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Split-attention and redundancy effects on mobile learning in physical environments

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This study investigated split-attention and redundancy effects in a mobile learning environment on leaf morphology of plants as a function of different combinations of media. Eighty-one fifth-grade students were randomly assigned to the following three conditions: texts with pictures embedded in the mobile device (TP condition); texts embedded in the mobile device and real objects that are outside of the mobile device (TO condition); and texts with pictures embedded in the mobile device and real objects that are outside of the mobile device (TPO condition). Differences in performance on comprehension tests and learning efficiency were examined across conditions. The TP condition was expected to perform better than the TO condition due to a split-attention effect. The TP and TO conditions were expected to perform better than the TPO condition due to a redundancy effect. The results indicated no difference between the TP and the TO condition in comprehension and learning efficiency, but the TP and TO conditions performed better than the TPO condition on both measures. The implications of the results for research and design of mobile learning environments are discussed.

1. Introduction

Mobile technology is a portable computer-based device that can support learning without the limitation of time and place (Hoppe, Joiner, Milrad, & Sharples, 2003; Liu, 2007; Liu et al., 2003), breaks the restrictions of the wire-based learning environment and creates new learning opportunities for students to learn in real and surrounding physical environments (Huang, Lin, & Cheng, 2010; Peng, Chou, & Chang, 2008). Learning with mobile technology has the potential to solve the problems that are often encountered in traditional learning in physical environments (Liu, Peng, Wu, & Lin, 2009), such as conditions and objects that cannot easily be observed by students (Tan, Liu, & Chang, 2007) and limited access of students to immediate support or learning resources (Dillon et al., 2006).

Therefore, many studies have tried to apply mobile technology to assist students' learning in rich physical environments which are conducted in the indoor environment, such as a museum (e.g., Chiou, Tseng, Hwang, & Heller, 2010; Sung, Chang, Hou, & Chen, 2010) or in the outdoor environment, such as a natural park (e.g., Chen, Kao, & Sheu, 2003; Tan et al., 2007) and campus (e.g., Huang et al., 2010). Besides, mobile technology can also be used to appropriately combine the indoor and outdoor learning environment (Liu et al., 2009). Although there is no general consensus about the effectiveness of mobile learning environments (Frohberg, Göth, & Schwabe, 2009), research has revealed positive effects in many different domains, such as biology (e.g., learning to identify plants, butterflies, or ecosystems, Chiou et al., 2010; Huang et al., 2010; Liu et al., 2009; Tan et al., 2007), and history (e.g., learning to identify monuments, Shih, Chuang, & Hwang, 2010; Sung et al., 2010).

Most studies on mobile learning in physical environments have focused on whether the mobile technology can improve students' learning performance by supporting their learning activities (e.g., Chen et al., 2003; Liu et al., 2009; Tan et al., 2007). Although cognitive load has been identified as the most important issue in instructional design (Ozcinar, 2009), few studies have used a cognitive load perspective to explore the impact of the instructional design of mobile technology-assisted learning. *Cognitive load* can be defined as the load imposed on

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a learner's cognitive system when performing a particular task (Paas & Van Merrienboer, 1994; Sweller, van Merrienboer, & Paas, 1998) and is often operationalized as the working memory resources that are used to achieve the goals of a task (Paas, Renkl, & Sweller, 2003).

When learning with mobile technologies in rich physical environments, students are provided with multiple media, including physical objects around students and the information (texts and pictures about these physical objects) on the mobile devices (e.g., Huang et al., 2010; Liu et al., 2009; Sung et al., 2010). Undoubtedly, the use of such multiple media in mobile learning in physical environments can have advantages for leaning. However, the availability of different media may not only be advantageous for learning, but also disadvantageous.

The advantages of learning from multiple media, such as verbal and pictorial information, are usually explained by multimodal theories of human memory. Two influential models that have inspired many other theories, such as cognitive load theory (Sweller et al., 1998) and the cognitive theory of multimedia learning (Mayer, 2005), are Baddeley's working memory model (Baddeley, 1992) and Paivio's dual-coding model (Clark & Paivio, 1991; Paivio, 1986). Baddeley's model divides working memory into a "visual-spatial scratch pad" for dealing with visually-based information and a "phonological loop" to deal with auditory, primarily speech-based, information. These two systems, in turn, are governed by a central executive. According to Paivio's model, verbal information and pictorial information are processed in different cognitive subsystems: a verbal system and an imagery system. Words and sentences are usually processed and encoded only in the verbal system, whereas pictures are processed and encoded both in the imagery system and in the verbal system. Thus, the memory-enhancing effect of pictures in texts is ascribed to the advantage of a dual coding as compared to single coding in memory.

Studies that have used these models to investigate combinations of written text and graphics have found positive effects on learning when written text was combined with task-appropriate graphics (Schnotz & Bannert, 2003), when text and pictures were explanatory, when verbal and pictorial content were related to each other, when verbal and pictorial information were presented closely together in space or time and when individuals had low prior knowledge about the subject domain but high spatial cognitive abilities (Mayer, 1997). Other studies, mainly within the context of cognitive load theory and the cognitive theory of multimedia learning, have used Baddeley's model to explain why combinations of spoken text and graphics are more effective than combinations of written text and graphics (i.e., the modality effect: for overviews see, Mayer, 2005; Sweller et al., 1998).

The disadvantages of learning from multiple media have mostly been investigated within the theoretical framework of cognitive load theory using Baddeley's working memory model. Those studies have typically focused on learning environments that required students to learn from different types of visual media. The negative effects on learning are explained in terms of too high cognitive load, in the sense that all of the media compete for limited resources of the same working memory system (for overviews, see Paas, Renkl et al., 2003; Paas, Renkl, & Sweller, 2004). Two characteristics of those learning environments have been identified as main contributors to the negative effects on learning. Firstly, the need for learners to split-attention between multiple sources of information that must be integrated before they can be understood (i.e., split-attention effect). Secondly, the need for learners to pay attention to multiple sources of information that are self-contained and can be used without reference to each other (i.e., redundancy effect).

This study used the theoretical framework of cognitive load theory to compare three mobile learning environments, which differed regarding the composition of three types of visual media (i.e., written text, pictures, and real objects), regarding their effects on students' learning performance and efficiency. Because of this exclusive focus on the visual modality, two cognitive load effects that may result from mentally integrating those materials, that is, the split-attention effect and the redundancy effect, were explored. Leaf morphology of plants was selected as the learning subject because of its importance in elementary education as well as the frequent use of mobile learning to teach this subject (e.g., Huang et al., 2010; Liu et al., 2009).

The next section discusses cognitive load theory (Paas, Renkl et al., 2003; Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Sweller et al., 1998) and the research on split-attention and redundancy effects, and applies this theory to formulate hypotheses about these effects on learning with different combinations of media in a mobile learning environment.

2. Cognitive load in mobile learning environments

Cognitive load theory is concerned with the development of instructional methods that efficiently use people's limited cognitive processing capacity to stimulate their ability to apply acquired knowledge and skills to new situations (Paas, Tuovinen et al., 2003). The theory argues that learning can be facilitated by managing cognitive load that is imposed by the learning materials and by the way those materials are presented (i.e., instructional procedure). Most importantly, for learning of complex tasks to be effective it is argued that the load that is imposed by the way that those materials are presented needs to be minimized for aspects that are not relevant to the learning process (i.e., extraneous load), and maximized for aspects that are relevant to the learning process (i.e., germane load). Two extraneous-load inducing aspects that are highly relevant to the design of mobile learning environments and that have been systematically investigated by cognitive load researchers are the need to split-attention between multiple sources of information that must be integrated before they can be understood (e.g., Ayres & Sweller, 2005; Bobis, Sweller, & Cooper, 1993; Chandler & Sweller, 1992; Kablan & Erden, 2008; Kalyuga, Chandler, & Sweller, 1999; Liu & Lin, 2011; Mwangi & Sweller, 1998) and the need to pay attention to multiple sources of information that are self-contained and can be used without reference to each other (e.g., Bobis et al., 1993; Cerpa, Chandler, & Sweller, 1996; Kalyuga et al., 1999; Sweller & Chandler, 1994).

Both the split-attention and redundancy effect have been found with different media, such as text and audio presentations (e.g., Mayer, Heiser, & Lonn, 2001), others by using text and image presentations (e.g., Rasch & Schnotz, 2009), different learning materials, including paper-based environments consisting of diagram and textual solutions (e.g., Tarmizi & Sweller, 1988) and computer-based environments consisting of animations with text (e.g., Kablan & Erden, 2008), and with different age groups, including primary school students (e.g., Bobis et al., 1993; Leahy, Chandler, & Sweller, 2003; Mwangi & Sweller, 1998), junior high school students (e.g., Cerpa et al., 1996; Tarmizi & Sweller, 1988), and undergraduate students (e.g., Liu & Lin, 2011; Mayer & Moreno, 1998; Rasch & Schnotz, 2009).

At least three types of media are involved when learning with mobile technologies in rich physical environments: (i) texts and (ii) pictures embedded in the mobile device, and (iii) the real objects that are outside of the mobile device in the physical environment. If students use texts and pictures to understand the objects they observe, such a combination of information sources may result in split-attention and redundancy effects, which may overload the capacity of the visual/pictorial channel and negatively affect students' comprehension and learning efficiency. Split-attention effects may result from the difficult integration of physically separated media, e.g., the texts and pictures embedded in the mobile device and the real objects outside of the mobile device. Redundancy effects may result from the similarity of the pictures and objects, which may force students to process the same information more than once.

Based on these assumptions, four hypotheses about the impact of learning materials embedded in a mobile learning environment on split-attention and redundancy effects in young children were formulated in this study. Firstly, it was hypothesized that due to a split-attention effect with different types of physically separated visual media, students who had learned with text and pictures on the mobile device would show higher comprehension performance (Hypothesis 1) and higher learning efficiency (i.e., better ratio between comprehension score and learning time; Hypothesis 2) than students who had learned with texts on the mobile device and objects outside of the mobile device. Secondly, it was hypothesized that due to a redundancy effect for the information conveyed by similar pictures and objects, students who had learned with texts and pictures, as well as students who learned with texts and objects would show higher comprehension performance (Hypothesis 3) and higher learning efficiency (Hypothesis 4) than students who had learned with texts, pictures and objects.

3. Methods

3.1. Participants and design

Participants were 81 fifth-grade students (42 boys and 39 girls; $M_{age} = 11$ years) from three classes of a public elementary school in northern Taiwan. All students had taken the same course on basic knowledge about plants 18 months prior to the experiment. In addition, all students were taught by the same natural science teacher.

A between-subjects experimental design was used to address the hypotheses. In this experimental design, "different combinations of media" was used as the between-subjects factor. Participants were randomly assigned to three conditions with different versions of learning material, which were composed of different media: 27 students had to work with texts with pictures (TP), 27 with texts and real objects (TO), and 27 with texts, pictures, and real objects (TPO).

The three conditions were compared using a simple factorial analysis of variance (ANOVA) according to their scores on a questionnaire about prior knowledge of leaf morphology and their final grades in Chinese Language and Nature Science in the previous semester. A series of simple factorial ANOVAs revealed no significant differences between the three conditions in their prior knowledge scores or their Chinese Language or Nature Science grades. Means and standard deviations of the variables and the results of the ANOVAs are displayed in Table 1.

3.2. Materials and apparatus

The instructional topic was "plant leaf morphology." Three characteristics of plant leaves, including venation, margin, and phyllotaxy were taught, including four subtypes of venation (parallel-veined, feather-veined, palmate-veined, and midrib distinct), four subtypes of margin (entire, dentate, palmately lobed, and sinuate), and five subtypes of phyllotaxy (alternate, decussate, distichous, whorled, and rosulate) were taught in this study.

The learning materials included three versions (TP, TO, and TPO) composed of texts (T), pictures (P) or objects (O). Of these three media, texts, and pictures were conveyed using computer-based material, while the objects were authentic plants. The pictures were photos taken of the plants from various angles and thus were similar to the objects.

Each version had 31 screens which were divided into four parts. Firstly, the first five screens introducing the purpose of this instruction and outlining the three characteristics of leaf morphology were the same for all versions. Secondly, the sixth screen was customized for the different versions of the learning material to illustrate how to use the material. Thirdly, the following 24 screens used six plants as examples to introduce the three characteristics of leaves. Each plant was introduced in four screens. Finally, the final screen was used to thank participants for their participation. The texts were constructed to be roughly equivalent in terms of the number of words: 972 words for the TP version, 972 words for the TO version, and 989 words for the TPO version. The pictures presented to the TP and TPO conditions were the same, and the objects presented to the TO and TPO conditions were the same plants.

Fig. 1 presents an example of how the information was presented in the third part of learning materials, which differed across the experimental conditions. This example display deals with the topics of venation, margins, and phyllotaxy of the first plant (Green Maple). As the original texts were in Chinese language, the texts were translated into English.

In the TP version, the text and picture were shown on the screen of the mobile device. The text and picture were used to describe and visualize the characteristics of plant leaves. Students could refer to the text and the picture to learn about the characteristics of plant leaves.

In the TO version, only text was presented on the screen to describe the characteristics of plant leaves. A corresponding real plant was given to the students for observing the characteristics of plant leaves. Students could study the text and the authentic plant leaves to learn about the characteristics of plant leaves.

In the TPO version, the contents on the screen were the same as those in the TP version. In addition, a corresponding real plant was given to the students for observing the characteristics of plant leaves. Students could study the text, picture and real plant leaves to learn about the characteristics of plant leaves.

Table 1
Means, standard deviations and ANOVA results for the variables.

Variable	TP		TO		TPO		ANOVA	
	M	SD	M	SD	M	SD	F (2,78)	p
Prior knowledge	17.78	3.91	16.93	2.1.	17.00	2.47	0.62	0.54
Chinese language	93.09	4.04	90.55	6.12	91.63	4.32	1.82	0.17
Natural science	91.61	4.09	90.40	4.19	90.17	4.32	0.92	0.40

Fig. 1. The learning materials for the first plant (Green Maple) in different combinations for each condition.

The mobile device was a Tablet PC with a 12-inch monitor without keyboard (see also, Liu et al., 2009; Sung et al., 2010). To examine the impact of different combinations of media, simple Tablet device-based instructional software developed in JAVA was used in the current study. This instructional software allowed students to learn at their own pace and recorded their learning time.

3.3. Measurements

The paper-and-pencil material used to assess students' prior knowledge and comprehension comprised a subject questionnaire and a comprehension test. Learning efficiency was also calculated according to the ratio of the comprehension score and learning time for each student.

The subject questionnaire investigated the students' prior knowledge about the educational material using four general items: "I can point out where the main vein is on the leaf," "I can point out where the petiole is on the leaf," "I can point out where the node is on the plant," and "I can point out where the veinlets are on the leaf." Students rated these items on a six-point scale. Possible responses included "strongly agree," "very much agree," "agree," "disagree," "very much disagree," and "strongly disagree." The Cronbach α reliability for the prior knowledge test was found to be 0.71. The highest possible score on the subject questionnaire was 24 points and the lowest possible score was 6 points. In consideration of the young age of the participants a questionnaire was considered less intimidating to get an estimate of their prior knowledge than a comprehension test.

The comprehension test about leaf morphology (13 items) comprised two types of questions. The first set consisted of eight leaf-characteristic drawing questions and the other set of five leaf-characteristic assembling questions. When responding to the leaf-characteristic drawing questions, the students were asked to draw the four types of venation and the four types of margins. When responding to the leaf-characteristic assembling questions, the students were provided with artificial leaves and five artificial stems and were asked to reconstruct the five types of phyllotaxy using the artificial materials.

The drawing and assembling questions were used as the comprehension test to determine how much knowledge the students had acquired about leaf morphology from the rich physical mobile learning environment. These two kinds of questions were used because the concept of phyllotaxy involved spatial characteristics. Therefore, we assumed that students' knowledge of phyllotaxy could best be tested by asking them to physically assemble the leaves. By doing so, we could avoid the problem that some students would perform poorly not because of a lack of knowledge but because of their inability to draw pictures of spatial concepts.

The highest possible score for the comprehension test was 13 points (each correct answer scored 1, and each wrong answer scored 0). Fig. 2 (a–d) shows samples of the items that were identified correctly or incorrectly in the drawing and assembling sections. In order to determine maximum learning time limits and the reliability of the comprehension test, a pilot study was conducted with ten fifth-grade students (5 boys and 5 girls; $M_{age} = 11$ years) that were randomly selected from another class of the same school. Two experienced Nature Science teachers were invited to score the data. Based on the high inter-rater agreement for the comprehension test (0.96) in the pilot study, the scoring of the data in the formal study was conducted by one experienced Nature Science teacher. The internal consistency reliability coefficient (KR-20) of the test was found to be 0.72.

Learning efficiency was determined for each student by dividing the total score for the comprehension test about leaf morphology by the student's time spent on learning to recognize leaf morphology using the different learning materials.

3.4. Procedures

The experiment was conducted in a botanical garden-like learning environment. All students took part individually in all three phases of the experiment.

3.4.1. Pretest phase

A prior knowledge questionnaire was administered to determine the participants' prior knowledge of the topic of leaf morphology.

3.4.2. Intervention phase

Immediately after the individual students had completed the pretest, they were given the version of the learning material that corresponded to the experimental condition they were assigned to. Students in the TP condition were asked to learn the leaf morphology by observing pictures and texts on the Tablet device. Students in the TO condition were asked to learn the leaf morphology by observing objects (plants) that were also presented in the texts on the Tablet device. The learning environment of the TPO condition was exactly the same as that of the TO condition, except that the content on the Tablet device consisted of texts and pictures. Students in the TP and TO conditions observed the objects in a fixed order to control some of the factors that may affect experimental effects.

Students could control the presentation of the computer-based learning material by a touch pen. The time limit of seven minutes was determined according to the results of the pilot study, which showed that all students could complete the learning activity within this time. The students could stop whenever they wanted, and the time that they spent on the activity was recorded.

3.4.3. Post test

Immediately after the individual students completed the learning activity, they were asked to complete a comprehension test to assess their understanding of leaf morphology. The time limit was ten minutes, which was determined according to the results of the pilot study. Fig. 3 depicts the chronology of the research.

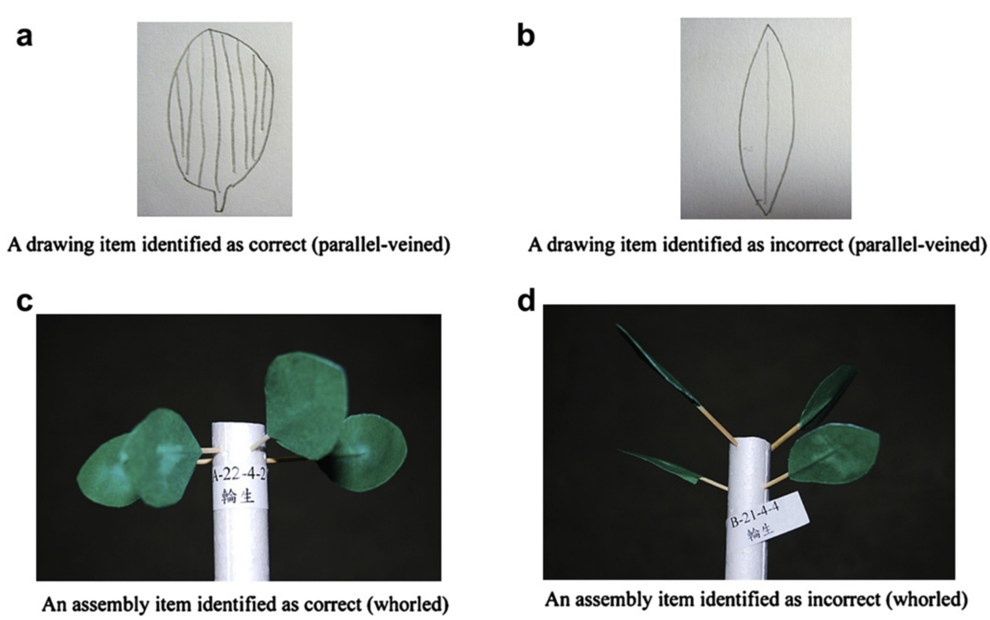

Fig. 2. Scoring examples on the comprehension test, (a) A drawing item identified as correct (parallel-veined), (b) A drawing item identified as incorrect (parallel-veined), (c) An assembling item identified as correct (whorled), (d) An assembling item identified as incorrect (whorled).

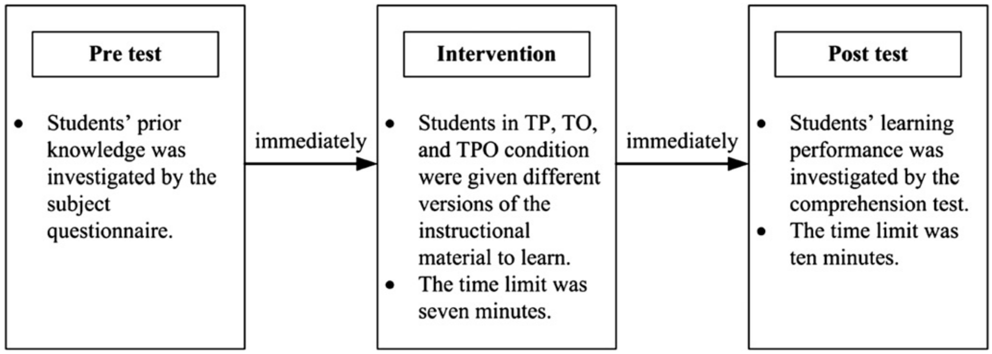

Fig. 3. The chronology of the research.

4. Results

A series of ANOVAs was conducted to analyze the differences of each measure in the current study, and planned contrasts were applied to further analyze the differences between the cells of the ANOVA. Statistical significance for all tests was set at $p < 0.05$. Table 2 presents the mean scores, standard deviations and the results of the ANOVAs for the dependent variables comprehension test score, learning time, and learning efficiency as a function of condition. The results of ANOVAs revealed significant differences for comprehension test score and learning efficiency but not for learning time. Planned contrasts were applied to further analyze the differences between the comprehension test score and learning efficiency of the conditions based on different combinations of media.

4.1. Split-attention effect (Hypotheses 1 and 2)

The results of planned contrasts between the TP condition and the TO condition showed no significant difference for comprehension test performance ($t_{(78)} = 0.14$, $p > 0.05$) and learning efficiency ($t_{(78)} = 0.23$, $p > 0.05$).

4.2. Redundancy effect (Hypotheses 3 and 4)

The results of planned contrasts showed that the TP condition ($t_{(78)} = 2.05$, $p < 0.05$, *Cohen's d* $= 0.56$) and TO condition ($t_{(78)} = 2.10$, $p < 0.05$, *Cohen's d* $= 0.57$) performed significantly better than the TPO condition on the comprehension test. In addition, the TP condition ($t_{(78)} = 2.79$, $p < 0.05$, *Cohen's d* $= 0.71$) and the TO condition ($t_{(78)} = 2.56$, $p < 0.05$, *Cohen's d* $= 0.72$) achieved a higher learning efficiency than the TPO condition.

To summarize, the results did not support the split-attention hypotheses 1 and 2 (TP condition would outperform the TO condition on the comprehension test and learning efficiency), but Hypotheses 3 and 4 (TP and TO conditions would outperform the TPO conditions on the comprehension test and learning efficiency) were confirmed.

5. Discussion

This study used mobile technology in a rich physical learning environment, in which students were provided with an individual mobile device in which three specific combinations of visual media, including texts, pictures, and real objects were presented. Because all media had to be processed through the visual channel, the need to mentally integrate those media, of which the pictures and objects provided similar information, split-attention and redundancy effects were expected.

Both effects were explored in the current study. It was hypothesized that due to the split-attention effect with different physically separated media, students who had learned with text and pictures on the mobile device would show higher comprehension performance (Hypothesis 1) and higher learning efficiency (i.e., better ratio between comprehension score and learning time; Hypothesis 2) than students who had learned with texts on the mobile device and objects outside of the mobile device. Secondly, it was hypothesized that due to the redundancy effect for the information conveyed by similar pictures and objects, students who had learned with texts and pictures, as well as students who learned with texts and objects would show higher comprehension performance (Hypothesis 3) and higher learning efficiency (Hypothesis 4) than students who had learned with texts, pictures and objects.

Hypotheses 1 and 2 were not confirmed by the results, indicating that there were no split-attention effects; the distance between the information on the mobile device and the objects in the physical environment did not affect students' comprehension and learning

Table 2
Mean scores, standard deviations and the results of the ANOVAs for the comprehension test, learning time, and learning efficiency.

Variable	TP		TO		TPO		ANOVA	
	M	SD	M	SD	M	SD	F (2,78)	p
Comprehension test	8.81	2.22	8.74	1.65	7.22	3.37	3.45	0.04
Learning time (min)	4.75	1.22	4.72	1.08	5.36	1.06	2.79	0.07
Learning efficiency	1.98	0.74	1.94	0.59	1.44	0.79	4.81	0.01

efficiency. However, hypotheses 3 and 4 were confirmed, indicating redundancy effects due to the fact that multiple media containing similar information had to be processed. The following sections discuss the reasons and possible alternative explanations for these results.

5.1. The split-attention effect on mobile learning in rich physical environments

Although most studies on the split-attention effect have proven that distance between media affects students' learning performance (e.g., Kablan & Erden, 2008; Liu & Lin, 2011), there are no studies that have explored split-attention effects in the context of mobile learning in rich physical environments. When comparing the TP condition with the TO condition in the current study, it is evident that the physical and cognitive distance between texts and pictures was less than the distance between texts and objects. However, the learning performance of the two conditions did not reflect this difference.

A possible explanation for this finding could be that the magnitude of the positive effects created by the authentic learning experience with the real objects exceeded the magnitude of the negative split-attention effect. Observing real objects is one of the main goals when learning in rich physical environments and "real objects" are seen as the most concrete type of educational media to represent abstract concepts in educational settings (Heinich, Molenda, Russell, & Smaldino, 2001). Compared to pictures and texts, real objects may provide students with experiences that they know from daily-life experience, and by which they can acquire strong memories (Brown, Collins, & Duguid, 1989; Falk & Dierking, 2000). Moreover, the experience of observing authentic objects may have the potential to enhance students' motivation and make them more involved in learning than other representation formats (Heinich et al., 2001). The above may be key factors to increase effective cognitive load, which can benefit learning (Wouters, Paas, & van Merrienboer, 2006). Therefore, this authentic experience of observing real objects may make up for the negative influence of the split-attention effect and may explain why the comprehension performance and learning efficiency of the TP and TO conditions did not differ. Future research should investigate the effects of "real objects" on students' motivation and its relationship with learning performance.

In addition, in this study we did not determine the students' allocation of attention, which only allowed indirect conclusions about the division of attention between the different learning materials. Consequently, we cannot be sure about the amount of effort invested in the different media. Future research could use more direct measures of the direction of attention, such as tracking of students' eye movements during learning to allow direct conclusions about the division of attention between different media.

5.2. The redundancy effect on mobile learning

The redundancy effect holds that spending time and energy to process two or more sources of similar information may impose an ineffective load on working memory and, consequently, hinder learning (Mayer et al., 2001; Mayer & Johnson, 2008; Sweller et al., 1998). Because pictures and objects conveyed similar information to students, in the current study, students who learned with the combination of texts and pictures (TP condition) or the combination of texts and objects (TO condition) developed sufficient knowledge about "leaf morphology." However, students who learned with the combination of texts, pictures, and objects (TPO condition), had to allocate attentional resources to objects and pictures that provided similar information, resulting in a redundancy effect that affected learning negatively. This may explain why the TP and TO conditions showed better comprehension performance and higher learning efficiency than the TPO condition.

In line with some previous studies of the redundancy effect (e.g., Chandler & Sweller, 1992; Sweller & Chandler, 1994), in this study the pictures and objects provided similar information to the same modality, as both sources had to be processed through the visual channel. Other studies, however, have investigated redundancy effects caused by presenting similar information to different modalities, for example by using a similar spoken and written text (e.g., Mayer et al., 2001).

For future research it would be interesting to look at the effects of the relationship between the level of overlap between different learning materials on the redundancy effect. For example, one could argue that the pictures in the present study, which were pictures of a part of the real object, did not convey exactly the same information as the real objects. Therefore, it would be interesting to investigate redundancy effects of different sources of fully overlapping information (e.g., pictures of whole real plant vs. real plant), or less overlapping information (e.g., schematic drawings of the real plant vs. real plant).

6. Conclusions and recommendations

The current study explored the impact of split-attention and redundancy effects in a mobile learning environment. The results did not show evidence for split-attention effects, because the TP and TO conditions did not differentially affect comprehension performance and learning efficiency. However, both the TP and TO condition showed higher comprehension performance and learning efficiency than the TPO condition, which confirmed our hypotheses on redundancy effects.

One explanation for these results is that when providing students with two complementary media, the negative effects on students' comprehension and learning efficiency arising from the cognitive distance between the information on the mobile device and the physical objects may be neutralized by the experience of observing real objects. However, the addition of a similar media may hinder students' learning.

The redundancy effect was detected in the current study when similar learning information was conveyed by pictures and objects, obliging students to invest extra effort to process similar information from different media. To avoid the negative effects of redundant elements on learning performance and learning efficiency when using mobile technology in rich physical learning environments (where objects and texts are necessary media), new media should be carefully designed. Redundancy effects have been found in many studies (e.g., Mayer et al., 2001; Rasch & Schnotz, 2009), and providing students with complementary learning information is the recommended method to avoid this effect (Mayer et al., 2001). In the context of the present study, complementary media, for example, the use of drawings to replace pictures to make the two media (drawings and objects) convey different information to students.

Another characteristic of the present study that should be taken into consideration when interpreting the results is the fact that the learning materials in the mobile environment were learner-paced. Previous studies have shown that the strength of other cognitive load effects, such as the modality effect (Sweller et al., 1998), is moderated by the pacing of the presentation, with a stronger effect for systempaced materials, but a lesser effect for self-paced materials (for an overview see, Ginns, 2005). The modality effect derives from the split-attention effect. It occurs under split-attention conditions when a written source of information, that must be integrated with another source of visually presented information, such as a diagram, is presented in auditory rather than visual (written) mode. Although the mobile learning environment in this study only consisted of visual sources of information, the type of pacing used, could explain why we did not find a split-attention effect. It would be interesting for future research to manipulate the type of pacing used in visually based mobile learning environments.

In recent years, more and more multi-functional instructional software has been designed for mobile devices to improve the effects of observation, such as a Mobile Plant Learning System (MPLS: Huang et al., 2010), a mobile butterfly-watching learning (BWL: Chen, Kao, & Sheu, 2005), and an Environment of Ubiquitous Learning with Educational Resources (EULER: Tan et al., 2007). The advancement of mobile technologies creates the opportunity to instructional designers to incorporate a greater variety of real objects for learning, and for learners to observe those objects.

From a theoretical perspective, the results of this study suggest that contemporary theories of instructional design, such as cognitive load theory (e.g., Paas, Renkl et al., 2003; Paas, Tuovinen et al., 2003) and the cognitive theory of multimedia learning (e.g., Mayer, 2005) might need to be specified for split-attention effects in mobile learning environments. For example, our findings suggest that spatially integrated written text and pictures of real objects are not more effective for learning than spatially separated written texts and real objects in the environment.

From a practical perspective, the results of this study could suggest some guidelines to instructional designers and teachers for the design of mobile learning environments. Although it is clear that the results of this study can only be subscribed to the specific configuration of different media, it seems that visual information presented on a tablet PC can be used by primary school children in combination with real objects without compromising their learning by a split-attention effect. In addition, instructional designers and teachers should be aware of redundancy effects when combining different media that convey similar information. However, it is clear that mobile learning environments may use many different media configurations, which need to be investigated before reliable conclusions can be drawn and instructional guidelines be formulated.

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