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Usability and Effectiveness Evaluation of Adaptivity in E-Learning Systems

Mohammad Alshammari
School of Computer Science
University of Birmingham
Birmingham, B15 2TT, UK
m.t.m.alshammari@cs.bham.ac.uk

Rachid Anane
Faculty of Engineering and Computing
Coventry University
Coventry, CV1 5FB, UK
r.anane@coventry.ac.uk

Robert J. Hendley
School of Computer Science
University of Birmingham
Birmingham, B15 2TT, UK
r.j.hendley@cs.bham.ac.uk

Abstract
Designing effective and usable adaptive e-learning systems represents a challenge because of the complexity which arises when meeting the needs of learners. This is compounded by the lack of well-designed experimental evaluations of adaptive e-learning systems in general, and of their usability and effectiveness in particular. This paper offers an experimental evaluation of the effect of adaptation, taking into account both the perceived usability level and learning effectiveness. A controlled experiment was conducted with 75 participants and produced significant results. They indicate that an adaptive version has a significantly higher level of perceived usability and of learning effectiveness than a non-adaptive version.

Author Keywords
Usability; Effectiveness; Adaptivity; Personalization; Learner-system Interaction; E-learning; Experimentation

Introduction
As a means of enhancing learner-system interaction, instructional material can be adapted to the learner's needs by, for instance, providing personalized learning paths, changing the interface layout or generating relevant material links [1,13]. However, designing effective adaptive systems is seen as a challenging task [18]. Adaptive systems may, for instance, violate standard usability principles such as consistency and learner controllability [18,19].

When a system is not sufficiently usable, learners may become frustrated and focus on the e-learning system rather than on the learning content [8]. An e-learning system can be usable in terms of its usage but not in terms of the underlying pedagogical perspective and vice versa. This issue may therefore lead to less effective and less efficient learner-system interaction. Both usability and learning effectiveness are important issues that should be taken into account when designing and evaluating adaptive e-learning systems (AESs) [10,19]. This points to a better understanding of where adaptivity in e-learning systems is useful and where it is harmful [8].

Many AESs have been designed and implemented. However, many suffer from a lack of useful experimental evaluation [1]. More particularly, usability and learning effectiveness evaluations are often not considered as key criteria in the iterative design process of these systems. Zaharias argues that "very little has been done to critically examine the usability of e-learning applications" [26].

This paper provides an initial experimental evaluation on the effect of adaptation in learning by testing the AdaptLearn system [2,6] against a non-adaptive version of the same system. The main aim is to determine whether adaptivity influences perceived usability and enhances learning given the fact that both systems have the same interface layout.

Background

This section presents a brief outline of learner characteristics such as learning style and learner knowledge. It also covers the concept of adaptivity in e-learning systems.

Learner Characteristics

Learners may differ in their characteristics such as goals, knowledge, skills and learning style, motivation and emotion [15]. These characteristics can be classified into cognitive (knowledge level, intellectual abilities and skills), conative (wants, intentions, goals and learning style) and affective (learner's emotions and motivation) categories [23]. Matching these characteristics is essential to supporting learner-system interaction in e-learning systems.

Learning style and knowledge level have often been considered as the most important learner characteristics to be integrated in AESs [13]. Learning style characterizes the way in which a learner obtains or perceives information in a learning environment for meaningful information connection and retention in memory [20]. Learner knowledge refers to the extent to which a learner understands, applies and recalls specific information related to a particular topic.

Adaptivity in E-Learning Systems

Adaptivity in the context of learner-system interaction is defined as the process of tailoring the presentation of learning material and its sequencing to meet the learner's requirements [13]. For example, instructional strategies can be adapted to meet the learning styles and preferences of learners. Systems that adapt according to different user characteristics such as preferences and skills are typically called adaptive systems or user-adaptive systems [5]. User-adaptive systems have been defined as "the technological component of joint human-machine systems that can change their behavior to meet the changing needs of their users, often without explicit instructions from their users" [16].

Brusilovsky [14] argues that adaptivity in e-learning systems is very important in order to meet the learner's characteristics such as knowledge level and learning style so that an AES can provide the learner with relevant learning materials and to facilitate navigation between them. AESs are an improvement to the dominant 'one size fits all' approach to the development of e-learning systems. A system may highlight appropriate information, recommend what that learner studies or construct personalized learning paths [13].

Adaptivity Approach

An AES, called AdaptLearn, was designed based on learning style and learner knowledge [2,6,7]. A screenshot of AdaptLearn is provided in Figure 1 displaying a recommended sequence of learning lessons to be studied by the learner, and presenting learning content related to a specific lesson. AdaptLearn is used in this work to investigate the effect of adaptation in learning.

AdaptLearn offers two main adaptive techniques: personalized learning paths and adaptive guidance. Personalized learning paths are generated for individual learners. These paths provide links to learning material in a customized order, hide links to material which is not appropriate to an individual learner or generate links to more relevant material as needed. The ordering, generation or removal of links are designed to meet learner needs in order to enhance learning and to facilitate the interaction with the system [14]. Although these adaptive techniques may violate some usability standards such as consistency and learnability [19], they still have a significant potential to enhance learning and learner satisfaction when appropriately incorporated in AESs [8]. The provision and recommendations of learning material may help learners to accomplish their learning tasks successfully and to support learner-system interaction [14].

The other technique, adaptive guidance aims to direct learners and offer recommendations and feedback as learners progress through their learning tasks. For example, when constructing or modifying a learning path, the system provides recommendations by highlighting which items to study and in which order. In addition, feedback on learning progress and motivational award messages are also provided.

Evaluation Methodology

A between-subjects experimental design, in which each participant experiences only one condition, was used in the experiment; it is considered more appropriate than a within-subjects design because it avoids the problems of carryover and learning effect from one condition or factor to another; these are usually associated with a within-subjects design, in which each participant experiences more than one condition [25].

Hypotheses and Variables

Two hypotheses are put forward for this research:

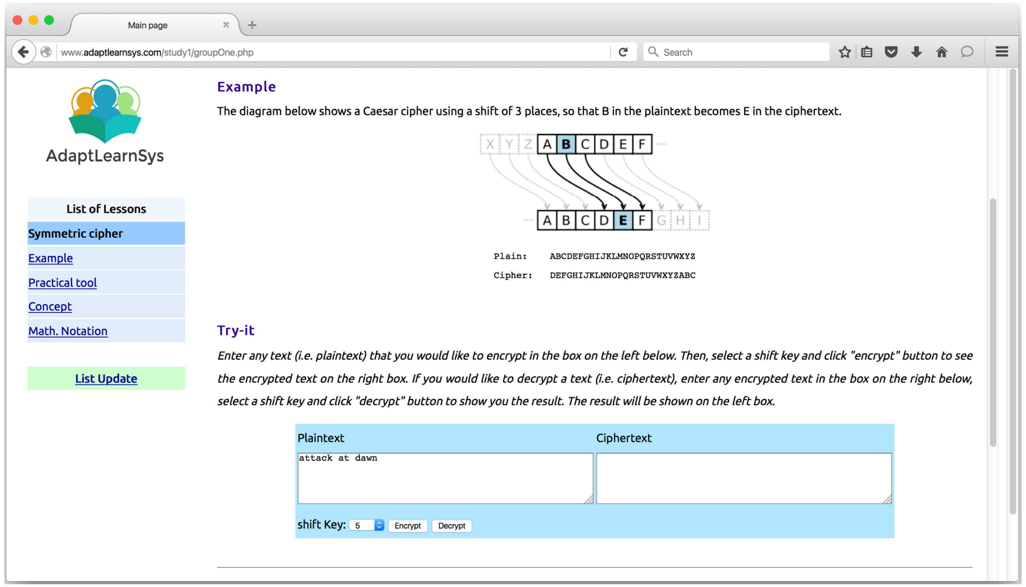

Figure 1: A screenshot of the AdaptLearn interface.

H1. An adaptive e-learning system based on learning style and knowledge level yields significantly higher levels of perceived usability than a non-adaptive e-learning system.

H2. An adaptive e-learning system based on learning style and knowledge level is significantly more effective than a non-adaptive e-learning system.

Two experimental conditions were proposed, an adaptive condition and a non-adaptive condition. In the former, participants interacted with the AdaptLearn system. In the non-adaptive condition, participants interacted with the same system but without the feature of adaptivity. The perceived level of usability and learning effectiveness are the main dependent variables measured in the experiment.

Measurement Tools

A reliable and validated instrument called the Index of Learning Style (ILS) questionnaire was used to identifying the learning style of learners [17].

The perceived level of usability is measured by the system usability scale (SUS) questionnaire [11], a quick, reliable and widely used test of system usability in both academia and industry [24]. SUS has 10 questions, each offering five responses with anchors ranging from “strongly disagree” to “strongly agree”.

Learning effectiveness is measured using a pre-test and a post-test. Each test involves 22 multiple-choice questions. Each question in the tests has five options, with the fifth option being "I do not know". Three domain experts took part in checking the validity of the learning content and the pre-test and post-test.

Procedure

The experiment involved eight sessions of about 85–110 minutes. Participants were welcomed and informed of the experimental procedure. They were asked to access the system through an Internet browser and completed a demographic data form and the ILS questionnaire using the system. Then, the system randomly assigned participants to the adaptive or non-adaptive group and directed them to complete a pre-test. The next step involved the study by participants of learning material on computer security, as the application domain of the system [3]. When each learning lesson is completed, a post-test was provided by the system to learners, so that the scores of these tests could be used to measure the learning effectiveness at the end of the interaction with the system. At the very end of the learning session the participants completed the SUS questionnaire.

Results

The experiment was conducted with 75 participants, 43 males (57.3%) and 32 females (42.7%). The adaptive group involved 39 participants whereas the non-adaptive group had 36 participants. The participants were undergraduate students in a computer science degree program. The mean age of the participants was 22.21 (*SD*=3.13), the maximum age was 36 and the minimum age was 19.

Usability

Hypothesis H1, which concerns perceived usability level, was tested. The usability scores for the adaptive system (*Mean*=79.46, *SD*=13.14) and the non-adaptive version (*Mean*=71, *SD*=13.67) should both be regarded as acceptable [2], as the average score of each system is larger than 70 [9]. This may imply that both systems are useful and valuable in learning and the learners found them easy to use.

In this experiment, the two versions (adaptive and non-adaptive) were also compared in order to gain a deeper insight into their usability and to establish whether the provision of adaptivity has any significant impact on usability. As there was homogeneity of variance between the study groups as assessed by Levene's test for equality of variances, F=0.07, p=0.79 and as data was normally distributed, an independent sample t-test was conducted to compare the two conditions by using an alpha level of 0.01. It was found that there was a statistically significant difference between the general usability score of the two versions, $t(73)=2.73$, $p<0.01$, $d=0.63$ [2]. H1 is therefore confirmed; it can be inferred that the adaptive e-learning system based on learning style and knowledge level yields significantly higher levels of perceived usability than a non-adaptive e-learning system.

Learning Effectiveness

It was found that the participants who used the adaptive version had higher learning effectiveness scores (*Mean*=86, *SD*=17.20) than participants who used the non-adaptive version (*Mean*=65.03, *SD*=19.85). Here, effectiveness is defined as the learning gain (the difference between the post-test and pre-test).

As there was homogeneity of variance between the study groups as assessed by Levene's test for equality of variances, $F=1.37$, $p=0.24$ and as the data was normally distributed, an independent sample *t*-test was also run. There was a statistically significant difference between learning effectiveness scores of the adaptive version and the non-adaptive version with a large effect size, $t(73)=4.90$, $p<0.001$, $d=1.13$. H2 is therefore confirmed; it can be concluded that the adaptive e-learning system based on learning style and knowledge level is significantly more effective than a non-adaptive e-learning system.

Discussion

This paper is concerned with the experimental evaluation of adaptivity in terms of learning effectiveness and perceived level of usability. This involved a controlled experiment set in a realistic learning environment with a number of participants. This conforms to a large extent to the approach which is advocated as appropriate in the evaluation of AESs [1,12]. This research contrasts with some of the related work where the experiments were limited in scope, and where the size of the sample was very small [1,12,22]. More importantly, this is one of the few studies which considers a combination of usability and learning effectiveness of adaptivity. This experiment provides more evidence and offers results on the perceived usability level and learning effectiveness and on the importance of adaptivity in e-learning systems to enhance learner-system interaction.

Although the adaptive system and the non-adaptive system used in the experiment displayed the same interface layout, significant results related to learning effectiveness and the perceived usability level of the adaptive version were generated; adaptivity in e-learning systems enhances both the perceived level of general usability and learning. The high level of perceived usability may lead to learners who are more satisfied, engaged and more motivated to use the AES [4,8,26]. It may be the case that a highly usable AES may improve learning and help learners to focus mainly on their learning tasks rather than system functionality [21].

This experimental evaluation is useful because it sheds some light on the potential benefits of adaptivity. Adaptivity may influence learners to believe that the system would support them dynamically in accordance with their knowledge and preferences. Learners may also find that an adaptive system which provides personalized feedback and recommendations based on their interaction with the system is easier to use. The recommendations of the adaptive system may also heighten their intellectual curiosity and improve satisfaction and engagement. It may be the case that once learners gain a deeper appreciation of the adaptive system, they may find it more useful. In contrast, learners may find the non-adaptive system rigid and unresponsive to their needs; they may thus be less likely to use the non-adaptive version as a tool for learning.

The experimental evaluation was based on a short-term study, and although the sample was adequate it was not very large. In addition, few learning resources were incorporated in the system. A long-term evaluation with more participants and with more objective measures of usability is desirable in future experiments.

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