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Reducing the spatial distance between printed and online information sources by means of mobile technology enhances learning: Using 2D barcodes

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ABSTRACT

Online information sources, such as pictures and animations on web pages are frequently used for complementing printed course material in educational contexts. The concurrent use of online and printed information sources by students, however, requires going back and forth between physically separated course material, such as a course book and a computer screen, thus leading to suboptimal learning outcomes. Compatible with the principles identified by the recent theoretical frameworks for multimedia learning, mobile technology provides learners with the opportunity to bring online and printed course material close together. Mobile phones make online information available within a small desktop space, in close proximity to printed course material. The challenges that are relevant to text input methods can be overcome by the 2D barcode technology. This study investigates the use of camera-equipped mobile phone and 2D barcode technology as an alternative to the use of computer screen for complementing printed course material. The results of the experimental investigation suggest that, by facilitating the access to online information sources by 2D barcode tags on course books, mobile phones have the potential to enhance learning.

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1. Introduction

Mark, a freshman at the Department of Computer Science Education, goes to the library to study for the final exam of the Computer Networks course. Using his course book, he starts studying the DNS (Domain Name System) chapter—a part of the course curriculum. He quickly grasps the basic functions of DNS: it is used for converting domain names, such as website addresses to IP addresses; this is how computers communicate on the Internet. Then he comes to the subsection *How DNS Works*. After reading the introductory sentences, he gets into trouble in understanding the underlying mechanisms of the DNS system, because he finds that the verbal descriptions provided in the book are not quite understandable for him. Fortunately, the authors of the book, who were also experienced educators, were concerned with this fact and they had already prepared a website which presents an animation of how DNS works. Mark decides to see the animation on the web page. He opens his notebook, connects to the web page and starts the animation. A snapshot of the animation is given in Fig. 1.

Following the instructions in the book, Mark plays the animation step by step by clicking the *proceed* button, thus going back and forth between the book and the computer screen. After studying for a while, however, he finds out that going back and forth between the book and the screen is exhausting because he has to split his attention between the two physically separated information sources.

The learning situation that is exemplified by this scenario is often referred to as *multimedia learning* (Mayer, 2009). The term *multimedia* is used for written or spoken language accompanied by static or animated depictive illustrations. The research in multimedia learning shows that, in its most basic form, humans learn better from picture and text than they learn from text alone. In other words, multimedia learning usually leads to better learning outcomes compared to learning from text. The facilitating role of multimedia in learning, however, can be achieved as long as a set of principles is followed in the design of the instructional material. For instance, Mayer's (2009) principles of multimedia design summarize the principles attained within the framework of the cognitive theory of multimedia learning conducted in the last two decades by Mayer and colleagues. In particular, relevant to the present study is the emphasis on the importance of integrating

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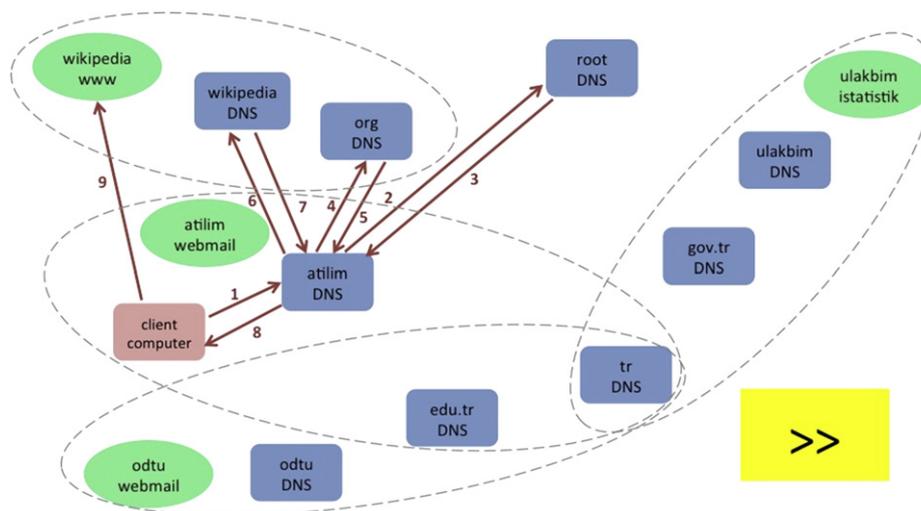


Fig. 1. A snapshot of the *How DNS Works* animation. The animation shows how a client computer gains access to a target computer: the client computer sends a DNS query to a local DNS server and the local server gets the necessary information by communication other DNS servers communicate in a hierarchical manner. The client computer and the DNS servers are represented by curved rectangles and the target computers are represented by ellipses. Arrows are used to represent the transaction of information between the servers and the client computer. The numbers on the arrows show the order of information transaction. The animation proceeds step by step when the user presses the *proceed* button (which is shown by >> marks) at the bottom right of the screen. In each step, an arrow is appended to the animation to represent how information transaction proceeds.

physically and temporally disparate sources of information (Ayres & Sweller, 2005; Mayer, 2009). In the scenario presented above, Mark's *going back and forth between the book and the computer screen* is such an instance of learning with physically disparate sources of information. In Mark's case, those information sources are the course book and the computer screen. The relevant research in the domain of multimedia learning is presented in more detail in Section 2. We introduce how Jane, a classmate of Mark, studies the same topic below.

Reading the introductory sentences from the course book, Jane also quickly grasps the basic functions of DNS. Then she comes to the subsection *How DNS Works*, and she faces the similar difficulties that Mark faces: she experiences difficulty in understanding the topic by reading the verbal descriptions provided in the book. She decides to play the animation from the web page. Nevertheless, instead of using her notebook to gain access to the animation, she decides to use her camera-equipped mobile phone because she notes the two-dimensional (2D) barcode tag on the book. She knows that 2D barcode tags can be used to connect to the web pages by mobile devices. By starting the appropriate scanner and encoder software in her phone, she scans the tag on the book and starts the animation (Fig. 2).

Jane places her mobile phone near the book and by reading the verbal instructions, she follows the animation step by step by using the touch-sensitive screen of the phone. As Mark does, she goes back and forth between the book and the screen to study the printed and online material concurrently. As a result of the close spatial distance between the book and the mobile phone screen, however, Jane experiences less difficulty in her learning how DNS works compared to Mark. Consequently, Jane achieves better learning outcomes... or, does she? This is the major research question of the present study in operational terms.

The learning situation that is exemplified by Jane's studying of the topic is usually called *mobile learning*, *m-learning* (e.g., Kukulska-Hulme & Traxler, 2005; Peng, Su, Chou, & Tsai, 2009; Sharples, Corlett, & Westmancott, 2002) or *ubiquitous learning* (Hwang & Chang, 2011; Hwang, Shih, & Chu, 2010). For educators, the attractiveness of mobile learning is due to the capability of mobile devices to make information available independent of location and time. The facilitating aspects of mobile learning, however, are limited by a set of constraints such as the limitations introduced by the small size of mobile device screens and the difficulties in text input by mobile device keyboards. On the other hand, the research conducted in mobile learning has not reached at a stable state recently; it is even "in its infancy and in an embryonic stage" (Motiwalla, 2007, p. 582). In consequence, specific research on the potential use of mobile devices and wireless communication technologies, such as the use of 2D barcode technologies in education, has been scarce. Mobile learning research, the 2D barcode technologies and the use of 2D barcode technologies in education are introduced in more detail in Section 3 and Section 4.

The present study aims at contributing to the research at the intersection between multimedia learning and mobile learning. The basic research question, in terms of the scenario introduced above, is whether Jane achieves better learning outcomes by using her camera-equipped mobile phone and employing the 2D barcode technology to gain access to the animation, compared to Mark who uses



Fig. 2. Using the 2D barcode technology in a course book. The first step is to scan and encode the information provided by the tag by using a camera-equipped mobile device and the appropriate tag reader software (left). Once the mobile device scans and encodes the information, it automatically gains access to the web page. In this figure, the device connects to the web page and starts the animation (right).

a computer screen to gain access to the animation. This question is scientifically relevant because the two students are in a multimedia learning situation under different conditions with respect to the spatial distance between the two information sources. Accordingly, the research question in more general terms is whether the reduced spatial distance between the printed information source and the online information source enhances learning. In the present study, this research question was investigated by an experimental study in which two groups of participants represented Mark's and Jane's method of study. The learning outcomes were measured in terms of the answers to a set of posttest questions. In the following sections, the theoretical aspects of the study are introduced. The experimental investigation is reported in Section 5. The last two sections discuss the results and conclude the paper by presenting proposals for future work.

2. Multimedia learning

The term *multimedia learning*, in its most basic form, refers to learning from words and pictures (Mayer, 2009). In a multimedia learning environment, the words may be written or spoken, and the pictures may be static or dynamic. Accordingly, multimedia instructions cover a wide range of instructional material, ranging from a written text accompanied by pictorial illustrations in a textbook to an animation accompanied by spoken language in a web-based learning environment. The most general finding in multimedia learning research is that humans learn better from picture and text than they learn from text because learners are able to construct richer memory representations in a multimedia learning setting (e.g., Ayres & Sweller, 2005; Mayer, 1989; Mayer & Sims, 1994; Plass, Chun, Mayer, & Leutner, 1998; Schnotz & Bannert, 2003, among others). The facilitating role of multimedia learning is also known as the *multimedia effect*. According to Mayer (2005, 2009), when learning from a multimedia instruction, the learner constructs a verbal representation of the text and a nonverbal representation of the pictorial illustration separately. The learner then constructs an integrated representation, which also corresponds to his/her mental model of the instructional material (also see Bodemer & Faust, 2006; Seufert, 2003, for relevant proposals).

The studies in the multimedia learning literature emphasize that the multimedia effect is constrained by a set of factors, as largely identified by the principles that have been developed within the framework of the cognitive theory of multimedia learning (viz., the principles of multimedia design, Mayer, 2009) and the framework of the cognitive load theory (Ayres & Sweller, 2005). In other words, simply presenting pictorial and textual information does not guarantee enhanced learning, especially if the limitations of the human cognitive architecture are not taken into account (Sweller, van Merriënboer, & Paas, 1998). In particular, relevant to the learning situations in which the learner needs to integrate the information contributed by representations in different modalities, such as text and depictive illustrations, the processes that are not directly relevant to learning, such as searching information in a picture after reading the text, cause extraneous cognitive load. Due to the limited storage and processing capacity of memory resources, less cognitive resources become available for learning, thus resulting in suboptimal learning outcomes. Accordingly, extraneous working memory load should be reduced by physically and temporally integrating disparate sources of information (Ayres & Sweller, 2005; Chandler & Sweller, 1991, 1996; Kalyuga, Chandler, & Sweller, 1999; Mayer, 2009; Mayer & Moreno, 1998; Sweller & Chandler, 1994; Sweller et al., 1998). In other words, the spatial distance between information sources has been shown to be an important factor in multimedia learning, and corresponding words and pictures should be presented near rather than far from each other.

The theoretical frameworks developed within the domain of multimedia learning research are particularly relevant to mobile learning contexts. Mobile devices, such as a mobile phone as a typical example of a portable and lightweight mobile device or a personal digital assistant (PDA), have the potential to help learners by physically bringing separate information sources close together. In the scenario presented at the beginning of this paper, we stated that Jane uses her camera-equipped mobile phone to gain access to the animation and she puts her mobile phone *near* the course book. On the other hand, Mark uses a notebook screen to gain access to the animation. Consequently, compared to Jane, Mark is in a multimedia learning situation in which he has to integrate the information contributed by physically separate sources of information. Within the framework of the cognitive load theory and the cognitive theory of multimedia learning, the mobile learning situation is expected to result in better learning outcomes compared to the more conventional learning with computer screen. Before discussing the predictions about learning outcomes within the theoretical frameworks of multimedia learning further, we present the state of the art research in mobile learning, 2D barcode technologies and the use of 2D barcode technologies in education in Section 3 and Section 4.

3. Mobile learning

Having been called *mobile learning* or *m-learning* by some researchers and *ubiquitous learning* by some others, recent findings in this research literature show that digital learning resources, alongside the real-world learning contexts, improve students' learning interest, motivation (Chen, Chang, & Wang, 2008; Chen, Kao, & Sheu, 2003; Liaw, Hatala, & Huang, 2010; Liu, Li, & Carlsson, 2010, among many others) and their learning achievement (Chu, Hwang, & Tsai, 2010; Chu, Hwang, Tsai, & Tseng, 2010; Hwang & Chang, 2011; Hwang, Kuo, Yin, & Chuang, 2010, among many others). Educators show interest in mobile devices due to their potential to provide the learners with spontaneous access to online resources, such as resources accessible via the Internet, and due to their low cost relative to desktop computers and notebooks (Kukulska-Hulme & Traxler, 2005). Another major aspect of mobile technology in education, as stated by Looi et al. (2009), is its affordance for *supporting multiple entry points*: due to the small space occupied in the desktop workspace of the student, mobile devices can be used alongside conventional paper-and-pencil technology without difficulty, thus allowing students to “move seamlessly between the paper-and-pencil technology and the computing technology” (p. 1125), thus facilitating students' creating personalized learning experiences. Researchers also emphasize that mobile learning can complement existing learning styles rather than replacing them (Liaw et al., 2010). Accordingly, certain capabilities of mobile phones have been employed for this purpose. For instance, the Short Message Service (SMS) have been employed for delivery of learning material to students (Levy & Kennedy, 2005; Saran, Seferoglu, & Gagitay, 2009; Thornton & Houser, 2004). From the perspective of the multiplatform learning approach (Goh, 2010), the present study exemplifies the investigation of a dual-platform learning setting, in which the mobile phone (or the computer screen)—as one component of the platform—augments the printed course book rather than replacing it.

Despite its potential for use in educational contexts, mobile technology faces a set of challenges, such as the small screen size and the difficulties that are relevant to text input methods and text editing. The small screen size has been a major challenge in effective use of



Fig. 3. A sample linear barcode tag (left) and two sample 2D barcode tags. The 2D barcode in the middle exemplifies the QR (Quick Response) code and the rightmost barcode exemplifies the High Capacity Color Barcode (HCCB). When used by an appropriate tag reader, the number 1810982232 will be read out of the linear barcode tag and the following website address will be read out of the 2D barcode tags: http://en.wikipedia.org/wiki/High_Capacity_Color_Barcode

mobile devices in general use, such as web-based search (Buchanan et al., 2001; Jones, Buchanan, & Thimbleby, 2003) and in use for educational purposes (Luchini, Quintana, & Soloway, 2004), depending on the context of use and the task of the user (see Churchill & Hedberg, 2008, for design recommendations for learning with handheld devices). Associated with the small screen size, another major challenge in effective use of mobile devices is typing and editing text. For instance, entering a simple URL by using a mobile phone can easily turn out to be a disruptive and tedious task (Metcalf & Rogers, 2010; Smørðal & Gregory, 2005). In response to this challenge optical recognition systems have been developed. The NFC (Near Field Communications)—RFID (Radio Frequency Identification; ECMA, 2004) technologies have been used in educational context such as for the purpose of detecting students' learning behavior and guiding students in real-world learning context augmented by mobile technology (Chu, Hwang, Tsai, & Tseng, 2010). A more appropriate technology that is capable enough to store website addresses is the 2D barcode technology, introduced in the following section.

4. 2D barcode technologies and their use in education

A barcode is the representation of data that can be optically read by specific barcode readers. The most widely used barcode is the *linear barcode*, which is composed of vertical lines of varying thickness. A *2D barcode*, also known as a *matrix code*, is another type of barcode, which has much higher capacity compared to the linear barcode (see Kato & Tan, 2005, 2007, for a classification and benchmarking studies on 2D barcode types).¹ The information encoded in a 2D barcode can be scanned and encoded by mobile phones equipped with built-in cameras and the appropriate software. The encoded information can be URL, text, or series of alphanumeric characters such as a phone number or an SMS. Sample barcodes of different types are presented in Fig. 3.

The High Capacity Color Barcode, developed by Microsoft Research, is one of the 2D barcode types that carry the advantage of high robust and reliable scanning and encoding as well as high data capacity.² 2D barcodes have a wide range of applications in industry, such as identification and certification systems in stock control and product management.

The potential use of 2D barcode technologies in education context has been investigated quite recently (Law & So, 2010; Low & O'Connell, 2006; Metcalf & Rogers, 2010; Ozdemir, 2010). Law and So (2010) reported a recent review of the use of QR code technologies in education, introducing applications that cover a wide range of applications such as the use of 2D barcodes in library catalogs and such printed material as posters and handbooks. In a study reported by Susono and Shimomura (2006), the students used mobile phones and QR codes to send comments and suggestions for improvement to the teacher and to the classmates within the lecture. Fujimura and Doi (2006) and Al-Khalifa (2008) report similar mobile systems that support the communication between the teacher and the students in a classroom setting by means of mobile phones that employ 2D barcode technologies. The study reported by Chaisatien and Akahori (2007) aims at using 2D barcode technologies for supporting communication between students and teachers in a large classroom environment. Liu, Tan, and Chu (2007, 2010) introduced a system for English learning that provides access to online information sources via 2D barcodes (viz., HELLO, Handheld English Language Learning Organization). Bischoff (2007) introduced a text-to-speech interface that employs 2D barcode for generating audio-based learning material from web pages. More recently, Laine, Vinni, Sedano, and Joy (2010) used 2D barcodes to implement context-awareness in the design of a pervasive mobile learning game platform. Chen and Choi (2010) employed 2D barcodes to integrate an online collaborative mapping and knowledge management platform with printed learning materials and textbooks in a classroom setting. These studies reveal the potential of the 2D barcode technologies to support educational settings as a multimedia-access tool (cf., Churchill & Churchill, 2008).

The reported applications that are summarized above mostly conduct usability evaluations of the proposed learning systems. A systematic empirical investigation of the measurement of learning outcomes is, however, lacking. More generally, as stated by Hwang and Chang (2011), the measurement of learning achievement is a challenging issue in mobile learning (also see Cheung & Hew, 2009 for a review of the use of research methodologies in mobile learning). Consequently, the use of 2D barcode technologies in education is one of those novel research domains that await empirical investigation of learning outcomes. The present study contributes to the research literature on mobile learning by measuring the learning outcomes in terms of participants' answers to a set of retention and transfer posttest questions.

The relevant aspect of the 2D barcode technology in the present study is the capability of camera-equipped mobile devices to make it easy to access online information by eliminating text input and by providing a closer spatial proximity between the information sources. In particular, when it is necessary to access online information such as an animation that complements written text in the textbook, the student can use his/her mobile phone instead of his/her computer to gain access to the online information source and he/she can place the mobile

¹ For instance, the maximum data capacity of a QR code, a specific sub-type of 2D barcode developed by Denso Wave Inc. is 7089 characters for numeric- and 4.296 characters for alphanumeric data, and 2953 bytes for binary data.

² <http://research.microsoft.com/en-us/projects/hccb/default.aspx>, retrieved on January 22, 2011.

phone near the book, thus bringing close together the textbook and the screen. The small size of the mobile phone screen, however, may turn out to be a disadvantage, as well. Consequently, it remains to be empirically investigated whether the reduced spatial distance between the printed and online information sources, introduced by the use of mobile technology, enhances learning compared to the more conventional learning situation that is based on the use of a computer screen. The following section introduces the experimental investigation.

5. Method

5.1. Participants

A total of 44 participants (14 females and 30 males) from the Atilim University participated in the experiment for extra course credit after signing the informed consent for the experiment. All the participants were undergraduate students, with an age ranging from 20 to 27 years ($M = 22.43$, $SD = 1.69$). The participants were randomly divided into two groups (each with 7 female and 15 male), corresponding to two experimental conditions, namely the *paper-plus-mobile phone* condition and the *paper-plus-computer* condition.

5.2. Materials

5.2.1. Instructional materials

The instructional materials were composed of a six-page booklet on paper and a set of animations that were shown on screen. The first page of the booklet introduced the basics of the domain name system (DNS). The remaining five pages of the booklet involved step by step verbal descriptions of *how DNS works* for five sample cases. In each sample case, the DNS transactions between a client computer and a set of DNS servers were verbally described on a booklet page. Each sample case was associated with an animation that was shown on the screen. The animations were presented on the screen of a mobile phone in the *paper-plus-mobile phone* condition, whereas the animations were presented on the screen of a notebook computer in the *paper-plus-computer* condition. Five animations were designed in Adobe-Flash for each sample case for this purpose (Fig. 1 shows a snapshot from one of the animations). In addition to the verbal descriptions, the booklet involved a computer icon in the *paper-plus-computer* condition and a 2D barcode tag in the *paper-plus-mobile phone* condition, for each of the five sample cases. Under the computer icon/barcode a figure caption was used (e.g., “Animation 1”) so that the participants associate the verbal descriptions in the booklet with the relevant animation on the screen. The participants in the *paper-plus-mobile phone* condition gained access to the relevant animation by scanning the barcode tag on the booklet with the phone. The participants in the *paper-plus-computer* condition selected the relevant animation from a drop-down list, which was already available on the computer screen (i.e., the participants did not enter a website address). Except for the computer icon and the barcode tag, the same booklet was used for both conditions. All materials were presented in Turkish, the native language of the participants.

The animations were identical in both conditions. Each animation included a labeled illustration of the DNS servers (e.g. root DNS, org DNS, wikipedia DNS, etc.). Following the verbal descriptions in the booklet, the participants used a button in a self-paced fashion to proceed with the next step in the animation. In each step, a moving arrow was displayed that represented the direction of the DNS query (e.g., from local DNS server to the root DNS server) and a number was displayed that represented the order of the DNS transaction. There was no back button on the animations, but the participants were free to play the animations again. The animations included neither sound nor narration.

The materials (the booklet and the animations) were based on the course materials used for a seminar series on computer networks by professional educators at the University. The booklet and the animations were prepared under the supervision of a professional educator and a technical DNS expert. The topic *how DNS works* was selected for the domain of the experiment, because the participants had limited knowledge on this topic. A prior knowledge test was conducted before the experiment, and a retention test, a transfer test, a matching test and a mental effort test were conducted after the experiment for each participant, as presented below.

5.2.2. Prior knowledge test

The prior knowledge test consisted of five statements (e.g. “I know the role of root name server in the domain name system (DNS)”, “I know the difference between authoritative name server and top-level domain name server”), which participants were requested to mark a five-point scale ranging from “very little” (associated with score 1) to “very much” (associated with score 5) to assess prior knowledge of participants about DNS. These self-reported tests are very common in the literature (e.g., De Koning, Tabbers, Rikers, & Paas, 2010; Mayer & Moreno, 1998). The sum of the scores on these five items for each participant formed the prior knowledge test score.

5.2.3. Retention test

The retention test included five open-ended questions to measure to what extent the content was comprehended. Four of these questions asked participants to indicate all DNS queries in order for different cases. An example of such a question is “Specify all DNS queries in order when x.turizm.gov.tr wants to access y.stanford.edu. Assume that the cache is empty”. The cases that were used in the retention test were similar to the ones in the instructional materials so that learners could easily answer these questions if they recalled relevant information from the material. Partial points were given for each correct DNS query stated in the answer of the participant. For instance, if the answer should include 8 DNS queries, participants were given 1/8 point for each correct DNS query. The other question in the retention test was “What is the function of domain name system?”. Participants were given either 0 or 1 point for this question. The sum of the scores on the five items formed the retention test score. In order to determine inter-rater reliability, another rater independently scored the retention tests of 10 participants (5 from the *paper-plus-mobile phone* condition, 5 from the *paper-plus-computer* condition) that were selected randomly. The intra-class correlation coefficient was .94, $p < .001$. This shows that inter-rater agreement between the raters was high for the retention test. In order to eliminate rater bias, the two raters were blind to the experimental conditions.

5.2.4. Transfer test

Participants were asked five open-ended questions in the transfer test to assess to what extent participants applied the learning contents to novel problems that was not directly addressed in the instructional materials. An example of a transfer test is “DNS cache is frequently

cleaned. Even if it is known that pairing of a domain name with an IP address takes up little space in memory, what may be the reason of cleaning the cache in fixed intervals?" Each correct answer on the transfer test was given 1 point. Transfer test score was calculated by summing up received points. The intra-class correlation coefficient, .79, $p < .001$, showed a high inter-rater agreement between raters.

5.2.5. Matching test

In this test, participants were requested to match the given DNS name servers (e.g. root name server, tr name server, gov.tr name server, etc.) on an illustration for a specific case (i.e. a client, compelab_pc1.atilim.edu.tr, wants to access a host, statistics.ulakbim.gov.tr). A similar case was mentioned in the instructional materials. For each correctly matched answer, participants received 1 point. Matching test score was found by summing these points.

5.2.6. Mental effort test

This was a nine-point scale ranging from 1 (very low effort) to 9 (very high effort) indicating subjective ratings of mental effort invested in learning (Paas, 1992).

5.3. Procedure

Each subject was tested individually in a laboratory session that lasted approximately 45 min. First, a demographic questionnaire was administered, followed by the prior knowledge test on DNS. Afterwards, participants underwent a short training phase to familiarize them with the use of the mobile phone or the computer to study the material. After the training phase, subjects were requested to study the instructional materials as long as they wanted. A stopwatch was used to measure the study time of each participant. Participants were also informed that tests would be given to assess their learning after the study phase. In order to examine the effect of spatial contiguity, the instructional material and the computer were placed physically far from each other (i.e. the distance between the centers of the notebook screen and the paper was approximately 45 cm) on the desktop table in the paper-plus-computer condition. On the other hand, participants in the paper-plus-mobile phone condition were requested to place the mobile phone next to the booklet. Based on informal observations of learners in this condition, we noticed that almost all participants preferred to place the phone very close to the booklet during their studying the material. A 3.2-inch touch-sensitive mobile phone was used in the paper-plus-mobile phone condition to gain access to the animation via a 3G (third generation) connection. By using the camera-equipped phone with the appropriate tag reader software, the participants were able to start the animations by scanning the 2D barcode tags on the booklet. Each barcode included encoded information of the website address of an animation.³ In order to minimize the effect of screen size differences between the conditions, a netbook having a relatively small screen size (10.1 inch) was used in the paper-plus-computer condition. The participants were able to play animations by selecting the corresponding animation name (e.g., "Animation 1") from a drop-down list in this condition. After studying the instructional materials, participants took the mental effort, retention, transfer, and matching tests. No time limitation was set to answer these paper-and-pencil tests.

5.4. Results

An independent-samples t -test was run in order to examine whether the participants in the paper-plus-mobile phone condition and the participants in the paper-plus computer condition had different prior knowledge of DNS. The results revealed that no significant difference existed between the paper-plus-mobile phone condition ($M = 11.14$, $SD = 3.54$) and the paper-plus-computer condition ($M = 11.09$, $SD = 4.20$), $t(42) = .40$, $p = .97$, indicating that the participants in both conditions were comparable in terms of background knowledge on the subject matter.

A separate independent-samples t -test was administered to assess the effect of condition on each learning outcome (i.e., retention, transfer, and matching performance). The effect of condition was significant on retention, $t(42) = 2.07$, $p = .045$, indicating that participants who studied the paper-based instructional materials with mobile phone recalled more information than the participants who studied the materials with computer (see Table 1). We found no significant difference in transfer scores between the paper-plus-mobile phone condition and the paper-plus-computer condition, $t(42) = .28$, $p = .78$. There were also no significant matching score difference between the group which used mobile phone to view the animation and the group which used computer to view the animation, $t(42) = 1.39$, $p = .20$. Moreover, the difference in subjective mental effort between the paper-plus-mobile phone condition and the paper-plus-computer condition was not significant, $t(42) = 1.07$, $p = .29$ (see Table 1).

Study duration of one participant in the paper-plus computer condition could not be recorded due to a technical problem. For this reason, the following analyses were conducted with the data collected from the remaining 43 participants. The study duration was found to be longer in the paper-plus-mobile phone condition ($M = 924$ s, $SD = 190$) than the study duration in the paper-plus-computer condition ($M = 764$ s, $SD = 224$), $t(41) = 2.52$, $p = .02$. This result suggests the possibility that superior retention performance of the participants in the paper-plus-mobile phone condition might be as a result of the longer study duration in this condition. To examine this possibility, we conducted a bivariate correlation analysis to test whether there was a correlation between retention scores and study durations of the participants on the instructional material. The results showed that there was no significant correlation between these two variables ($r = -.15$, $p = .34$), suggesting that the difference in the retention test scores between the two conditions was not due to the difference between the study times. In addition, a median split was performed to test whether the participants who studied the instructional material longer would have higher retention test scores. Accordingly, the median split classified the participants who spent a long time or a short

³ We selected the High Capacity Color Barcode (HCCB) developed by Microsoft Inc. for empirical investigation in this study. Accordingly, we used the Microsoft Tag Reader software, which is a free application for mobile phones. On the other hand, we note that a QR code or an alternative type of 2D barcode would equally serve for the purposes aimed at this study, as long as a compatible speed and reliability of scanning and encoding is achieved. A comparison between the QR Code technology and the HCCB technology is beyond the scope of this study.

Table 1
Mean Scores and Standard Deviations for Two Conditions on Retention, Transfer, Matching and Mental Effort Tests.

Condition	Retention		Transfer		Matching		Mental effort	
	M	SD	M	SD	M	SD	M	SD
Paper-plus-computer	1.47	1.29	1.63	1.59	3.36	1.92	4.36	1.40
Paper-plus-mobile phone	2.24	1.18	1.75	1.44	4.32	1.55	4.91	1.95

time to study the materials and a *t*-test was performed with this new grouping (i.e., the study duration as a dichotomous variable). The results suggested that the participants who studied the material for a longer time did not perform better in the retention test than the ones who studied for a shorter time, $t(41) = .40, p = .69$. To examine the possibility that the difference in the retention score between the two conditions may be influenced by the difference in the duration of study, a one-way analysis of covariate (ANCOVA) test was run with the study duration as a covariate. The results showed that, adjusted for differences on the study duration, the effect of condition on retention performance was still significant, $F(1,40) = 8.14, p = .007$. Taken together, these findings suggest that the difference in retention scores between the two experimental conditions was not due to the difference between the duration of study. The following section discusses the experimental findings under the theoretical frameworks aforementioned in the previous sections.

6. Discussion

The major goal of this study was to empirically investigate the learning situation in which the learner has to integrate information contributed by separate information sources, such as printed textbook and screen-based instructional material. In particular, we tested whether bringing physically separate information sources close together by means of using mobile technology enhances learning compared to the more conventional learning with computer screen. According to the cognitive theory of multimedia learning (Mayer, 2009, 2005; Mayer & Moreno, 2002) and the cognitive load theory (Ayres & Sweller, 2005; Sweller et al., 1998, and colleagues), reducing the spatial distance between disparate sources of information reduces extraneous cognitive load, thus leading to an enhanced learning. The results of our experimental study provided supporting evidence for the predictions of the relevant theoretical frameworks in the multimedia learning literature. Consistent with these expectations, the results of our experimental study reveal that the participants in the paper-plus-mobile phone condition had higher retention test scores than the participants in the paper-plus-computer condition. The major difference between the two conditions was the closer spatial distance between the mutually referring verbal and visual information sources (i.e., the textbook and the screen) in the former than the latter. On the other hand, no significant effect in transfer and matching test scores was found between the conditions. Finally, the participants did not find an experimental condition easier or harder than the other one in terms of the mental effort spent to study material. In other words, participants' subjective judgments of mental effort were similar between the two conditions.⁴

We also found a significant difference in the duration of the study between the two conditions: the participants in the paper-plus-mobile phone condition spent more time studying the instructional materials compared to the participants in the paper-plus-computer condition. However, further analysis of the relationship between the retention test scores and the study durations revealed no significant correlation between these two measures. In addition, we examined whether the participants who studied the instructional material for longer durations had higher retention scores in this test. The results revealed that spending more time on the materials did not enhance retention. Finally, the difference between the two conditions remained significant after statistically adjusting for differences in study duration by an ANCOVA test. These analyses suggest that the observed performance difference in the retention test between the two experimental conditions was not an outcome of the difference between the study durations. Greater task involvement and enhanced motivation of learners (Corbalan, Kester, & van Merriënboer, 2008) in the paper-plus-mobile phone condition may account for participants' investment of more time to study the instructional materials compared to the paper-plus-computer condition. In other words, the participants might have been relatively motivated to study with this novel mobile technology (Keller, 1983), thus devoting more time on the instructional materials. Collecting data on participants' motivation for studying the material would reveal a better understanding of these findings in future studies.

Several methods have been proposed to minimize attention split between physically or temporally separate information sources in multimedia learning. Textual information may be physically integrated at appropriate locations on diagrams (Chandler & Sweller, 1996). Spoken rather than written explanations may accompany pictures (e.g. Mayer & Moreno, 1998). Mutually referring information between different representations may be presented in the same color (e.g. Kalyuga et al., 1999; Ozcelik, Karakus, Kursun, & Cagiltay, 2009). Spoken words may be presented simultaneously with corresponding visual materials (e.g. Mayer & Anderson, 1991). Relevant elements of visual materials associated with verbal information may be signaled with appropriate cues (e.g. Ozcelik, Arslan-Ari, & Cagiltay, 2010; Tabbers, Martins & van Merriënboer, 2004). In all these methods, content creators need to alter the learning materials. The current method examined in this study keeps the modifications on the instructional material minimal: a 2D barcode is used instead of the computer icon that refers to the animation on the screen, keeping the text part of the instructional material intact.

Another benefit of using 2D barcode technology with mobile phones is "just-in-time information presentation for accomplishing a task (Kester, Kirschner, van Merriënboer, & Bäumer, 2001). Prior research has shown that learning is enhanced when relevant information is immediately available (Kester, Kirschner, & van Merriënboer, 2004). Mobile phones provide the opportunity with learners to have necessary computing power when needed (Peng et al., 2009). Mobile phones can "extend the mind" by aiding cognitive processes of users (Clark & Chalmers, 1997). In addition to providing spontaneous access to online resources, the findings of the present study suggests that mobile phones have the potential to improve access in an efficient manner, by complementing existing learning styles (Liaw et al., 2010).

⁴ One of our reviewers suggested that no difference in mental effort between the two groups indicates no improvement in reducing split attention (cf. the split attention effect, Ayres & Sweller, 2005; Mayer & Moreno, 1998; Sweller et al., 1998). The measurement of mental effort in the present study was based on subjective judgment scores of the participants. Therefore, we propose that further research with more robust measures of mental effort is needed to clarify this point. We thank to our reviewer for his/her remarks on this issue.

Concerning the challenges in the use of mobile technology in educational contexts, the smaller size of the mobile phone screen, compared to the computer screen, did not turn out to be a problem in this study. Another major challenge in the use of mobile phones is text input, which was solved by the use of 2D barcode technology in this study. Due to higher storage capacity, the 2D barcode technology is more appropriate to store information such as web pages compared to alternative technologies such as NFC and RFID, as stated in Section 3. The 2D barcode technology is also compatible with mobile computational devices with built-in camera other than mobile phones, such as PDAs (Personal Digital Assistants) and wrist-worn devices (see Sharples & Beale, 2003, for a technical review of mobile computational devices). Therefore, the use of the 2D barcode technology is generalizable to a wide range of educational contexts that involve mobile technology.

A more complete generalization of the findings obtained in the present study would be possible by conducting complementary studies that investigate the aspects that were beyond the scope of this study. One of those aspects is usability evaluation of the learning system, since learning efficiency and effectiveness is influenced by usability of mobile devices, depending on the context of use. In particular, a major pitfall in using mobile devices for learning and teaching is that it may introduce additional effort compared to more conventional technologies (Kukulska-Hulme, 2005). Another aspect is the evaluation of individual differences. The findings in the domain of multimedia learning show that multimedia instructions are more useful for low-knowledge learners compared to high-knowledge learners. According to Mayer's (2009) individual differences principle, this difference between high-knowledge learners and low-knowledge learners is mainly due to formers' easier construction of the necessary image representations out of verbal material compared to low-knowledge learners. In addition to the knowledge of the learner, other individual differences such as differences in mechanical and spatial abilities might be factors that influence learning (cf. Differential Aptitude Tests developed by Bennett, Seashore, & Wesman, 1947, among many others). Previous findings show that learners with relatively low verbal abilities exhibit higher performance with multimedia instructional material compared to learners with high verbal abilities (Winn, 1987). In addition, students with higher spatial abilities exhibit higher performance with multimedia material compared to learners with lower spatial abilities (cf. the individual differences principle, Mayer, 2009). Consequently, previous knowledge and abilities of learners might be a factor in learning outcomes, which should be addressed in future studies. Finally, we selected the domain name system (DNS) as the topic of study due to practical limitations introduced by the nature of the experimental investigation, such as participants' time to study the experimental material. Further research is needed to evaluate the generalizability of the results. Methodologically, eye tracking recording of the participants would reveal more robust data for the evaluation of participants' mental effort to study the instructional material under different experimental conditions.

7. Conclusion

Despite the rapid technological development in electronic learning systems, recent studies show that regardless of their individual characteristics such as their experience in computer use, students do prefer textbooks rather than e-books (Woody, Daniel, & Baker, 2010). Mobile devices provide the opportunity with learners to integrate online information sources and printed information sources, such as animations and textbooks. The present study shows that mobile devices have further advantages over notebook computers in learning with multiple information sources, compatible with the expectations of the recent theoretical framework of multimedia learning. In particular, in addition to their low cost and the affordance to improve access to online information sources, the findings obtained in the present study suggest that camera-equipped mobile phones have the potential to complement printed information sources in a more effective way than notebook computers.

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