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Assessing the effectiveness of new devices for accessing learning materials: An empirical analysis based on *eye tracking* and learner subjective perception

Ana I. Molina *, Miguel A. Redondo, Carmen Lacave, Manuel Ortega

Departamento de Tecnologías y Sistemas de Información, Escuela Superior de Informática de Ciudad Real, Universidad de Castilla-La Mancha, 13071-Paseo de la Universidad, 4, Ciudad Real, Spain

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A B S T R A C T

Mobile device usage has become part of our daily routine. Our interest is centered on their use in teaching–learning contexts: the so-called *m-learning*. In this work we try to empirically analyze the use of these portable devices for accessing learning materials. To this end, two empirical studies have been conducted with the aim of analyzing the effectiveness of several interaction devices for supporting study tasks. In an initial experiment we compared conventional access, by means of a desktop computer, with the access through *mobile phones*. A replica of this first experiment was conducted to compare these two devices with the use of *tablet* devices. In both experiments we use several sources of information: *subjective perception* of the students, their *profiles*, their *performance* on a study task, as well as the physical evidence provided by an *eye tracker*. The results obtained allowed us to conclude that the use of devices with visualization limitations (such as mobile phones) is not suitable to access and visualize learning materials, due to the fact that they impose an additional cognitive load. The results also indicate positive perception of the use of PCs and *iPads* for studying, although the latter is considered more motivating for learners.

1. Introduction

The use of mobile devices is acquiring a greater presence. They can be used for supporting a wide variety of tasks: access to the Internet, social networks, e-mail, etc. The portability of these new devices provides benefits in multiple domains. Our interest is centered on their use in teaching–learning contexts: the so-called ***mobile learning*** or ***m-learning*** (Hashim, Ahmad, & Ahmad, 2010; Motiwalla, 2007). The main advantage of this new paradigm is the possibility to access learning materials and resources "*anytime and anywhere*" (Quinn, 2001). The benefits of using mobile devices in the classroom have been researched and proved (Churchill & Churchill, 2008; Liaw, Hatala, & Huang, 2010; Uzunboylu, Cavus, & Ercag, 2009). *Smartphones* and *tablets* are ultra portable, making them easier to carry. Students can download apps to study, tweet questions, answer polls or look up information during class, obtaining all these services instantaneously. Mobile devices are familiar to students. The use of these devices does not require technological training, does not intimidate users, and remains unobtrusive in classrooms (Nyiri, 2003). These features have the potential to attract more and more learners, at least some of whom might be more motivated by lessons if these new devices were incorporated.

However, the use of these interaction devices also presents a series of disadvantages and drawbacks, mainly related to their visualization limitations (Findlater & McGrenere, 2008; Vogel, Kennedy, Kuan, Kwok, & Lai, 2007). Thus, some of these devices are not suitable to support certain tasks as, for example, the editing of long documents (Cui & Roto, 2008) or for web searching (Jones, Buchanan, & Thimbleby, 2003), in the case of *smartphones*. Also, some studies have proved that these small devices make reading more difficult and slower (Dillon, Richardson, & McKnight, 1990; Findlater & McGrenere, 2008). In conclusion, it is clear that people use these small devices differently from how they use desktop computers, and for supporting only certain tasks.

An important question to answer in this new learning scenario is whether these small devices indeed provide an equivalent experience to more traditional full-size displays (e.g., displays on desktop computers). In this work we intend to empirically answer this research question. In this article we describe two experiments in which we evaluate the access to learning materials using different interaction devices. In this work we compare access using three types of devices: desktop computers (PCs), mobile phones and *tablet* devices. In this empirical study we consider several sources of

* Corresponding author. Tel.: +34 926295300; fax: +34 926295354.
E-mail addresses: AnaIsabel.Molina@uclm.es (A.I. Molina), Miguel.Redondo@uclm.es (M.A. Redondo), Carmen.Lacave@uclm.es (C. Lacave), Manuel.Ortega@uclm.es (M. Ortega).

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information to evaluate the learning experience: the *subjective perception of students*, *learning efficiency* (based on *time* spent on studying the materials and task *performance*) and some evidence, of physical nature, provided by an *eye tracker* device (Nielsen & Pernice, 2010). The concept of ***eye tracking*** refers to a set of technologies which monitor and record the way a person looks at a particular scene or image, and specifically in what areas they fixed their attention, for how long and in the order in which he/she visually explores the material provided. The *eye tracking* technique has been applied in various disciplines and areas of study: marketing, advertising, evaluation of user interfaces (including web pages) (Nielsen & Pernice, 2010; Poole & Linden, 2004). Recently, several authors have proposed the use of this technique to provide new empirical evidences in the study of the effectiveness of educational materials and resources (Hyöna, 2010; Mayer, 2010; Ozcelik, Arslan-Ari, & Cagiltay, 2010; She & Chen, 2009; Tai, Loehrb, & Brighamc, 2006; Tsai, Hou, Lai, Liu, & Yang, 2012; van Gog & Scheiter, 2010). We believe that there is great potential in using this new source of information (of physical nature) for assessing learning technologies. Using all the aforementioned sources of information together we can analyze the learning experiences more completely. We can complement the data provided by more subjective sources of information (for example, the learner subjective perception collected by satisfaction questionnaires) and contrast them with a more objective source of information (as that which was provided by an *eye tracking* device).

This article is structured in the following sections. In the next section we present the problem derived from the use of mobile devices to access learning materials. Section 3 describes two empirical studies performed to analyze and compare the use of several interaction devices (desktop computers, mobile phones and *tablets*) to access learning materials. In this section we also briefly review the main theories and frameworks to evaluate learning resources, including the use of *eye tracking* techniques. Finally, in Section 4 the conclusions extracted from this work and possible future lines of research are presented.

2. Problem: Access to learning materials using mobile devices

From its origins, the paradigm of *m-learning* is increasingly attracting the interest not only to educators and researchers but also to companies developing learning systems and, in general, to anyone involved in the publication of educational materials. However, regardless of the interaction device used to support teaching and learning tasks, there are certain ***design principles*** or recommendations (*guidelines*) which should be taken into account when using educational materials and resources that prove to be effective and of high quality. In this regard we highlight the contributions made by Mayer, who proposes a set of design principles from the perspective of *cognitive theory* (Moreno & Mayer, 2000). These principles are: modality, contiguity, multimedia, personalization, coherence, redundancy, pre-training, signaling and pacing (Mayer & Moreno, 2004). For example, the *multimedia principle* states that better transfer occurs from animation/pictures and narration/words than from words alone. Or the *pacing principle* states that better transfer occurs when the pace of presentation is controlled by the learner, rather than by the program. Other authors, as Sorden (2005) proposes several instructional design techniques based on *Cognitive Load Theory*. These instructional principles are identified as the goal-free effect, worked example effect, completion problem effect, split-attention effect, modality effect, redundancy effect, and the variability effect. Thus, the *modality effect* asserts that effective working memory capacity can be increased by using auditory and visual working memory together rather than using one or the other alone. The *split-attention effect* states that instruction should not be designed in such a way that would cause the learner to have to divide attention between two tasks, such as searching for information to solve a problem or reading a manual while trying to practice a software application on a computer. These design recommendations and frameworks like Mayer's Cognitive Theory of Multimedia Learning provide empirical guidelines that may help us design and use learning resources and technologies more effectively.

Teachers are not usually familiar with these recommendations, and they propose the use of new resources or interaction devices without checking whether they comply with such principles and, therefore, if they benefit or, on the contrary, interfere in the learning process. Such is the case of the use of mobile devices, which have certain drawbacks, mainly derived from the physical limitations imposed by the device itself. Thus, the limited *size* of the display dedicated to visualization force users to split the content onto different screens (Findlater & McGrenere, 2008). This involves breaching two design principles proposed by Mayer: the ***spatial** and **temporal contiguity principles*** (Ginns, 2006). These principles state that "*learning is more effective when related content (e.g., graphics and associated explanatory text) are presented simultaneously, both temporally and spatially*". *Temporal contiguity* means that corresponding words and pictures should be presented at the same time, while *spatial contiguity* means that corresponding words and pictures should be presented near rather than far from each other on a page or screen. In other words, this principle states: "*don't place a visual image on one page or frame, and then discuss it on a preceding or following page/frame without continuing to show the visual image*". However, the use of interaction devices (as *smartphones* or *tablets*) to access learning content requires, in many cases, splitting the information to display onto several screens or pages, violating this principle.

Other problems, related with the use of these new devices, arise from the *interactions* necessary to visualize learning materials. The student must *navigate* between different screens to display all related information (Morrison & Duncan, 1988), or *zoom into* more clearly visualize the content (Sanchez & Goolsbee, 2010). The use of *scroll* is also necessary in many cases, which adversely affects the understanding and assimilation of materials displayed (Sanchez & Wiley, 2009). We denote the time spent on these interactions as "*not useful*" time because it is time in which the student does not devote to studying and understanding the content displayed.

All these aforementioned issues can explain the reasons why some students are dissatisfied with certain experiences framed within the *m-learning* paradigm. It is important for us to try to understand these reasons. To this end, we have conducted two empirical studies, which we will proceed to explain in the following section.

3. Empirical studies

In this section we describe the details of two empirical studies performed by the CHICO (*Computer–Human Interaction and Collaboration*) research group of the University of Castilla-La Mancha (UCLM), in Spain. In both experiments we analyze and compare the use of several interaction devices (desktop computers, mobile phones and *tablets*), to access learning materials. According to Liaw, Huang and Chen (Liaw, Huang, & Chen, 2007) there are four elements to include and therefore must be considered in *e-learning* systems: the *characteristics of the learning environment*, *satisfaction* with their environment, their own *learning activities* and *characteristics of the student*. With this in mind, in this experiment we considered multiple entries of information that allow us to consider these four aspects.