information processing within the context of mobile hypertext and hypermedia interactive environments. Based on previous findings of the authors in the field of adaptive eLearning, the main purpose was to enhance the quality of information presentation and users' interactions in the Web by matching their specific needs and preferences. Our more recent experiments, explore how to improve learning process by adapting course content presentation to student cognitive styles and capabilities in mobile environments such as PDA phones. A framework has been developed to comprehensively model student's cognitive styles and visual working memory span and present the appropriate subject matter, including the content, format, guidance, etc. to suit an individual student by increasing efficiency during interaction. Main aim is to overcome constraints like small screen size and processing/memory capabilities for navigation enhancements that limit the presentation and guidance of the material. An increase on users' satisfaction as well as more efficient information processing (both in terms of accuracy and task completion time), has been observed in the personalized condition than the original one. Consequently, it is supported that human factors may be used in order to enhance the design of mobile hypertext (or hypermedia) environments in a measurable and meaningful way.*

*Keywords: Web Personalization and Adaptation, User Modelling, Mobile Web Environments, Cognitive Styles, Working Memory Span.*

# 1 INTRODUCTION

The rapid technological growth and especially the progress made in Computer Science managed to create new, unconventional ways of interaction and learning over the Web interfaces. In the latter case, the adoption of new technologies in the learning process is referred to as electronic learning (eLearning). Numerous Web-based learning systems such as Blackboard and WebCT made eLearning a part of our daily lives. In the same line as eLearning, applications for mobile devices started to emerge, changing the education / learning scene radically.

The availability of advanced mobile technologies, such as high bandwidth infrastructure, wireless technologies, and handheld devices, has started to extend eLearning towards mLearning (Sharples, 2000). This phenomenon fits well with the new paradigm "anytime, anywhere computing" (Lehner & Nösekabel, 2002). However, the development of mLearning is still at rather early stage and many issues have yet to be resolved. One of these issues is to personalize the learning process of the mobile learner.

A big variety of applications using mobile technology to help education is already available; from providing learning modules, to allowing learners to communicate with lecturers. However, the positive impact of mLearning in education does not depend solely on the services that mLearning applications can provide. The ability of educationists to design and develop environments that enhances learning is necessary as well. It is therefore important to define the applications of mobile technologies that contribute to the learning process, and to understand contemporary learning theory (Brown, 2005).

Since the WWW is by definition a huge resource of information, it would make much sense that individuals' information processing characteristics should be taken into consideration. To that direction, our efforts are focused on improving the effectiveness of eLearning and mLearning provision by employing methods of personalization. As part of our previous research, it has been demonstrated that the incorporation of human information processing factors in eLearning environments leads to better comprehension on behalf of the users (Germanakos et al., 2008, Germanakos et al., 2007b).

The information processing parameters that we have used in the case of an eLearning environment, which had an actual effect on performance, comprise a comprehensive user model that includes the following three dimensions: Cognitive Style, Cognitive Processing Efficiency and Emotional Processing. The first dimension is unitary, whereas Cognitive Processing Efficiency is comprised of (a) Working Memory Span (WMS) (Baddeley, 1992) (b) speed and control of information processing and (c) visual attention (Demetriou et al., 1993). The emotional aspect of the model focuses on different aspects of anxiety (Cassady & Jonhson, 2002; Cassady, 2004; Spielberger, 1983) and self-regulation.

Based on this experimental evaluation, our next step was to apply such individual differences theories in mLearning. From a wide perspective that emphasizes on information processing and learning along with the technological constraints of mobile/wireless technologies, the constructs of cognitive style and working memory were opted for as personalization parameters, considering that their effect in the case of our eLearning experiments was highly significant.

This paper explores how to improve learning process by adapting course content presentation to student learning styles in mobile environments such as PDA phones. A framework has been developed to comprehensively model student's cognitive styles and visual working memory span and present the appropriate subject matter, including the content, format, media type, and so on, to suit an individual student.

Some other attempts that utilize personalization techniques in various ways in mLearning environments and systems are: MoMT: MoMT (Mobile Mathematics Tutoring) (Zhao et al., 2008) is an eLearning system that implements a functional architecture for personalized adaptation contents. It also uses various algorithms to create adaptive and intelligent contents for learners; ACE: Adaptive Courseware Environment (ACE) (Specht & Oppermann, 1998) provides certain mechanism to adapt to student's learning styles. When a student starts to use a new courseware, the student are asked for their learning strategies, such as learning by example, reading texts, or learning by doing. Based on the learning model, the domain model and the pedagogical model, the presentation component selects appropriate learning units and generates individual hypermedia documents for student. In strict learning style theory in education, its supporting learning styles may be classified into student preference; mELDIT (Trifonova et al., 2004) is a mobile version of an existing online language learning system, called ELDIT. The main scope of the ELDIT project is to create an innovative electronic language learning system for the population of South Tyrol in Italy to prepare for the exams in bilingualism.

Section 2 of this paper emphasizes the theoretical background of our approach and presents the proposed cognitive approach for the development of effective mLearning environments. Section 3 describes the mAIWeb system and its architecture and section 4 presents a preliminary evaluation. Finally, section 5 concludes the paper.

# 2 PROPOSING A COGNITIVE APPROACH FOR THE DEVELOPMENT OF EFFECTIVE MLEARNING ENVIRONMENTS

Our main aim is to create methodologies that will efficiently reconstruct and deliver the learning content over mobile devices, adapted on users' individual characteristics for improving their learning performance. Previous experience and experimentation on eLearning environments (Germanakos et al., 2008) revealed that the adaptation of learning content based on users' intrinsic perceptual characteristics (such as cognitive and emotional processing parameters) are significant for the improvement of students' academic performance and satisfaction. A three-dimensional model has been proposed in the past (Germanakos et al., 2008; Germanakos et al., 2007b) with the two of the cognitive parameters to be used initially in the current research, due to the constraints of mobile technologies (Germanakos et al., 2007a). More specifically, we elaborate on efficient content reconstruction based on the implications of cognitive style and visual working memory span on particular content characteristics of mLearning environments.

## 2.1 Cognitive Styles

Cognitive styles represent the particular set of strengths and preferences that an individual or group of people have in how they take in and process information. By taking into account these preferences and defining specific learning strategies, empirical research has shown that more effective learning process can be achieved (Boyle et al., 2003), and that cognitive styles nevertheless correlate with performance in a Web-based environment (Wang et al., 2006).

Regarding the hypermedia information space, amongst the numerous proposed theories of individual style, a selection of the most appropriate and technologically feasible cognitive (and learning) styles (those that can be projected on the processes of selection and presentation of Web-content and the tailoring of navigational tools) has been studied, such as Riding's Cognitive Style Analysis (CSA) (Verbal-Imager and Wholistic-Analytical) (Riding, 2001), Felder/Silverman Index of Learning Styles (ILS) (4 scales: Active vs Reflective, Sensing vs Intuitive, visual vs Verbal and Global vs Sequential) (Felder & Silverman, 1988), Witkin's Field-Dependent and Field-Independent (Witkin et al., 1977), and Kolb's Learning Styles (Converger, Diverger, Accommodator, and Assimilator) (Kolb & Kolb, 2005), in order to identify how users transforms information into knowledge (constructing new cognitive frames).

In this regards, we consider for our research Riding and Cheema's Cognitive Style Analysis (CSA), since it has been used as a very representative theory of cognitive (not learning) style; additionally, the two independent scales of the CSA (Verbal/Imager and Wholist/Analyst) correspond ideally to the structure of hypertext environments. A personalized environment that is supported by an automated mechanism can be altered mainly at the levels of content selection and hypermedia structure; the content is essentially either visual or verbal (or auditory), while the manipulation of links can lead to a more analytic and segmented structure, or to a more holistic and cohesive environment. These are actually the differences in the preferences of individuals that belong to each dimension of the CSA scales (Sadler-Smith & Riding, 1999). Furthermore, the CSA can be mapped on the information space more precisely (the implications are consisted of distinct scales that respond to different aspects of the Web-space) and can be applied on most cognitive informational processing tasks. The CSA implications are quite clear in terms of hypermedia design (visual/verbal content presentation and wholist/analyst pattern of navigation), and is probably one of the most inclusive theories, since it is actually derived from the common axis of a number of previous theories.

### 2.2 Working Memory

One of the predominant theories of working memory (WM) is Baddeley and Hitch's multicomponent model (Baddeley, 1981). According to Baddeley, "the term working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" (Baddeley, 1992). Baddeley also refers to individual differences in the WM (digit) span of the population, thus providing a very good argument for using this construct as a personalization factor. Since WM is considered to be a predictor of academic performance, it would be of high importance to alleviate learning difficulties of learners with low levels of WM.

Primarily, in search of a more coherent approach, the term of working memory (Baddeley, 1981) has also been introduced in our model as a personalization factor. A brief description of the working memory system is that it consists of the central executive that controls the two slave systems (visuo-spatial sketchpad and phonological loop), plus the episodic buffer that provides a temporary interface between the slave systems and the Long Term Memory (Baddeley, 2000). Since web-environments are predominantly visual, we have focused currently on visual working memory span (VWMS) (Loggie et al., 1990).

Each individual has a specific and restricted memory span. Our system takes into account each user's VWMS, altering the amount of simultaneously presented information. The aim is to decrease the possibility of cognitive load in a hypermedia environment (DeStefano & Lefevre, 2007).

The idea of exploring the role of differences in WM in the context of hypertext environments has indeed generated research. DeStefano and LeFevre (DeStefano & Lefevre, 2007) reviewed 38 studies that address mainly the issue of cognitive load in hypertext reading, and WM is often considered as an individual factor of significant importance, even at the level of explaining differences in performance.

Lee and Tedder (Lee & Tedder, 2003) examine the role of WM in different computer texts, and their results show that low WM span learners do not perform equally well in hypertext environments. Also, the term Cognitive Load Theory is often used when referring to guidelines for designing hypermedia applications, related to WM span (Kirschner, 2002).

### 2.3 Design Implications

Consequently, our research interest is whether we could develop a mobile educational platform on which we would be able through experimentation to evaluate and illustrate an instructional approach that in our opinion "translates" the cognitive theories that we have adopted into mobile design implications and henceforth improves interaction.

At the level of eLearning instruction, it should be mentioned that there is no consensus on a concrete set of design guidelines in relation to cognitive/learning styles, which consequently is also the case with adaptive mLearning systems. The working memory span implications, on the other hand, seem to be better elaborated. In any case, Table 1 shows the way we have translated the cognitive factors to actual learning personalization parameters, remaining as consistent as possible to the theories described in the previous section (Riding & Cheema, 1991; Baddeley, 1992).

It is evident that the instructional value of such an approach can be evaluated only empirically, in the absence of grounded theoretical mLearning guidelines.

For a better understanding of the two cognitive dimensions' implications and their relation with the information space, Figure 1 shows the possible learning content transformations / enhancements based on the mapping process that takes place during the adaptation process and the influence of human factors.

| Learner Characteristic | Implication on the educational environment |
|---|---|
| **Imager (cognitive style):** | Images, diagrams and schemes are used, when possible, for the representation of information. Specifically, instead of lengthy verbal descriptions, a schematic approach has been adopted as an equally important mean of instruction. Text is also used, but is reduced by app. 40% in comparison to verbal learners. |
| **Verbal (cognitive style):** | The prominent representation of information is textual, and images are used when required, accompanying and not replacing texts. |
| **Analyst (cognitive style):** | In the analytic condition, learners are free to navigate through the educational environment. They are not guided externally, though they may choose to follow a linear suggested path.<br>They have also access to a separate index of concepts in order to follow an analytic path in accessing information and forming knowledge. The information is extensively interconnected since hypertext is used at a greater extent, and users can access at the same time different parts of the educational content. |
| **Wholist (cognitive style):** | In the wholist condition learners navigate through the environment in an externally guided way, which provides prefixed linkage and descriptions of the sequentially interconnected information. The organization of the distinct parts of the course is strict and outlined in a clear way. Users have access to previously acquired information, but they do not have access to links that lead to information of chapters not visited. Additional guiding information is constantly given. |
| **Intermediate (cognitive style):** | Intermediate users are provided with an environment which combines characteristics of all dimensions of cognitive style, in order to maintain a balance; moreover, they serve as a control group. |
| **Low Working Memory Span:** | Since a large amount of information, especially when presented in the form of hypertext, may impair learners' comprehension, the system presents web-objects in a consecutive way, allowing users to devote more reading time to each resource. Learning objects do not disappear when the next ones are provided; on the contrary, each lesson "unfolds" gradually. |
| **Medium/High Working Memory Span:** | Users with medium and high WMS are treated the same, since we are interested in alleviating difficulties and not boosting efficient learners. |

*Table 1. Implications of Learners' characteristics on the web-educational environment*

According to Figure 1, the cognitive meta-characteristics of a user profile are deterministic (at most 3); Imager or Verbalizer, Analyst or Wholist and Working Memory level (considered only when low), and have a particular impact on specific characteristics of the information space (images, text, information quantity, links – learner control, navigation support). These transformations represent groups of data affected during the mapping process with the selected human factors. The main reason we have selected the latter tags is due to the fact that they represent the primary subsidiaries of a Web-based educational 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.

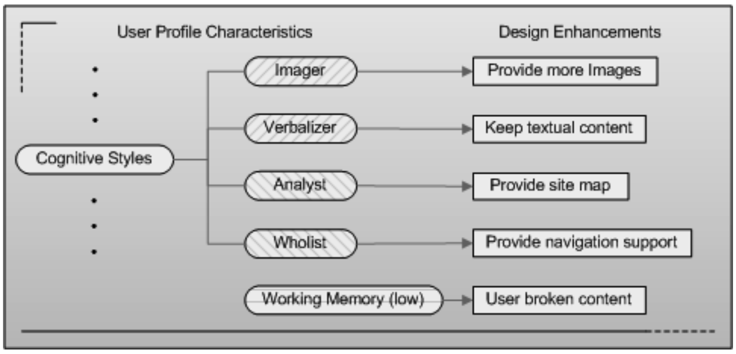


*Figure 1. Web design enhancements / transformations*

A practical example of the aforementioned conceptualization is the following: A user might be identified as, Verbalizer (V)/ Wholist (W) – regarding his/ her Cognitive Style, with low Working Memory Span (weighting 2/7) capacity. The transformations affected, according to the rules created, for this particular instance are the: Images (few images displayed), text (any text could be delivered), provide navigation support, and info quantity (less info quantity).

# 3 THE MAIWEB SYSTEM

Based on the abovementioned considerations an adaptive mobile Web-based environment is overviewed. The current system, mAIWeb[1] (see Figure 2) is a mobile Web application (a Web application that takes into consideration mobile phone constraints) that can be ported on mobile devices. It is composed of three interrelated components[2], each one representing a stand-alone Web-based system briefly presented below:

*Component 1 - Profile Construction:* This is the initial step the user takes for the mAIWeb System's personalization process. At this point users create their comprehensive profiles, which are going to be mapped at a later stage with the personalized content. It has to be mentioned, that the profile construction process is taking place on a desktop computer because of the peculiarity of the online psychometric tests a user has to take (i.e. real-time responses).

Therefore, users provide their "Traditional" and Device / Channel Characteristics and further complete a number of real-time tests (attention and cognitive processing efficiency grabbing psychometric tools) which are preloaded and executed on the client in order to get actual response times of their answers.

More specifically, the psychometric tests that we have used, in order to identify users' perceptual characteristics, include:

- Riding's CSA (Riding, 2001) for the Learning / Cognitive Styles dimension
- A series of real-time measurements for Working Memory, similar to tests developed on the E-prime platform[3].

This component has been positively evaluated (Germanakos et al., 2008; Germanakos et al., 2007b) and will not be further analyzed in this section since this paper focuses on the mobile context of the system.

*Component 2 - Adaptation and Personalization Process (Mapping Rules):* In this section, all the system's components interact with each other in order to create and provide personalized and adapted content to the end user. The author of a 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 mAIWeb server and comprise the main body of the adaptation and personalization procedure of the provider's content, according to the user's comprehensive profile. For experimental

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[1] See http://www4.cs.ucy.ac.cy/adaptiveWeb
[2] The technology used to build each Web system's component is ASP .Net http://asp.net
[3] See http://www.pstnet.com/products/e-prime/

purposes, we have authored an eLearning environment with a predefined content for adaptation and personalization.

Component 3 – Intelligent User's Interface: mAIWeb User Interface is a Web application/framework running on user's device, enabling the navigation over the raw or personalized content of the provider. Based on the user's profile further support will be provided to him / her with the use of navigation support features and learner control attributes adjusted accordingly.

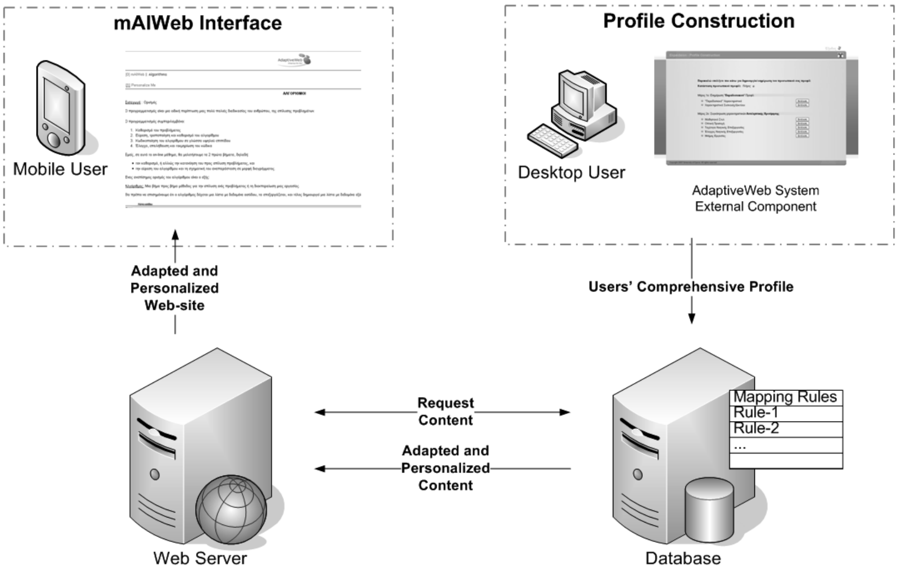


*Figure 2. mAIWeb System Architecture*

## 3.1 Content Authoring

In order to evaluate the system's performance as well as the impact of our model's dimensions into the mobile context, we have designed an experimental setting in the application field of mLearning, by authoring predefined content for adaptation and personalization.

The mLearning environment includes a course named "Introduction to Algorithms" and is a first year mLearning course that aims to provide students with analytic thinking and top-down methodology techniques for further development of constructive solutions to given problems.

In order to provide a better insight of the adaptation process and data flow, we hereafter discuss how the personalized content (the "Introduction to Algorithms" predefined mLearning environment) interacts with the Comprehensive User Profile, using specific mapping rules.

The entire environment's information and provider's content is divided into objects that are stored in the system's database. Each object is defined by special attributes that are used by the mapping algorithms to filter out the object's format (i.e. text or image) that match the user's profile. Hence, the original environment is reconstructed with the appropriate objects accordingly.

For a better understanding we will further present some real examples of the content's adaptation process.

The original content of the Algorithms lesson stored in the database is depicted in Figure 3.

```
<p><u>Introduction</u>: Algorithms/p>
<p>In mathematics, computing, and related subjects, an algorithm is an effective method
for solving a problem using a finite sequence of instructions. Algorithms are used for
calculation, data processing, and many other fields.</p>
<p>Each algorithm is a list of well-defined instructions for completing a task. Starting from
an initial state, the instructions describe a computation that proceeds through a well-
defined series of successive states, eventually terminating in a final ending state. The
transition from one state to the next is not necessarily deterministic; some algorithms,
known as randomized algorithms, incorporate randomness.</p>
<p>Some examples of Algorithms are the following: </p>
!D0! !W1! <br />
!D1!
```

*Figure 3. Example of provider's original content stored in database*

The general layout (template) of the Web-site is stored on the Web server and the content dynamically changes accordingly based on the user's profile and navigation position. All the Web-site's information and content are stored as objects in the database. Special characters are used inside the content, where necessary, in case adaptive objects are needed and change based on the user's typology. As depicted in Figure 3, the special characters !Dx!, where x is a positive number, represents the objects that adapt according the users' cognitive styles. The adaptation based on the user's working memory span is achieved with the special character !Wx!, where x is a positive number.

An example of an object based on the user's cognitive style, stored in the database is depicted in Figure 4.

```
Imager: <img alt="Compare Numbers" src="images/viscomparenumbers.jpg"/>
Verbalizer: <img alt="Compare Numbers" src="images/vercomparenumbers.jpg" />
Intermediate: <img alt="Compare Numbers" src="images/vercomparenumbers.jpg"/>
```

*Figure 4. Example of dynamic objects stored in database*

The objects stored in a database concern the adaptation regarding the Imager/Verbalizer typology. Accordingly, each object has three instances in the database. Each instance (record) corresponds to one of the three types of the Imager/Intermediate/Verbalizer typology. On the other hand, the special characters !Wx!, a different approach is used. In this case no objects are stored in the database. Based on the user's working memory span, the content is adapted based on the position of !Wx!.

### 3.2 Adaptation Process based on users' profiles

After the content is authored and stored in the system's database, the system contains all the necessary information for the content adaptation process. While navigating, the content is retrieved from the database. Before the content is presented, the !Dx! characters are traced and all the objects that correspond to the user's profile are filtered and retrieved from the database. Each !Dx! character is then replaced with the corresponding object (Figure 5). Regarding !Wx! character, in case a user has low working memory span (Figure 6), the content is broken in two sections. All the objects before the !Wx! character are initially shown to the user and then the remaining objects are displayed gradually upon user's demand.

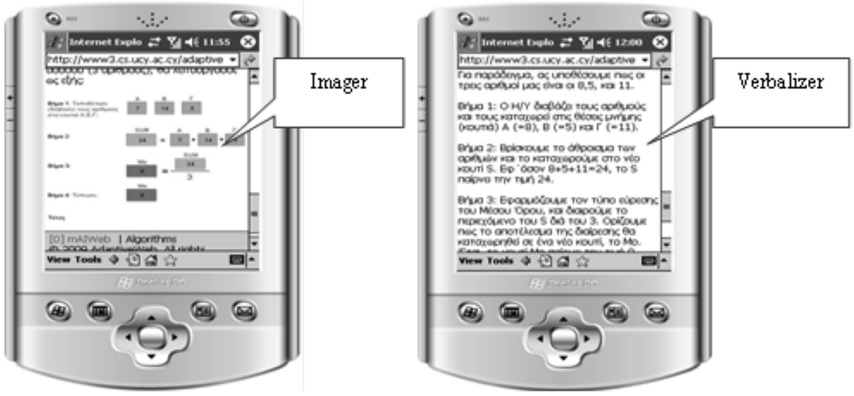


*Figure 5.* *Content Adaptation for an Imager and Verbalizer*

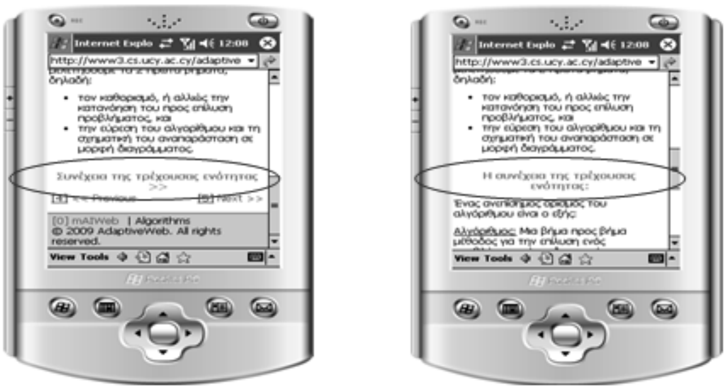

*Figure 6.* *Content Adaptation based on user's low working memory span*

Dynamically changing the original content, the Intelligent User Interface provides users with navigation support features and learner's control. More specifically, a sitemap with each section's summary description as well as a learner control is provided. The correlation rules used on the Web server check the current Web-page the user navigates and provides the corresponding navigation support and learner control based on the Wholist/Analyst cognitive factor.

Based on theory (Sadler-Smith & Riding, 1999), the navigation and learner control support provided to a "Wholist" (Figure 7) are more restricted and specifically provided for guidance. On contrary, in the "Analyst" condition (Figure 8), a linkable sitemap of the whole mLearning lesson is provided, allowing unrestricted navigation and organization of the learning process.

*Figure 7.* *Content adaptation based on Wholist*

The learner control shows him/her only the current chapter's pages (s)he learns and lets him / her navigate only to the next and the previous visited pages. As mentioned before, the Wholist user needs more guidance than the Analyst user.

*Figure 8. Content Adaptation based on Analyst*

# 4 EVALUATION

In order to validate the abovementioned approach in designing a mLearning application, an empirical evaluation was conducted with the participation of university students. The aim of this experimental procedure was to elucidate whether personalization on cognitive factors may promote more efficient learning in the context of mobile devices, since such a positive effect was found in previous experiments on desktop applications (Tsianos et al., 2009).

## 4.1 Method

The design of the single experiment of the empirical evaluation was between-participants. The number of participants was 49, with a mean age of 22.4; they were all students from the University of Cyprus, 60% female and 40% male (participation in the experiment was voluntary). The procedure was as follows: the individuals were initially asked to take the online profiling tests (cognitive style and VWMS) on a desktop computer; thereupon, they navigated with the use of HP iPAQ mobile devices in an online introductory course on computer science and algorithms (a subject on which they had no previous experience). As soon as they had completed the course, they were asked to take an exam, on a desktop computer, on the subject they had just been taught; the score on this exam was the dependent variable indicating learning performance.

Half of the participants were taught within a matched, as it concerns their cognitive style and VWMS, environment; the other half received a mismatched environment. The characteristics of each distinct aspect of the environment that was correspondingly altered are described in section 4.3.

More specifically, by the term matched we refer to the condition in which the presentation and structure of the environment is consistent to each individuals' style preference and VWMS; on the contrary, in the mismatched condition the attributes of the environment do not coincide with individuals' preferences and abilities, and thus are the opposite.

The purpose of this approach was to examine at a first level whether there is possibly to positively affect learners performance; if personalization on style and visual working memory is of any significance, then learners in the matched condition would outperform those in the mismatched. It should finally be noted that learners were also grouped with regards to their VWMS, since the matching condition is reversed for the case of medium and high working memory learners (full content instead of segmented).

### 4.2 Results

A one-way analysis of variance on the data has shown that there are differences in the learning performance between the different user groups: $F(5,43)=2.803, p=0.028$. However, it is evident from the table of means that only learners with low VWMS were actually benefited in the matched/personalized condition (see table 2).

| Condition | N | Mean Score | Standard Deviation |
|---|---|---|---|
| Low VWMS Matched | 6 | 70,67 | 16,990 |
| Low VWMS Mismatched | 6 | 51,00 | 16,852 |
| Medium VWMS Matched | 11 | 79,82 | 17,730 |
| Medium VWMS Mismatched | 7 | 80,14 | 14,938 |
| High VWMS Matched | 8 | 79,75 | 11,260 |
| High VWMS Mismatched | 11 | 78,36 | 22,357 |
| Total | 49 | 74,88 | 19,119 |

*Table 2. Mean scores in each condition*

Correspondingly, table 3 presents the statistical significant score differences between all learner groups (LSD post-hoc analysis of variance).

| (I) Condition | (J) Condition | Mean Difference (I-J) | Sig. |
|---|---|---|---|
| Low VMWS Matched | Low VMWS Mismatched | 19,667* | **,050** |
| Low VMWS Mismatched | Medium VWMS Matched | -28,818* | **,002** |
| | Medium VWMS Mismatched | -29,143* | **,005** |
| | High VWMS Matched | -28,750* | **,004** |
| | High VWMS Mismatched | -27,364* | **,004** |

*Table 3. Post hoc analysis of variance between learner groups.*

Therefore, according to these initial findings, it seems that VWMS is a catalytic factor in the learning performance of mobile users in this experiment, since:

- the differences in performance are highly related to differences in VWMS, and
- the corresponding personalization techniques were proven effective only on the low VWMS group of learners.

On the other hand, these findings seem to undermine the role of cognitive style, though it is not possible to directly distinguish the effect of each separate factor.

# 5 DISCUSSION

This paper explored how to improve learning process by adapting course content presentation to student cognitive styles in mobile environments. A framework has been developed to comprehensively model student's cognitive styles and working memory span and present the appropriate subject matter, including the content, format, media type, and so on, to suit individual student.

According to the empirical data, visual working memory was found to have a significant impact on learners' performance, while mismatching cognitive style did not seem to have an adverse effect. The small sample size of the experiment and the undistinguishable effect of each personalization technique do not allow robust explanations; nevertheless, the following interpretations may be suggested:

1. VWMS is a predictor of performance; still, it is possible to increase the performance of learners with low VWMS by providing lesser amounts of content. As it concerns learners with medium or high levels of VWMS, the amount of information does not have an impact on their performance, since in both conditions (full or segmented content) they perform exactly the same.
2. Cognitive style is not related to learning performance in mobile devices, since mismatching the instructional method to learners' style preferences does not adversely affect them. However, matching/mismatching style could perhaps have had an effect only on users with low VWMS, though the plausibility of this explanation is rather low.

Considering the abovementioned limitations and shortcomings of the study, further testing on various types of mLearning environments is required in order to establish a rigid connection between human factors and information processing in mLearning hypertext / hypermedia environments.

At another level, our future work will also include the integration of emotional processing parameters, with the use of sensors and real-time monitoring of emotional arousal (Galvanic Skin Response and Heart Rate).

Finally, at a technical level, we will extend our 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 hypertext/hypermedia content based on the comprehensive user profile. The final system will provide a complete adaptation and personalization Web-based and mobile solution to the users satisfying their individual needs and preferences.

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