Complex Mobile Learning that Adapts to Learners' Cognitive Load

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ABSTRACT

Mobile learning is cognitively demanding and frequently the ubiquitous nature of mobile computing means that mobile devices are used in cognitively demanding environments. This paper examines the use of mobile devices from a Learning, Usability and Cognitive Load Theory perspective. It suggests scenarios where these fields interact and presents an experiment which determined that several sources of cognitive load can be measured simultaneously by the learner. The experiment also looked at the interaction between these cognitive load types and found that distraction did not affect the performance or cognitive load associated with a learning task but it did affect the perception of the cognitive load associated with using the application interface. This paper concludes by suggesting ways in which mobile learning can benefit by developing cognitive load aware systems that could detect and change the difficulty of the learning task based on the cognitive state of the learner.

Keywords: *Application Interface, Cognitive Load Theory, Mobile Devices, Mobile Learning, Mobile Usability*

INTRODUCTION

Current mobile device use is presenting previously unconsidered problems. Mobile devices are now ubiquitous. The size, portability, battery life and computational power of mobile devices suggest that they can be used for a diverse range of uses in an equally diverse range of environments (Weilenmann *et al.,* 2007, Reed and Green, 1999, Middleton *et al.,* 2013, Boulos *et al.*, 2011). Usability, or HCI (Human Computer Interaction), is primarily concerned with "ease of use" and "learnability" (e.g. how easy a system is to learn to use) (Neilsen, 1994). Mobile devices are challenging this notion of Usability as these devices are used in new ways. *Firstly,* mobile devices are used in complex distracting environments and these distractions interfere with the user's cognitive resources. *Secondly,* mobile devices are becoming advanced and powerful and this allows more sophisticated applications to be used on them.

Such applications are already cognitively demanding but the use of mobile devices for learning also brings a much higher demand for cognitive resources. Couple this demand

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to situations when the mobile device is used in a distracting environment and this leads to scenarios where the user's cognitive resources become overloaded or stretched. Cognitive Load Theory explains how the human mind interacts with instructional materials for learning and has several guidelines that are used to assist in the design of instructional material used for learning. These guidelines suggest methods to discourage extraneous cognitive processes and encourage germane cognitive processes. This paper will present the results of an experiment that demonstrate how mobile learning, Cognitive Load Theory and mobile usability interact.

LITERATURE REVIEW

Learning is considered to be the acquisition and development of memories and behaviors, including skills, knowledge, understanding, values, and wisdom. Specifically, from the perspective of the Information Processing Model (Broadbent, 1958, Neisser, 1967), it is the changes made to long term memory, usually schema creation or automation. Learning has traditionally taken place in learning institutions or schools. However, this may not be the best place for learning (Dewey, 1916, Bloom, 1964). In modern times, not only is high literacy demanded of everyone but the ability to think and reflect is now a valued attribute in the workplace. "Knowing" has shifted from being able to remember and repeat information to being able to find and use it (Simon, 1996). The role of education now should be the development of intellectual tools and learning strategies needed to acquire that knowledge (Bransford *et al.,* 1999).

Mobile learning can address some of these challenges. Mobile learning is defined in this paper as *"Learning with the aid of a Mobile device"*. In this definition a mobile device is simply a computer that is not restricted to a specific stationary environment or location. Specifically, mobile devices can be used in multiple environments; anytime, anywhere. It is this notion of anytime, anywhere, that is causing a dichotomy. On the one hand it is great that technology can enable learning to take place in multiple environments and contexts, but on the other hand it is these multiple environments and contexts that may have unintended effects on mobile learning. Some of these effects have been explored in recent research (Coens *et al.,* 2011) where jogging can be seen to have an effect on learning from a podcast via a mobile device.

Attempts have been made to explore the design of mobile learning applications (Eliasson *et al.,* 2011, Pemberton and Winter, 2011) with guidelines being created from an interaction design perspective. (Eliasson *et al.,* 2011). Although these guidelines refer to interaction design they also refer to the learning content / pedagogical aspects of the application e.g. "let teachers assume roles, and encourage face-to-face communication." Quite often applications are not developed or designed by teachers or pedagogues and therefore it is also beneficial to explore these applications from a purely interaction design, HCI or usability perspective.

Previously, the current authors investigated mobile learning from a usability perspective and put forward a classification of mobile learning applications based on Usability (see Deegan and Rothwell, 2010a). Usability is defined by the ISO as "*the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments.*" (ISO 9241, 1998). A usable system should be easy to use (utility) and easy to learn (learnability) (Nielsen, 1994). In recent years the notion of 'ease of use' has been applied to Usability where the general philosophy is based on making things 'easy' for the user. This approach stemmed from work done by Miller (1956) which determined that human cognitive resources were limited. Working memory plays a large in these limited cognitive resources. This association between working memory and mobile learning has been explored (Li *et* al., 2009) but as the authors suggest, it is difficult to generalize from the experimental conditions and further work is needed. However one theory that strongly affects working memory is Cognitive Load Theory, this theory could enhance the existing work associating working memory and mobile learning.

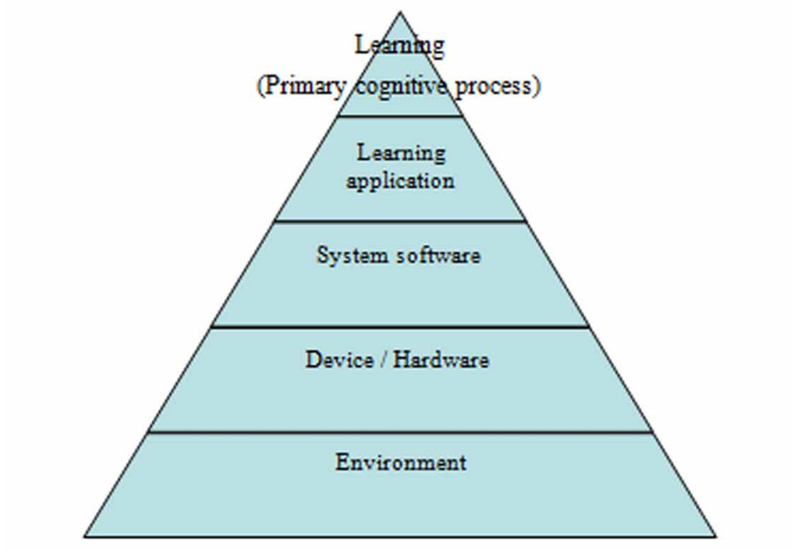
One of the primary concerns raised during the creation of the authors' classification (Deegan and Rothwell, 2010a) was the issues surrounding cognitive load. Cognitive load is the demand for mental resources associated with processing information in working memory. Usability practitioners attempted to reduce the inputs that humans had to process; making things easier (less cognitive load) meant making things more effective, efficient and satisfying to use. It was thought that systems that demonstrated a lowering of cognitive load would ensure that users were not over-burdened by the system. Computing began to reduce the cognitive load in an attempt to remove the burden of choice and thought from the user (Chalmers, 2003). Computer software is now easier to use and it is in part due to this that computer users of today generally have low cognitive loads applied to them (Sharp *et al.,* 2007).While usability practitioners attempted to lower cognitive load, pedagogues and cognitive load researchers were finding that an increase in cognitive load could be beneficial for learning. Research reported in Sweller, (1988), Sweller and Chandler, (1994), Sweller *et al.,* (1998), and Paas *et a.,* (2004) etc. argues that our cognitive load can and will vary depending on the characteristics of the task and those of the user. Cognitive Load Theory (CLT) was developed to help understand how humans learn effectively with specific regard to problem solving. CLT is defined as being "concerned with techniques for managing working memory load in order to facilitate the changes in long term memory associated with schema construction and automation" (Paas *et al.,* 2004). CLT posits three types of cognitive load that affect learners: Intrinsic, Extraneous and Germane Cognitive Load (Bannert, 2002, Sweller *et al.,* 1998): Intrinsic Cognitive Load (ICL) is due to the inherent difficulty of the task, Extraneous Cognitive Load (ECL) is due to distractions not directly related to the task and Germane Cognitive Load (GCL) results in changes to our long term memory due to the task (typically this is schema creation, manipulation, and assimilation). This activity, that leads to changes to long term memory, is directly associated with learning (Sweller *et al.,* 1998).

CLT actively encourages designers to increase the load associated with this schema creation (i.e. the GCL) and to reduce ECL in order to best use the learner's limited cognitive resources and thus improve performance. The usability practitioners' focus on increasing the ease of use of applications is, in CLT terminology, actually a focus on the reduction of ECL. These two contradictory aspects affect Mobile learning; as one aspect attempts to lower cognitive load another seeks to increase it. Van Nimwegen (2008) refers directly to this paradox: he questions the assumption that indiscriminately increasing the ease of use necessarily results in better applications. He determines that for certain types of applications it is actually beneficial to make the users' task activities more difficult because this results in deeper thought processes and thus increased learning performance. Hollender *et al.,* (2010) says there is no CLT counterpart in HCI for fostering germane load, perhaps because the goal of HCI is to reduce Cognitive Load (Sharp *et al.*, 2007). However, it is notoriously difficult to measure cognitive load. If cognitive load can be measured it is then extremely difficult (if not impossible) to differentiate between its constituents: ICL, GCL and ECL. There have been advances in measuring the load especially in relation to user centered educational design (Oviatt, 2006), however, little work exists that can accurately measure the different types of load by discriminating between them. This is particularly interesting to Usability and specifically learning applications where one needs to determine what aspects of cognitive load are aiding or inhibiting learning i.e. which aspect of instructional design is affecting the ECL or GCL.

MOBILE LEARNING INTERFACES

Without a doubt learning is a cognitively demanding activity. As a result of the current au-

Figure 1. Sources of cognitive load



thors' previous work (see Deegan and Rothwell, 2010a), the need to balance cognitive load for the mobile learner was identified as a serious concern. Subsequently, the authors presented a model of external sources of Cognitive Load that are relevant to mobile learning (Figure 1, see Deegan and Rothwell, 2010b). This model acknowledged that Cognitive Load comes from the intrinsic nature of the learning (itself) but also suggested other extraneous areas that can contribute Cognitive Load and affect learning.

At the top of the model is the actual learning and this represents a small portion of likely cognitive load distractions (ECL's), perhaps the material being learned itself causes a distraction, e.g. by its means of presentation. The learning application interface refers to the application itself and how the user interacts with the application, e.g. uses its controls etc. The system software itself can also contribute to sources of cognitive load, e.g. badly timed error messages etc. The device could also contribute to cognitive load if it is badly designed or too heavy etc. Finally, the environment can contribute to cognitive load, and this represents the largest category of possible sources of cognitive load distractions. By combining several methods of balancing cognitive load (Kirschner, 2002, Mayer and Moreno, 2003, Van Merrienboer *et al.*, 2002, Sweller *et al.*, 2011) instructional designers can ensure that the learner's cognitive load is at a suitable level with regard to the material being learned. They can make certain that the ICL and GCL of the instructional material is appropriate and make efforts to reduce or eliminate ECL. This addresses the cognitive load at the top of the model, the actual learning.

Usability professionals can make efforts to reduce likely sources of ECL with regard to the application interface itself. However it is unlikely that those associated with the creation of mobile learning applications will also have complete autonomy to control the cognitive load that is inflicted by the system software or the actual hardware of the mobile device. Attewell (2005) suggested that the technology selection used in mobile devices varied greatly and therefore the system software and device hardware is deemed beyond the range of control of the mobile learning application developer.

Finally the application developers could make efforts to develop mobile learning context aware applications that are also sensitive to the environment. In this way the cognitive load of the mobile learning application can be altered to suit the cognitive load of the environment. This will be a crucial attribute of a mobile learning application as mobile learning takes place with cognitively demanding applications in cognitively demanding locations.

An early research question was formed that asked how exactly does a cognitive load, inflicted from a distraction, affect a learner's performance, and is it possible for a learner to distinguish between several different sources of these cognitive loads? Specifically, could a user distinguish between the cognitive load associated with the learning content, the cognitive load associated with the application interface and the cognitive load associated with the environment (e.g. a distraction)? If a user could distinguish between these loads it may be possible for the application to distinguish between the loads also. Developers could then create cognitive load aware applications which could alter the cognitive load that the application inflicts (e.g. making the application easier when a distraction is detected and more difficult when the distraction is removed).

EXPERIMENT TO DISTINGUISH BETWEEN COGNITIVE LOADS

This experiment is quite complex as it measures elements of learning, as well as measuring usability and cognitive load. Ultimately this is a behavioral study and therefore guidelines set out by the American Psychological association[1] for the design and reporting of this experiment have been adopted.

Traditionally cognitive load based experiments would ask the participant to perform a learning task. This learning task would have a specific ICL, or difficulty, and it may have an associated ECL based on its design. The user then would impose a GCL while completing the task. A total measurement of cognitive load would be ascertained at this stage. Usually one of these loads would be theoretically (as they cannot be measured separately) manipulated e.g. a distraction, that inflicts an ECL, is added to the experimental conditions. Finally another overall level of cognitive load is measured and any change in overall load would be a reflection of the added distraction, yet what cognitive load this distraction affected would not be certain.

This experimental design is different in that it will attempt to measure the "added" cognitive load, as well as the cognitive load associated with the learning task and the cognitive load associated with using the application interface. This experiment will determine if this added load actually effects the performance or cognitive load associated with the learning task or interface i.e. rather than adding an extraneous cognitive load and measuring the overall cognitive load, this experiment will attempt to add an extraneous cognitive load and separately measure it and its effect on the original tasks and loads.

Method

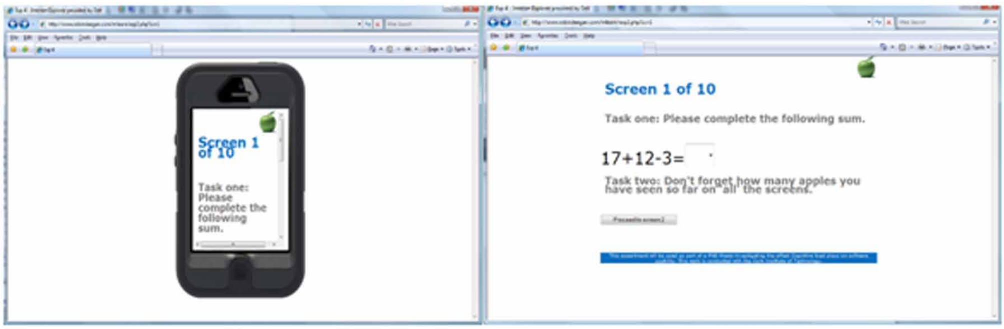
Participants

104 participants were recruited from the online site Mechanical Turk[2]. Several recent studies have found Mechanical Turk a valid source of participant recruitment for behavioral and user studies (for a full overview please see; Kittur *et al*., 2008, Buhrmester *et al*., 2011, Paolacci *et al*., 2010, Callison-Burch, 2009). In fact, Buhrmester *et al*., (2011) and Ipeirotis, (2010) suggest that the representative demographic characteristics of Mechanical Turk may be at least as diverse and more representative than traditional college or online based recruitments. Each participant was paid $0.10 to complete the task which took approximately 4 minutes. No demographic information was obtained. All participants agreed to give their consent. Participants were not able to complete the experiment more than once.

Materials

Participants were expected to have their own computer and access to the internet. The learning task was a series of 10 mathematical problems in which the participants needed to add or

Figure 2. Mobile Simulator desktop app and desktop app



subtract three "two" digit numbers. The answer will always be two digits and fall between 25 and 90. Cognitive load was measured using a 9 point Likert scale developed by Paas (1992). This scale is widely accepted as being a very accurate measure of cognitive load (Sweller *et al.*, 2011).

Procedure

For the purposes of this experiment it was desirable to investigate the load associated with the application interface and not the device itself. For this reason two versions of the application were shown to the participants. A web based version and a web based mobile phone simulator version (Figure 2). The only difference being the application interface i.e. how the information is presented and accessed.

One may ask "what exactly is the purpose of using a simulated mobile device instead of an actual mobile device?" If the web based version was to be compared to a mobile version it could not be a direct comparison. The interface is different as is the interaction style. However, if a simulated mobile version is used on a desktop then the only difference is the interface, as the interaction style (e.g. mouse and keyboard) remains the same, and therefore a direct comparison can be made. Once a distinction has been made between the various interface styles, then it will be fair to do the same comparison with a mobile device and you can then determine what changes are due to the interface and by deduction, once a mobile device is used, the interaction style.

For this experiment the distraction required the learners to remember how many apples were displayed at the top of various pages (see figure 2) throughout the primary task of completing the mathematical calculations. The low distraction was to remember seven apples over the ten mathematical tasks and the high distraction was to remember seventy apples over the ten mathematical tasks. The participants were randomly split into 4 groups. Group 1 completed the mathematical task with the desktop interface and low levels of distraction. Group 2 completed the mathematical task with the desktop interface and high levels of distraction. Group 3 completed the mathematical task with the mobile interface and low levels of distraction. Group 4 completed the mathematical task with the mobile interface and high levels of distraction. In addition to measuring the cognitive load of the mathematical task and cognitive load of the distraction, the cognitive load of the application interface was also measured.

The added distraction was designed to bring the learner close to a state of cognitive overload. There were two levels to this distraction, easy (low cognitive load) and hard (high cognitive load). Referring back to Millers (1956) work which suggests that humans working memory is limited, it was decided that this distraction will be a memory task which will run simultaneously to the learning task. The actual distraction is unimportant as long as it inflicts a similar (for the purposes of this experiment) cognitive load on the participants.

Ultimately there are two tasks in this experiment; firstly the learning task, and secondly remembering the apples. In the high cognitive load group they are remembering 70 apples; in the low cognitive load group they are remembering 7 apples. One cannot consciously "give" ones cognitive load to any process, rather cognitive load is a "sum" of all cognitive processing at a given time. When a learner is completing a task and remembering 70 apples she is under a high cognitive load compared to the learner remembering 7 apples.

Depending on the individual, a high cognitive load may result in a failure to learn, a failure to interact with the application or a failure to remember the apples or a mix of all three. Essentially, the learner will create an order of priority for their cognitive processes (conscious ones such as the learning task and remembering and subconscious ones such as interacting with the device, walking or navigating etc.) and their working memory will then distribute as many cognitive resources as possible to the cognitive processes.

The two interfaces (simulated mobile and desktop) are not designed to inflict a cognitive load in this experiment but if someone has an aversion to images of a mobile device or small screens this may cause an unintended cognitive load. Unfortunately this cannot be planned or anticipated, but it is also not the goal of the experiment to exploit these scenarios.

The experimental hypotheses are as follows. H1: The learner can measure several cognitive loads simultaneously, including loads that the mathematical task, the device interface and the distraction inflict. H2: The distraction will affect the mathematical task. H3: The cognitive load associated with using the mobile interface will be higher than for the desktop interface.

Results

The analysis focused on the mental effort and performance associated with the mathematical learning task (task 1) and distraction (task 2), the mental effort associated with using the interface. 54 participants completed the task with the easy distraction (29 with the desktop interface and 25 with the mobile interface), and 54 completed the task with the difficult distraction (27 with the desktop interface and 27 with the mobile interface). Difficulty and interface type were the independent variables with two levels each, respectively. The dependent variables were task1 effort rating, task 2 effort rating, interface effort rating, task 1 performance and task 2 performance. The data was normally distributed; assumptions of variance-covariance and homogeneity of variance were met. As such a two way MANOVA was used to analyze the data.

Using Pillai's trace, there was no combined effect of difficulty and interface on accuracy of task1 or task 2, or the mental effort ratings of task 1, task 2 or the interface, $V=.059$, $F(5,100)=1.247$, $p=.293$, observed power of .43. However the MANOVA for difficulty alone, $V=.131$, $F(5,100)=3.026$, $p=.014$, showed that the difficulty of the task had a significant effect on the dependent variables with an observer power of 0.85. Also the MANOVA for the interface type alone $V=.064$, $F(5,100)=1.37$, $p=.242$ showed that the interface type did not have a significant effect on the dependent variables, with an observed power of 0.46.

Follow up univariate analysis showed that difficulty had a significant effect on task 2 effort rating $F(1,104)=4.991$, $p=.028$ with an observed power of 0.60. This indicates that the difficulty of the distraction affected the distraction rating between the easy group ($M=5.46$, $SD=2.67$) and hard group ($M=6.56$, $SD=2.24$). Surprisingly, the difficulty of the distraction also had a significant effect on the interface ratings; $F(1,104)=5.58$, $p=.020$, observed power 0.65, between the easy group ($M=4.22$, $SD=2.56$) and hard group ($M=5.46$, $SD=2.55$).

Discussion

Hypothesis 1 was accepted, the learner was able to distinguish between several sources of cognitive load simultaneously. One of the main issues with Cognitive Load Theory is that it is very difficult to differentiate between sources of ICL, GCL and ECL, whereas an overall level of cognitive load can be measured (Sweller *et al.*, 2011). In this experiment the learning task contains both ICL (17+12-3 has an inherent difficulty) and ECL (perhaps the presentation could have distracting elements). The distraction and the application interface are both sources of ECL, however they are simply measured by asking the learner to rate them. This is interesting as it suggests that it may actually be possible to differentiate between the various load types, although asking the learner to do so may inflict another ECL in itself.

Hypothesis 2 was not accepted, the distraction did not significantly affect the performance of the primary task. This was unusual as current research suggests that a high secondary cognitive load can affect the primary performance. Sweller *et al.* (2011, p78) state,

If the primary task imposes a heavy cognitive load, performance on the secondary task deteriorates. In contrast, a lower cognitive load on the primary task can result in improved performance on the secondary task.

Unfortunately, a performance measurement for "using the application interface" could not be obtained so it is unclear whether the distraction made a difference in the performance associated with this action. As it seems there is a correlation between the mental effort associated with the distraction and the interface type, it is a distinct possibility that there could also be a relationship between the distraction and the performance associated with using the application interface. This possibly serves to highlight the importance of differentiating between the various cognitive loads so that individual relationships between load types can be determined and understood. For example, why did the distraction affect the cognitive load associated with the interface and not the learning task?

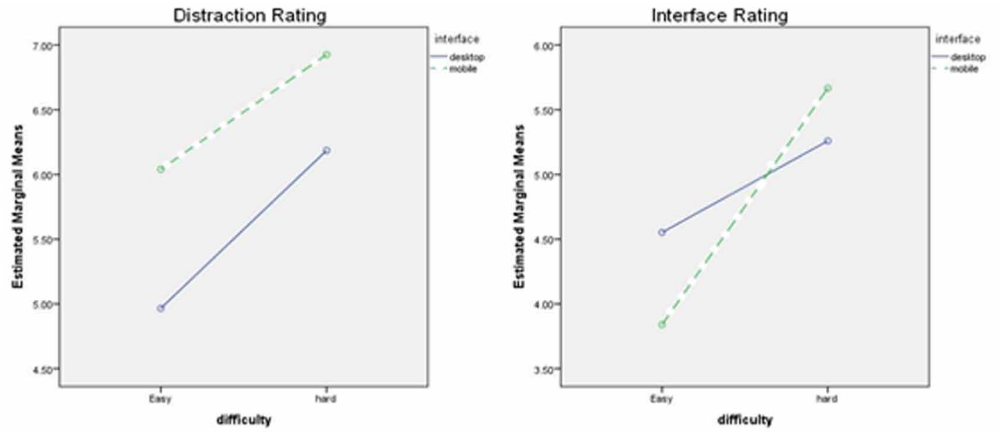
Hypothesis 3 was also not accepted, there did not seem to be any significant effect of interface type on mental effort ratings or performance. This is good news for the mobile learning community. However, the actual conclusion may not be that clear. From the graphs in Figure 3 it can be seen that the distraction was more pronounced (although not significantly different) for the mobile interface group than the desktop interface group. Interestingly, the univariate analysis for the effect of *interface type* on *distraction* ratings showed that there was a difference and while it was close to significant, it was not actually significant ($F(1,104)=3.709$, $p=.057$ with an observed power of 0.48). It appears that while *difficulty* had an effect on the *interface* rating ($p=.20$) the *interface type* had a near significant effect on the *distraction* rating. It is unclear why this relationship between distraction and interface type exists but it does suggest that a mobile learning application interface should possibly be tested under a state of high cognitive load in order to see these types of issues (e.g. interface problems) may not be apparent when the learner is not in a high state of cognitive load. Other univariate analysis for the effect of the interface type did not yield any significant or interesting results.

RELATED EXPERIMENTS

This experiment is the fourth experiment in a series of six related experiments. The first experiment (Deegan & Rothwell, 2011), which served as a pilot, investigated the effects of distracting environments on mobile learners. One of the key findings of this experiment was the *"lingering effect"*. This effect suggested that when distractions were removed the mobile learners remained distracted.

Leading on from the pilot, two experiments were conducted that set out to identify if learners could identify separate sources of cognitive load (Deegan, 2013a). The results of these experiments demonstrated that learners can indeed identify separate sources of cognitive load relating to performance and distractions. The experiment looked primarily at desktop users; the first experiment used one distraction and the second used two distractions.

Figure 3. Distraction and interface ratings



After this initial experiment, which determined that cognitive loads could be identified, the experiment presented in this paper was undertaken. The purpose of this experiment was to extend the research from the desktop learner to the mobile learner. Specifically, a simulated mobile interface was used to eliminate any extra cognitive loads that may have occurred due to mobile / gestural interface.

The next experiment, leading on from this paper, eliminated the desktop learners and simulated mobile learners. It repeated the experiment with actual mobile devices and similar results were obtained (Deegan, 2013b). Specifically, the usability of the interface seemed affected by the distractions.

Finally the previous experiment was repeated, but this time a second more engaging distraction was included in the experiment (Deegan, 2013c). The overall results of this experiment concluded that certain simultaneous distractions affect the usability of mobile learning software while other interweaved distractions affect the performance of the actual mobile learning itself, due to the "lingering effect".

This series of experiments demonstrate the importance of understanding how distractions actually affect the use and related performance of cognitively complex applications used in cognitively complex environments.

CONCLUSION

This particular experiment, presented in this paper, demonstrated that individual ratings of cognitive load can be obtained instead of one overall level. Using this method various relationships between individual cognitive loads can be shown that would otherwise have gone unnoticed. In Cognitive Load Theory's search for a meaningful way to measure the relationship between individual loads this approach may be of benefit. Cognitive Load Theory is primarily concerned with the cognitive loads associated with a learning task and its instructional design but, as this research hopefully shows, Cognitive Load Theory can be applied beyond learning itself to the application interface and distractions. Also, possibly, when Cognitive Load Theory is applied in this way (to non learning elements), learning itself will benefit.

Usability and mobile usability can benefit from these results by understanding the capacity for the user to differentiate between various sources of cognitive load. These individual sources of cognitive load may demonstrate that that perceived usability of an artifact may in fact vary based on the cognitive load of the user. The results of this experiment show that the mental effort needed to use an artifact changes based on the cognitive load of the user, e.g. available mental resources. This is beneficial to usability in general but it may be critical to mobile usability specifically as the user moves between various environments and various sources of cognitive load.

Learning is a cognitively demanding activity. This experiment measures other sources of cognitive load and demonstrates interactions between these loads. Mobile learning is concerned with 1) learning anytime, anywhere and 2) learning with the aid of mobile devices. Both of these activities inflict a great deal of cognitive load on the user, and should be considered when developing or planning mobile learning solutions.

In fact, mobile learning applications should be developed with cognition aware systems that can interpret sources of cognitive load (e.g. camera, motion, sound sensors to detect environmental distractions etc.) that affect the learner and adjust the cognitive load (difficulty) of the instructional material to suit, so as not to overload the learner. Further similar experiments could help generate a more robust model of sources of cognitive load for mobile learning and this can be used to build such a system.

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ENDNOTES

1 http://www.apa.org/ethics/code/index.aspx
2 http://www.mturk.com/