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Efficacy of Learning: Digital Sources Versus Print

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Abstract

As technology continues to develop, teaching curriculums in both schools and universities have begun adopting a more computer/digital based approach to the transmission of knowledge and information, as opposed to the more old-fashioned use of textbooks. This gives rise to the question: Are there any differences in learning from a digital source over learning from a printed source, as in from a textbook? More specifically, which medium of information results in better long-term retention?

A review of the confounding factors implicated in understanding the relationship between learning from the two different mediums was done. Alongside this, a 4-week cohort study involving 76 1st year English Language female students was performed, whereby the participants were divided into 2 groups. Group A studied material from a paper source (referred to as the Print Medium), and Group B studied material from a digital source (Digital Medium). The dependant variables were grading of memory recall indexed by a 4 point grading system, and total frequency of item repetition. The study was facilitated by advanced computer software called SuperMemo.

Results showed that, contrary to prevailing evidence, the Digital Medium group showed no statistically significant differences in terms of shift from Remember (Episodic) to Know (Semantic) when all confounding factors were accounted for. The shift from Random Guess and Familiar to Remember occurred faster in the Digital Medium than it did in the Print Medium.

Keywords: Digital Medium, Print Medium, long-term memory recall, episodic memory, semantic memory, Super Memo**,** Forgetting Index, frequency of repetitions, total time spent.

Introduction

There has been a continuing exponential growth in the use of computer-based learning throughout all levels of education in the past 30 years. Such a shift has never before occurred in human history, unless one considers the shift from learning by verbal transmission to that of the written tradition from papyrus or wax slates.

In such a major shift, it is essential to establish the differences between the 'old' medium of transmission of knowledge (print) and that of the new one (the digital medium). These differences must be established in order to answer the question: Which of these two mediums is it best to study from?

Students nowadays face this question daily when presented with university material transmitted across computer networks; do they print the lectures, or do they simply save paper and study them from the laptop screen?

This paper aims to provide an answer to such questions, supported by empirical evidence. In particular, the aim of the paper is to find out which medium of learning results in a higher efficacy of long-term recall, as it is the information which sticks that will most likely be applied to practise in the future.

It has been recognized that the differences that exist may not solely be due to the innate nature of the mediums, but can arise from multiple factors. This study therefore also attempts to account for such factors in order to establish any existing relationship.

In the process, a brief review of papers discussing such issues will be displayed. We will begin by reviewing the literature regarding the different outcome measures of performance used in studies searching for a difference between digital information and printed information. Then, we will present an analysis of the deeper aspects of long-term memory types and the paradigm shifts that occur in such types with regards to learning. After that, a look into the effect of frequency of repetition on efficiency of recall will be presented. Finally, the effects of sex on the neurobiology of learning and memory will be reviewed, thus completing the full picture required before the study methodology and results are presented and discussed.

1. Performance Outcome Measures in studies investigating the differences between Digital versus Print

A critical review of the available published literature, aimed at distinguishing between performance differences in digital learning versus print learning (Dillon, 1994), provided deep insight into the study topic. Due to the

great variability in study method, Dillon decided to organize the review in terms of outcome measure. This brief review will focus on the outcome measures that might contribute to the learning process, that is, reading speed and comprehension, as classified by Dillon.

1.1 Reading speed

Reading speed refers to the ability to process (that is, understand) a specific piece of information in a certain amount of time; such a factor clearly contributes to efficiency of learning, and is therefore useful in expounding the differences between learning from digital versus print.

Such an outcome was mainly assessed in terms of amount of time required to proof-read a certain document. Dillon (1994) stated that it took on average 20-30% longer to read documents from a digital source (that is, a computer screen) as opposed to reading the same material on paper. A similar finding was reported by a number of researchers in this regard (Wright and Lickorish, 1983; Gould and Grischkowsky, 1984; Belmore, 1985; Gould et al., 1987a,b; Wilkinson and Robinshaw, 1987).

However, it is worth noting that not all studies regarding the matter showed a lack of any significant differences between either medium (Askwall, 1985; Creed et al., 1987; Cushman, 1986; Keenan, 1984; Muter and Maurutto, 1991; Oborne and Holton, 1988).

On the whole, however, Dillon rules the evidence in favour of there being a relationship, and attributes the inconsistencies to weakness of study methodology.

1.2 Comprehension

Comprehension is the most vital measure contributing to the ability to learn information, as understanding greatly facilitates recall. Such a component has been assessed through a number of ways.

Studies have used post-reading tests to assess for comprehension, although this also appears to be testing their inherent ability to recall information at the same time, which may distort the purely comprehensive component (Mason et al., 2001; Mayes et al., 2001; Noyes and Garland, 2003; van de Velde and von Grunau, 2003; Bodmann and Robinson, 2004; Garland and Noyes, 2004). Such studies have failed to show a significant difference in terms of comprehension between both media. The same conclusion was reached by Dillon (1992) in his review; the consistency of these results allows us to safely establish that comprehension across both mediums is equal.

1.2.1 ‘Remembering’ versus ‘Knowing’

Whilst the previously mentioned outcome measures portray interesting differences between either medium, it is important to develop a deeper understanding of long-term memory, in order to decide how it may accurately be tested for.

There are a number of theories as to how long-term memory encoding occurs. Garland (2004) cites the famous studies by Tulving (1983; 1985) which provide a basic framework upon which the organization of long-term memory is processed. Tulving starts off by describing semantic memory and episodic memory as two separate but interactive systems of memory. According to Tulving, knowledge is automatically filtered into the relevant memory systems over time in a step-wise process, starting with the episodic memory system, and then gradually losing context and shifting into the semantic memory system. By losing context, Tulving refers to the environment which the learner was present in whilst learning the item of information. An example of this is remembering the position of a fact written on a white-board in a specific class-room. Over time, the position of the fact and the whereabouts of the person at the time of learning may be forgotten, but the fact itself may be ‘known’.

Memories recalled from the semantic memory system, however, were not associated with position, environment, or perception of self. They were simply abstract concepts that were reconstructions of the episodic memories; memories that were stripped of the excess useless details.

Tulving used a system of memory categories accompanied by descriptions in his studies; subjects attempting to recall information would be asked to subjectively decide which category their recollection fell into. In this system, a Remember response represented retrieval from episodic memory, and a Know response represented retrieval from the more abstract semantic memory.

In doing so, Tulving was able to test for the gradual shift from episodic to semantic that he had theorized, and demonstrated such a shift occurring within 7 days after material had initially been studied.

Garland (2004) also cites Knowlton and Squire (1995), who noted the same phenomenon occurring after 7 days. (It is worth noting that this same study analyzed patterns of brain activity during recall as well, and found differences in such activity depending on the type of recall of the participant. This further supports Tulving's initial theory of episodic and semantic being 2 separate processes).

Likewise, Nuthall (2000) described a gradual shift of memory type amongst elementary grade students over the

course of a year. This was not determined by the standard Remember-Know response criteria, but was established after routine, extensive interviews with the students.

As for the actual Remember/know response as an outcome measure, the study by Gardiner (1998) provides further support for its efficacy at determining the type of memory recall; transcripts were provided alongside the gradings chosen by the participants, describing the details of the memories being recalled. Most of the responses for Remember involved a perception of the self along with the surrounding environment, whereas Known answers were simply described as being less detailed, more familiar, and more abstract.

1.2.2 Is Knowing considered a higher form of memory than Remembering?

In the study by Garland and Noyes (2004), it was noted that the number of correct and wrong answers were similar across both media. As a result, it can be concluded that if any differences were present, they would be too subtle to be detected by such an outcome measure. However, by noting the shift in TYPE of memory recall, a significant difference was discovered between digital and paper. But in order to distinguish between the better medium for learning, one must be able to first determine which of the grades (Remember or Know) reflects better memorization.

On the one hand, Remembering involves recollection of numerous extra details, such as spatial awareness, environment, perception of self, and other contextual details. When compared with the stripped down, abstract recollections of semantic memory recall, it is obvious that the participant is remembering larger quantities of information per fact recalled. However, does this necessarily reflect a higher level of learning?

Towards the end of the nineties, Conway et al. (1997) did a study on First year Psychology students, whereby the students were presented with MCQs based on the course content. Alongside the questions was a grading system ranking the type of recall into recollective experience (remember), "just know" (know), feeling of familiarity (familiarity), or guess (answer chosen at random). Conway found that initially, higher performing students achieved more 'Remember' responses than 'Know' responses on lecture material, and more 'Know' responses than 'Remember' for research methods. At first glance, this may appear confusing, but such a difference may be due to the more abstract nature of statistics used in the research methods course. A retest that was done 24 weeks later demonstrated a shift of more Knows than Remembers for the higher performing students in both the lecture material and the research methods material.

Later research by Herbert and Burt (2001) attempted to replicate the Conway study and found a similar trend in the results. Again, it was the higher performing students that experienced a shift of majority response from Remember to Know. This was explained to be a reflection of more advanced internal schematization of learned knowledge; a vital component in the conversion from episodic memory to semantic.

On the basis of such findings, one may safely conclude that a sooner shift from Remembering to Knowing reflects more efficient learning.

1.2.3 Effect of Frequency of Rehearsal/Repetition on Learning

After a thorough review of the methodologies of studies cited in the previous two sections, it was noted that the frequency of rehearsal for items tested amongst the participants in the digital versus print groups could have varied greatly, as such a confounding factor is almost impossible to control when dealing with large participant numbers. Therefore, we have presented a brief overview of the literature discussing the effects of repetition on long-term memory.

In the 1970s, research was published that proposed a hypothesis, stating that the retrieval speed of a memorized item from a categorized list is dependent upon the organized repetition of those items, in that the most frequently rehearsed item is retrieved earliest (and thus has the shortest 'Interword Response Time (Kellas et al. 1973). This was later supported by the study by MH Ashcraft (1975), which concluded that there was a direct correspondence between the frequency of rehearsal and the speed of retrieval of learnt information.

Contrastly, Kyungmi Kim et al. (2012) did a study in which they investigated the effects of increased rehearsal of information upon recollection of the location and source of where the information was found (e.g. fact x was present in the top right part of the page). The study demonstrated that the higher the frequency of repetitions of an item of information, the lower the recall of the source of the item. Such a finding was attributed by the authors to be mainly due to greater interference of source information from similar, frequently repeated items (Postman, 1971; Underwood, 1949). Such a loss of source information may in fact represent a shift from episodic to semantic, whereby the knowledge of items becomes gradually more abstract.

Overlearning is the continued learning of an item of information even after mastery of recall. Studies looked into the effect of applying such a learning strategy to the memorization of items of information, and found that it positively increased retrieval speed of recall (Krueger, 1929; Narens, 1982).

An interesting finding notes that very high frequency of rehearsal or overlearning of information from a single

source may actually cause the learnt item to become too 'context bound' (Baker & Santa, 1977). Such a phenomenon occurs whereby students may have the ability to reproduce an entire section of a textbook, but may not be able to integrate the knowledge into situations which require manipulation of the information in a slightly less familiar manner. In such scenarios, the shift from episodic to semantic appears to almost be impaired due to a much stronger neural pathway leading down the episodic memory system. Such a finding may have its implications for the study in question, and will be further discussed in the study discussion.

1.2.4 Sex differences in females versus males with regards to learning and memory

All of the studies mentioned in the review so far have involved a mixture of male and female participants. The current study by the authors, however, was focused only on a population of female students. It is therefore important to establish any prevailing differences present amongst the two sexes in terms of memory ability before the study results may be expounded.

The effects of sex differences upon learning and memory can be analyzed by looking at the neuroanatomical, neurochemical, physiological, and behavioural differences related to memory that exist between the two groups. However, this section of the review will not delve into the first 3 categories in this paper.

In order to accurately assess the differences in memory, one must first define the categories of memory involved in the current cohort study. Clearly, not all modes of memory would be utilized in such a task, and as such, a complete categorization of the different types of memory is not necessary.

The types of memory tested for in the study can be divided into Spatial Memory, Verbal Memory, and a third component that may be attributed to Episodic Memory. Clearly, these 3 components greatly overlap, and as a result, they all have implications upon one another, and serve as confounding factors in the studies cited.

1.2.4.1 Verbal Memory

Verbal memory is defined as the memory of words and abstract concepts involving language. Such a component of memory has been mainly tested in the form of tests of verbal fluency and tests of verbal recall. The outcome measure that concerns our study is verbal recall.

Studies have consistently shown that females have more of an advantage than males when it comes to verbal recall. Superior verbal memory, as measured by recall of word lists, has been shown in both controlled experimental tasks (Kail & Siegel. 1978; Kimura & Seal. 2003) and larger surveys (Stumpf & Jackson 1994; Portin et al. 1995; Kramer et al. 1997).

1.2.4.2 Episodic Memory

Autobiographical memory is believed to be the long-term recollection of details regarding one's life, and episodic memory is theoretically classified as a subcomponent of autobiographical memory. Whilst there is no agreement on such categorization, it would be sufficient to keep in mind that in the context of this study, episodic memory is understood as the component of memory which contains elaborate details regarding an experience, such as the context (i.e., surroundings), smells, and relative time-frame, giving rise to a recollective experience.

In such an understanding, episodic memory draws upon a combination of components that are neither explicitly spatial nor verbal (Herlitz & Rehnman 2008). For this type of memory, 2 studies exist which state that females have a general episodic advantage (Herlitz et al., 1997; Herlitz & Rehnman, 2008). However, such studies do not account for the verbal components that contribute to the episodic memory findings. In contrast, when a study removed the verbal component in the episodic memory test by using nonsensical inkblots, neither sex succeeded in showing an advantage over the other (Lewin et al., 2001).

Based on the above reviewed studies, one may conclude that females exhibit a stronger verbal memory than their male counterparts. The effect is so strong that it has been seen to spill over into episodic memory, as internal verbalization is used as a strategy to achieve better retention and recall. However, episodic memory is equal in both males and females when the verbal memory component is removed.

1.2.4.3 Spatial Memory

It is well established that males have a greater advantage of innate ability in spatial memory (Linn & Petersen, 1985; Voyer et al., 1995). However, spatial memory is not actually a single homogenous component; for it consists of multiple components which each differ in terms of performance within the two genders. Spatial memory may be subdivided into spatial rotation, navigation, and object location memory (Andreano & Cahill, 2009).

What concerns us in this study is object location memory. This may be defined as the ability to recall the location of an object. In contrast to the advantage that males demonstrate in spatial ability, females surprisingly exhibit a more superior ability in object location memory (Choi & Silverman, 1996; James & Kimura, 1997; McBurney et al., 1997; McGivern et al., 1997; Levy et al., 2005; Silverman et al., 2007 cited in J.M. Andreano

and Cahill, 2009). At first glance, this may appear to be confusing. However, a deeper understanding of how the mind deals with object location tasks provides an ample explanation for such findings.

It appears that the object location tasks tested for in the above-cited studies use images of common items, and therefore, a strategy of internal verbalization is adopted. Therefore, high performance on object location tasks may be seen as a component of verbal (Lewin et al., 2001) or item memory (James & Kimura, 1997). Females are more superior in both of these types.

At the same time, studies that tried to provide object location tasks without verbal or item memory components demonstrated superiority in the male population (Postma et al., 2004; James & Kimura, 1997), verifying, then, that it is the verbal/item memory that makes females better at object memory. The implications of such findings will be expounded in the discussion phase of the paper.

2. Study Structure

The aim of the study was to find out which medium of study resulted in better long-term recall; digital or print. In order to meet the aim, the following questions had to be answered.

a. Which of the study mediums resulted in a sooner shift of Remember to Know?

b. If such a shift was noted, was it due to the varying frequency of repetitions done by participants, or was it due to the innate nature of the medium?

2.1 Design

A-between-subjects-design was used for two study mediums: Digital medium (that is, LCD screen), and Print medium (paper booklet). The dependant variables were grading of memory recall indexed by a 4 point grading system, and total frequency of item repetition. A within-subjects-design was utilized for the material learned, as well as the answers that were required.

2.2 Participants

The participants were 1st year English language students in Kuwait University who all spoke Arabic as their first language. All the participants were female, and were matched as far as practically possible in terms of age across both groups (Digital group: 22.7 years, Print: 24.2 years) and in terms of computer experience as measured by the BAC questionnaire. Other than that, the selection of individuals into either group was random.

2.3 Apparatus and Materials

Both digital and print groups required the use of a Windows OS powered laptop in order to run the program Supermemo. Supermemo is a spaced-repetition software that spaces out repetitions of set items of information in the form of digital flashcards over optimal intervals of time, in order to ensure retention of such information to a level set by the user. This level is defined as the 'percentage chance of remembering the item at any point in time'. The level was set to 96% for all participants.

Supermemo provides the repetitions in a 'question', 'answer' flashcard format. In this study, the questions were the same for all participants in both groups (digital and print). However, the answers presented in the program after the recall attempt had been made were set to be different for both groups.

The digital group had the answer to the vocabulary item presented in the interface of the program. The print group had the POSITION of the answer presented in the interface of the program; the position being a reference to the page number of a booklet that was handed out to the members of that group.

The content of both answers in the program's interface for the digital group, and the answers in the booklet of the print group, were both identical in font size and content.

The laptops used were not all of the same type and size, as each laptop was the user's own personal property. However, the type of screen was LCD across all laptops.

The study material itself was derived from the Al Mawrid Arabic-English dictionary. It comprised of flashcards of 50 vocabulary words; this was transferred onto paper for the print group, and the booklet comprised of 25 double-sided pages with both the Arabic meaning and its English equivalent. Page dividers that stuck out from the booklet lined the long side of the booklet and served as quick finders to select the page in mind. Each page was placed between two page dividers, which covered the entirety of the page. This was done to prevent accidental, non-data-based learning that was queued by Super Memo, in order to prevent interference with the results.

3. Procedure

To begin with, the participants were briefed about the study by their lecturer. The lecturer had set a course objective: to adhere to the requirements of the study in order to learn a pre-set range of difficult English vocabulary. This was relevant to the students' course, as it was a 2nd Language English course. Full adherence to the study was going to be rewarded with 30 marks as part of the university program, specifically in the Free

Reading component. The students were further motivated by being briefed on the nature of the program that would be used to conduct the study; it was explained that it was going to help them achieve 96% rates of retention long-term using the least effort required to maintain such a high standard.

Participants were initially given BAC (Books and Computers) Questionnaires (Garland, K., Noyes, J., 2006) which enquired about their level of experience with regards to various aspects of computing. After that, the participants were given a vocabulary assessment which contained all the words that were to be used in the study. The vocabulary was assessed by presenting the English word to the participant on paper, and by asking them to define or translate that term into their native language (Arabic) on paper. Words that were correctly identified were replaced with words that were unknown to the participants.

The participants were given a presentation by the researchers, whereby the study's purpose was explained, and instructions were given on how to operate the program that was going to be utilized in the study. Any questions posed at that point were answered (the instructions were augmented with the physical guidance of the researchers in order to ensure complete understanding).

Super Memo was installed onto each of the participants' laptops separately by the researchers, and the settings were adjusted by the researchers in order to ensure standardization of retention level.

Immediately after the program was installed, the digital group's participants were instructed to spend 40 minutes doing repetitions of the entire vocabulary list, whilst the print group's participants were instructed to spend 45 minutes doing repetitions of the entire vocabulary list.

Prior to starting the program repetitions, the grading system was explained to the participants thoroughly, and they were provided examples during the briefing presentation. Also, detailed descriptions of the 6 level grading system was given out in the form of paper notes to the participants, and they were instructed to adhere to the descriptions whilst grading their repetitions.

The first learning session was immediately followed by a 30 minute assessment of the vocabulary knowledge, whereby the students were asked to translate an Arabic word into its English meaning. The English words that were to be used had to be part of the 50 original words provided to the participants. Accompanying the answer, a 4 level grading system identical to the one described earlier was to be utilized by the participant.

This examination was repeated 5 times, at the following intervals.

Examination 1: Immediately after first learning session

Examination 2: Two days after examination 1.

Examination 3: One week after examination 1.

Examination 4: Two weeks after examination 1.

Examination 5: Three weeks after examination 1.

There were no monitored study sessions performed immediately prior to the examinations except in the first examination session; for the remainder of the study, the learning of the set vocabulary was instead confined to the recommendations of the Super Memo program on a daily basis. The number of repetitions that could be done at home could not exceed the limit recommended by Super Memo, but participants had the option of not doing all the repetition that Super Memo had recommended for a specific day.

Super Memo recorded the number of repetitions each participant had done at home for every single separate item of vocabulary, and this was compared to the results of the vocabulary assessment, specifically that of the grading system statistics collected from the examination sessions. Such comparisons were done for the digital group in order to attempt to identify if there was any significant relationship present. This was then repeated for the print group, and the collective analysis was then compared.

3.1 The examination sessions

Examination 1: The full set of 87 participants (45 from the digital group and 42 from the print group) sat the assessment after a quick briefing regarding the nature of the program. It is important to note that a considerable number of these participants did not cooperate fully with the study. In such circumstances, those individuals were removed from the study analysis, so as not to distort the findings. Of the 87 participants, only 60 were considered valid (40 from the digital group, and 20 from the print group).

The grading system used in the program had been explained on 2 different occasions, and was explained a third time on the day of the examination. Detailed descriptions of the 6-level grading system was given out to the participants, and they were instructed to adhere to the descriptions whilst grading their repetitions.

The participants in the digital group were given 40 minutes, whilst those in the print group were given 45 minutes (thus accommodating for increased time required to locate words from the booklet) to do as many repetitions as they could from the program for the first time, and were then immediately presented with the paper examination.

Examination 2: 80 participants attended the 2nd examination (43 Digital and 37 Print). After ruling out the invalid cases, 40 remained in the Digital group, and 20 in the Print group. The examination was not immediately preceded by a learning session; the last learning session would have been done at home the night before.

Examination 3: The same participants attended the 3rd examination, with 39 being valid for the Digital group, and 22 being valid for the Print group. The procedure was done in the same manner as that of the previous examination.

Examination 4: 76 participants attended the 4th examination session, (41 Digital and 35 Print), in the same manner as that of the previous examination. Of those, 38 were valid for the Digital group and 22 were valid for the Print group.

Examination 5: 76 Participants attended the final examination, in the same manner as that of the previous examination. Of those, 38 were valid for the Digital group and 22 were valid for the Print group.

4. Results

4.1 Remember/Know Paradigm Shift

A series of Chi-square tests were conducted to compare between the frequency of the digital and the paper groups' responses across five assessment sessions. The results showed a significant shift from guess and familiar into remember between sessions 1 & 2 ($p=.014<.05$) (Table 1), and sessions 2 & 3 ($p= .032$) (Table 2) within the digital group only. This may indicate a sooner shift to remember within the digital group compared to the paper group. Paper group, however, showed a significant shift to remember between sessions 3 & 4 ($p= .02<.05$) (Table 3).

As for sessions 4 & 5, the results showed that none of the two groups (digital/paper) showed any significant shift to remember between the two sessions. This could be an indication to a general sooner shift to remember amongst the digital group.

The shift to know, on the other hand, tended to occur at a similar rate within both paper and digital groups across the first three assessment sessions, as indicated by the significant p values of the Chi-square tests ($p=.001$/ $.002$; $.001$/ $.001< .05$) (Tables 4 & 5).

The results of the fourth assessment session have also showed a significant shift to Know, when compared to the results of session three ($p= .03$; $.03< .05$) amongst both digital and paper groups (Table 6). Similar significant results were shown between sessions 4 & 5 amongst both groups ($.03$/ $.01< .05$) respectively (Table 7).

Bearing in mind the big number of significant values that the Chi-square tests represented across the various sessions of assessment, we decided to look at a mean-graph that represents the mean scores of the two groups on remember/know responses of the two groups (digital vs. paper), and across the five performed sessions of assessment. Evaluation of the mean scores, we believe, would help us to identify the group with the sooner shift to remember/know responses.

4.2 Mean remember/know response comparison

A thorough examination of the line graphs (Figures 1 and 2) that represent the mean scores of Remember/Know responses of the digital vs. print groups across the five sessions showed that the two groups have scored their lowest means in session one, and gradually escalated, yet with a few exceptions, throughout sessions 2, 3, 4 and 5.

The digital group responses showed a higher mean of remembering when compared to the paper group in session 1, a finding that may have indicated a more efficient short-term memory as the session took place right after looking at the information from their laptop screens or booklets. On the other hand, Remember responses escalated up to a higher level in session 2, where both groups performed almost equally.

In session 3, however, the digital group showed a significant performance progress, as their Remember responses dropped in favour of Know responses. Yet, such a drop did not apply to the paper group, who showed a continuous escalation towards higher means of remembering along the same session. A larger difference in the mean scores of the digital group on remembering in session 3 may signal a more powerful shift towards the Know response amongst the participants in the digital group compared to the paper group (2.75, 13.79; 8.17, 9.26 respectively). In session 4, the digital group has shown significantly higher performance with their mean scores reaching point 13.79, compared to the paper group whose means have only escalated from 8.00 to 9.00. The huge shift in remembering tends to slightly drop in session 5, as the digital mean score decreased from 14.00 to 11.00. The paper group however, seems to have almost stabilized at that point (9.26, 9.33).

Similar to Remember responses, the participants' Know responses tend to be at their lowest level in session one for both digital and paper groups. A huge shift towards Know response in session 2 is shown through the mean scores for both groups, with a difference reaching almost six points from the previous session. In session 3, the results indicate a continuous progress towards Know response by the digital group, yet, an unremarkable

progress by the print group. Session 4 results' indicate a steady progress towards Know response, which tends to accelerate by session 5, where the shift to Know seems to have reached its highest point. Likewise, the paper group results show a steady progress towards Know response, yet, at a slower pace.

In general, one could conclude that the digital group' mean scores reveal a more accelerated shift towards Know response.

4.3 Total frequency of repetition, total spent time, and average forgetting index

A one-way between groups analysis of variance was conducted to explore the impact of medium (digital vs. print) on the total number of repetitions, total time spent learning, and the average percentage of forgetting index, as measured by the Super Memo program. The measured forgetting index is a value measured by the program, which states the percentage of items being forgotten during study periods.

Subjects were divided into two groups according to their assigned medium of revision (Group 1: Digital & Group 2: Paper). The results showed no statistical significance for the two groups on any of the dependent continuous variables, namely frequency of repetitions, average revision time and forgetting index.

Despite the statistically insignificant results, there seems to be a tendency of the subjects within the digital medium group to reach out to higher number of repetitions, longer spent time, yet unremarkable difference percentages of forgetting index with the means of the two groups reaching (1084, 841; 84m, 55m; 40%, 42%) for the three above mentioned variables respectively (Figures 3 and 4).

Bearing in mind the importance of the three above mentioned variables (frequency of repetitions, total spent time, individual forgetting index) as strong confounding factors that might have affected the participants' memorizing abilities, it was extremely essential to measure their effects on the participants' memorization process. Finding no significant differences between the two groups in terms of the three above mentioned variables would strengthen our findings in relation to the medium of revision utilized by each group.

5. Discussion

According to the results yielded from the study performed, a number of conclusions may be reached. However, before such conclusions are set in stone, factors that may have implications upon the results will first be discussed. Such factors have been alluded to throughout the review section of the paper, and will now all be brought together to complete the picture.

The first and most important factor that must be mentioned is that of the applicability of such conclusions to male and female sexes in the future. After a thorough analysis of the differences in learning between males and females, it was concluded that males have a much more highly developed spatial memory in comparison to females, whereas females are superior to males in verbal memory.

The implications for such conclusions are obvious; verbal memory is essentially a form of semantic memory, in that it constitutes highly abstract information. Spatial memory, on the other hand, is much more highly episodic, as episodic memory includes source locations and surroundings. It is therefore erroneous to assume that the results of females in this study can be applied to males as well.

On that note, it is fair to say that it is unwise to allow a mixture of male and female participants to take part in a study of this nature, as the differences will distort the true findings and lead to erroneous results. Such considerations have not been made in all the previous studies looking into learning differences between either medium. This may perhaps explain some of the inconsistencies between such studies, and at the same time, weakens the validity of their results.

The second factor is that of the frequency of repetitions of individual items made. It was concluded in the review that frequency of repetition or rehearsal of information has an effect on recall; the higher the frequency of repetitions, the greater the shift from episodic memory into semantic, and the faster the retrieval speed. Such an effect is consistent when repetitions are done in moderation. However, with very high repetitions, a counterproductive effect is seen, and knowledge appears to be withheld in the episodic memory of the brain.

After a thorough analysis of the studies looking into a relationship between digital learning and print learning, it was noted that all the different methods of testing employed did not account for repetition frequency. Whilst for some of the studies, the time frame was monitored and set to be consistent, the researchers had no control over how many times the participants would rehearse a certain item in the allocated time period.

It is clear that not all participants are at equal levels in terms of their ability to learn and memorize, and therefore, some participants may have done many more repetitions than others. As a result, such a confounding factor must be kept in mind when interpreting previous study results.

In the current study however, the total frequency of repetitions was recorded through the Super Memo software. After the results were gathered from the program from each individual participant, it was noted that there was a wide range of variation in total frequency of repetitions amongst the participants. At first glance, this may appear

to weaken the results. However, a better understanding of the Super Memo program must first be established before jumping to conclusions.

Whilst Super Memo is an automated flash-card program, it is dependent upon input from the participant in the form of self-grading of recall ability. The program integrates this input into its preset algorithm, which has been established through extensive research (Wozniak, 2008) over a decade's worth of data by its developer, Dr Wozniak. The program thus decides when the next repetition will be depending upon the ability of the individual, and aims to achieve a level of 96% recall for every user. Therefore, those with poorer memorization ability were required to do more repetitions and spend more time learning than those who were gifted with a better ability to memorize. This ultimately provides a balance whereby all students achieve 96% recall.

This is further demonstrated when the results of total frequency of repetition were statistically analyzed. According to the analysis, there were no significant differences between frequency of repetitions, total time spent learning, and the individual forgetting index of the participants. What this means is that the number of repetitions done had not changed the level of overall retention of the material that was being learnt. Such a finding verifies Super Memo's consistency in achieving a set level of retention, regardless of the ability of the individual.

However, it is still important to note that in order to achieve such a level of retention, the subjects within the digital medium group had to perform a slightly higher number of repetitions, and spend a longer period of time learning. Whether this is related to poorer overall memorization ability amongst the individuals in the digital group, or whether it is due to an inherent inefficiency of the digital group, is something that cannot be differentiated at this point. Still, however, the difference was not statistically significant, and cannot therefore be interpreted into anything conclusive.

Interestingly, the results had showed that there occurs a significant, sooner shift of recall from Guess/Familiar to Remember amongst the digital group. This implies that studying from a digital LCD screen allows for the transfer of knowledge into episodic memory faster than studying from paper.

Such a finding has not been demonstrated in the literature previously, and is contrary to common sense. One would assume that there would be less interference in a paper booklet than in an LCD screen, as the position of the answers in the booklet provide an extra dimension of spatial information. This should theoretically contribute to a better episodic recollection. Perhaps it is the poor spatial ability inherent in females that resulted in less interference occurring during digital repetitions, and, whilst the repetitions that they did were slightly (although not significantly) more numerous, such a difference may have manifested.

However, we have already established that it is semantic recall that points to superiority. This was represented by the shift to ‘Know’ responses, and it was shown that such a significant shift tended to occur at a similar rate within both paper and digital groups across the assessments.

But when the mean scores of the two groups on Remember/Know responses were compared, it was noted that the digital group demonstrated a more accelerated shift towards Know response, as the number of jumps from Remember to Know were greater in the last 3 sessions, compared to the slower but more consistent and steady pace of Remember-to-Know shift happening across the assessments within the print group.

Such a finding could suggest that the digital learning may provide a very slight advantage, albeit insignificant, over paper learning, in promoting semantic recall. However, bearing in mind the previous studies that state the superiority of paper over digital, and bearing in mind the slightly (albeit insignificant) increased total frequency of repetition in the digital group-regardless of its null effect on forgetting index- it would be unwise to assume such a relationship.

Another finding that is worth noting was the fact that as many as half of the Print group participants were considered invalid for the study, and were thus not suitable for the analysis phase of the study. They were classified as being invalid due to their lack of commitment to the repetitions required by the Super Memo program. Such a phenomenon occurred to a very minor degree in comparison amongst the Digital group. This appears to suggest that difficulty plays an important role in learning: if the participant does not have to exert a significant amount of effort locating the information that is to be learned, or if the information accessed can be more immediate, the participant is much more likely to commit to learning over long periods of time. This method can be easily done for digitalized information, but the same cannot be said for paper-based information in textbook format, which requires the student to locate the information and browse through pages first.

6. Conclusions:

After a thorough analysis of the results, the previous similar studies, and accounting for the many confounding factors, a number of conclusions may safely be reached.

Firstly, previous studies investigating the differences between effects of learning from digital sources versus learning from paper sources have included mixed populations of male and female sexes, and have therefore distorted results which may well have lead to inaccurate conclusions. This means that similar tests need to be

repeated for both sexes in the future, in order to separate the different effects of sex on learning type, and thus provide more accurate guidance for the future generations faced with such questions.

Secondly, it was concluded that there was no significant difference between learning from a digital source versus learning from a paper source amongst females, as the female object location memory -better understood as spatial ability- is not developed to the point where the extra dimension of spatial information supplementing learned knowledge would make a significant difference.

Future recommendations from the authors would be to stress the important role of software as a tool for research amongst researchers, especially in the field of cognitive psychology. Over the course of the study, it was realized that the use of software technology such as that of Super Memo in assessing memory and learning can provide a big leap towards more accurate measurements, and can achieve tasks that were previously not achievable due to the limits of the tools available. It is therefore essential that researchers be aware of such tools, and that they achieve a reasonable level of proficiency in them in order to fully put them to use.

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Table 1: Digital vs. Print shift to **Remember** in sessions 1 & 2

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	142.781[a]	108	*.014
	Likelihood Ratio	93.214	108	.844
	Linear-by-Linear Association	14.712	1	.000
	N of Valid Cases	40		
2 Paper	Pearson Chi-Square	42.807[b]	32	.096
	Likelihood Ratio	30.579	32	.538
	Linear-by-Linear Association	2.852	1	.091
	N of Valid Cases	20		

Table 2: Digital vs. Print shift to **Remember** in sessions 2 & 3

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	229.984[a]	192	*.032
	Likelihood Ratio	129.725	192	1.000
	Linear-by-Linear Association	8.741	1	.003
	N of Valid Cases	40		
2 Paper	Pearson Chi-Square	124.292[b]	104	.085
	Likelihood Ratio	65.434	104	.999
	Linear-by-Linear Association	10.887	1	.001
	N of Valid Cases	19		

Table 3: Digital vs. Print shift to **Remember** in sessions 3 & 4

Medium		**Value**	**Df**	**Asymp. Sig. (2-sided)**
1 Digital	Pearson Chi-Square	374.021[a]	336	.075
	Likelihood Ratio	160.937	336	1.000
	Linear-by-Linear Association	4.962	1	.026
	N of Valid Cases	39		
2 Paper	Pearson Chi-Square	220.183[b]	182	*.028
	Likelihood Ratio	91.139	182	1.000
	Linear-by-Linear Association	8.137	1	.004
	N of Valid Cases	22		

Table 4: Digital vs. Print shift to **Remember** in sessions 4 & 5

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	405.228[a]	399	.404
	Likelihood Ratio	166.407	399	1.000
	Linear-by-Linear Association	5.829	1	.016
	N of Valid Cases	38		
2 Paper	Pearson Chi-Square	225.042[b]	196	.076
	Likelihood Ratio	90.598	196	1.000
	Linear-by-Linear Association	14.606	1	.000
	N of Valid Cases	22		

Table 5: Digital vs. Print shift to **Know** in sessions 1 & 2

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	106.615[a]	65	*.001
	Likelihood Ratio	46.734	65	.958
	Linear-by-Linear Association	3.940	1	.047
	N of Valid Cases	40		
2 Paper	Pearson Chi-Square	69.708[b]	40	*.002
	Likelihood Ratio	43.958	40	.308
	Linear-by-Linear Association	7.186	1	.007
	N of Valid Cases	21		

Table 6: Digital vs. Print shift to **Know** in sessions 2 & 3

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	321.924[a]	234	*.000
	Likelihood Ratio	125.571	234	1.000
	Linear-by-Linear Association	30.713	1	.000
	N of Valid Cases	40		
2 Paper	Pearson Chi-Square	117.698[b]	72	*.001
	Likelihood Ratio	55.496	72	.925
	Linear-by-Linear Association	15.032	1	.000
	N of Valid Cases	20		

Table7: Digital vs. Print shift to **Know** in sessions 3 & 4

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	468.480[a]	378	*.001
	Likelihood Ratio	166.689	378	1.000
	Linear-by-Linear Association	11.202	1	.001
	N of Valid Cases	39		
2 Paper	Pearson Chi-Square	115.451[b]	90	*.037
	Likelihood Ratio	56.857	90	.998
	Linear-by-Linear Association	16.439	1	.000
	N of Valid Cases	22		

Table8: Digital vs. Print shift to **Know** in sessions 4 & 5

Medium		Value	Df	Asymp. Sig. (2-sided)
1 Digital	Pearson Chi-Square	561.028[a]	500	*.030
	Likelihood Ratio	184.031	500	1.000
	Linear-by-Linear Association	9.029	1	.003
	N of Valid Cases	38		
2 Paper	Pearson Chi-Square	181.867[b]	143	*.016
	Likelihood Ratio	77.956	143	1.000
	Linear-by-Linear Association	15.082	1	.000
	N of Valid Cases	22		

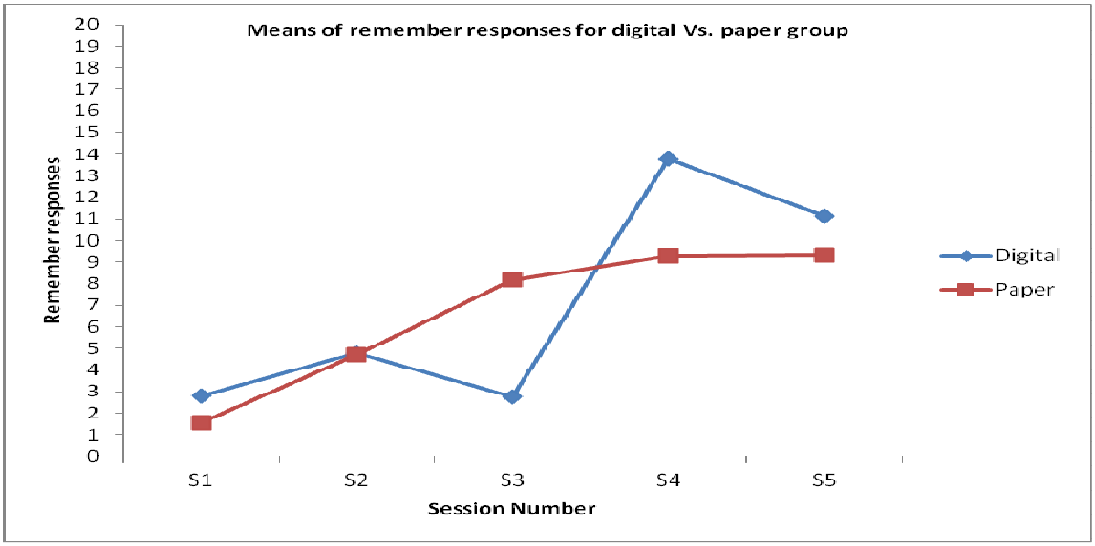

Figure 1. Accumulative mean of Remember responses (Digital vs. Print) across 5 examination sessions

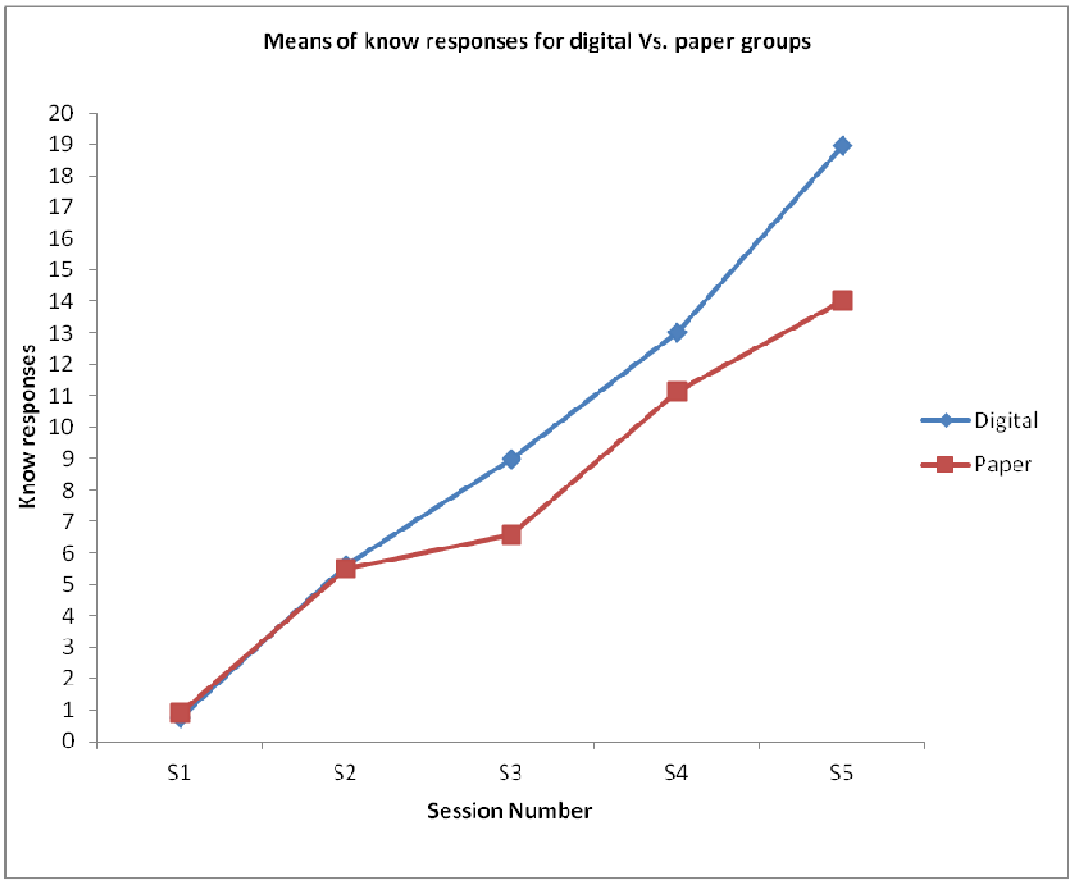

Figure 2. Accumilative mean of Know responses (Digital vs. Print) across 5 examination sessions.

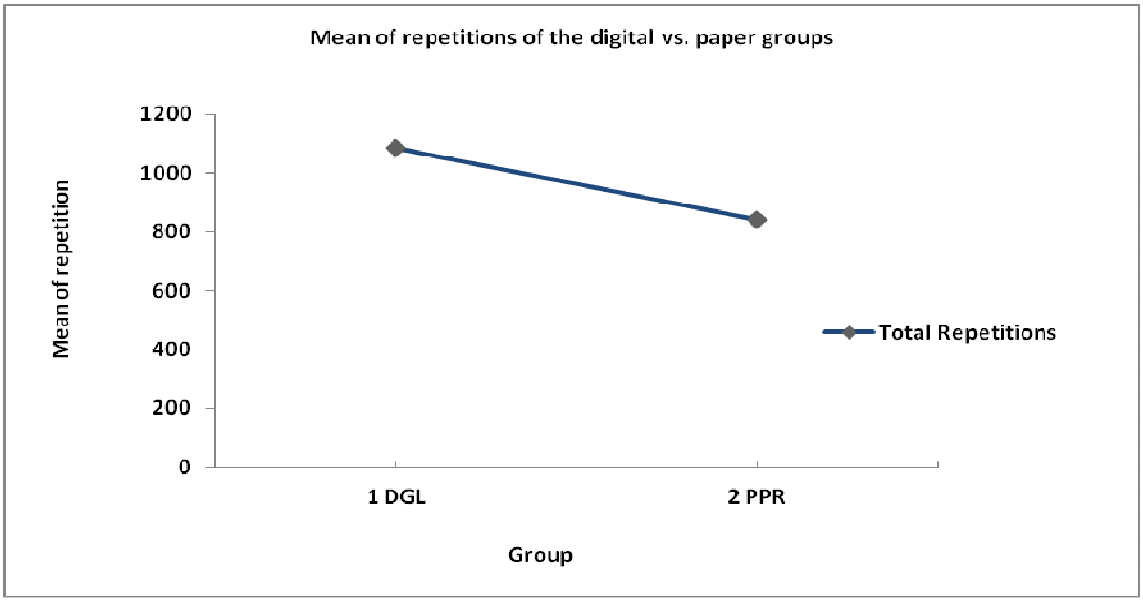

Figure 3. Average frequency of repetitions in Digital vs. Print groups

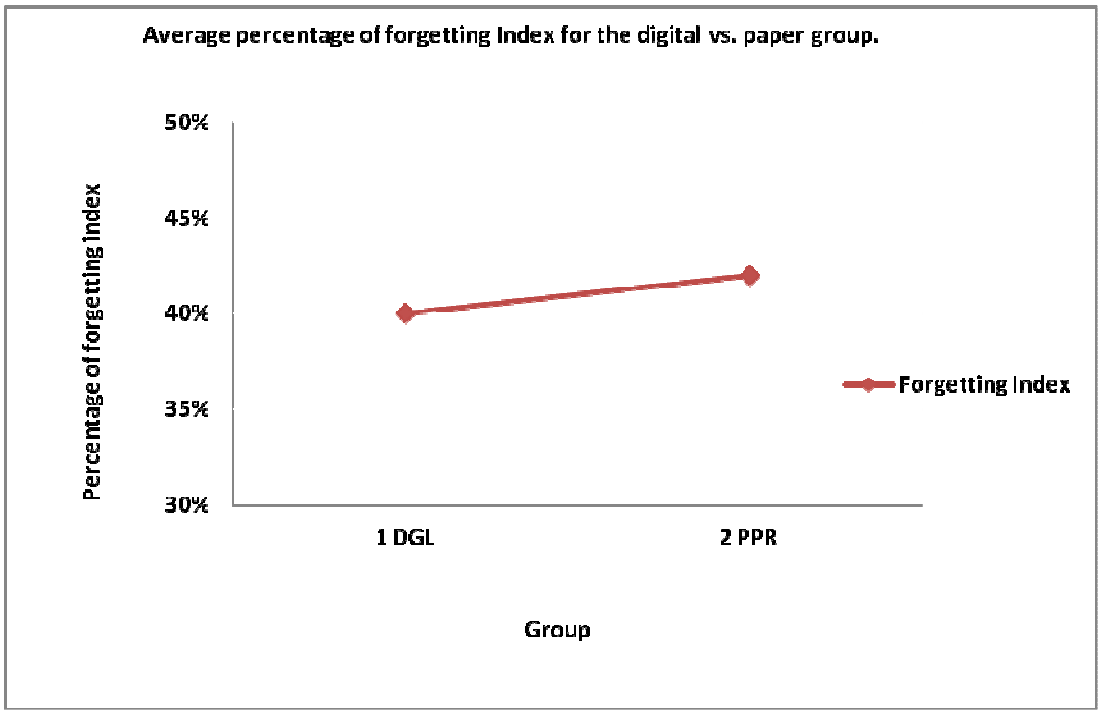

Figure 4. Average forgetting index in Digital vs. Print groups

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