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Personal computing device interfaces and their impact on learning in South African secondary school students

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Supervised by Dr Michael Pitman



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A dissertation submitted to the Faculty of Humanities in fulfilment of the requirements for the degree of Master of Arts by research in the discipline of Psychology.

University of the Witwatersrand, Johannesburg, 2017.

Abstract

Education is an immensely powerful agent of development and innovation and as such, educational outcomes are given high priority in most settings. The advent of highly functional mobile personal computing (PC) devices such as tablet computers and related technologies has helped to generate great interest in and hype surrounding educational technology and its potential to improve educational outcomes, democratize knowledge and skills development and to kick-start development, particularly in socio-economically depressed environments. However, education has made use of technology from its very inception, with the written word itself being a prominent example, making PC device-based educational technology simply a newer entrant into the field, equally worthy of scrutiny along with other existing technologies. The written word plays a fundamental role in learning and is therefore a key vehicle through which to examine the impact of PC device-based educational technology on learning.

This dissertation examines the notion of the analogue (physical) and digital word and uses both existing theoretical considerations and research experiments to better understand differences which may exist between the two and the subsequent impact on learning. Existing empirical evidence and a range of theoretical contributions are used to construct a theoretical framework which argues for the uniqueness of the digital in comparison to its analogue predecessors. A research experiment was conducted with high school-age research participants using tablet PCs and printed paper to complete a reading task or a reading and note-taking task, followed by a test on the text passage read approximately one week later. Results obtained suggest real, but weak effects, with participants using paper performing better for questions which test factual recall in the reading-only condition and better for questions testing conceptual understanding in the reading and note-taking condition. These findings support the view that the digital word is not necessarily

equivalent to its analogue predecessors and point towards further research in this area. It is concluded that further research is required in order to better understand the mechanisms which underpin the digital word and that its primary strength lies in its ability to expand the usefulness of the written word in conjunction with the more traditional analogue word.

Key words: educational technology, reading, handwriting, the digital word, tablet PCs e-learning.

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To those who hold a special place in my heart, mentioned and unmentioned, thank you for who you are. You are very special to me.

Declaration

I declare that:

Personal computing device interfaces and their impact on learning in South African secondary school students

is my own, unaided work. It is being submitted in fulfilment of the requirements for the degree of Master of Arts in the field of Psychology to the University of the Witwatersrand, Johannesburg. It has not been submitted before for examination at any other university.

Signed on this, the 15th day of March 2017

George Thomas Wrigley

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Chapter 1

Introduction

1.1. Educational technology and PC devices in education

Education carries with it immense potential to effect lasting change. It has been described as the "most powerful weapon we can use to change the world" (Mandela, 2003), an assertion few would challenge as hyperbole. One of education's most important strengths is its unique ability to drive human advancement by facilitating technological development and socio-economic development at both micro- and macro-economic levels, among other areas. Given the principal importance of education, technological tools which proffer enhanced and more effective learning – i.e. educational technology (Garrison, 2003; Richey, Silber & Ely, 2008) – are an exciting and important area of research and development.

Arguably the primary medium through which 'modern' educational technology (ET) is seen to be implemented is personal computing (PC) devices. Although the term 'PC' is most often associated with desktop computers, in this context refers a range of personal computing electronic devices, from the pocket calculator to desktop computers, smartphones and tablet PCs. All of these devices are used as educational tools in at least one context, with their prevalence being largely a function of income levels and device cost, although a range of other factors also come into play.

The oldest of these devices – the pocket calculator – is also one of the most widespread and widely-used (Banilower et al., 2013). In the educational context, desktop PCs are generally either owned and operated by private users (individual learners and/or their families) or are present in facilities such as libraries or computer laboratories and have multiple users per device (Cuban,

2003). Laptop computers are more portable than desktop PCs and are more often individually owned and operated than desktops (again, in the educational context), although individual learners owning a laptop for their exclusive personal use is generally but not exclusively limited to higher-income families and university students. Smartphones can be used as educational tools but their roles are typically different to other PC devices due to a range of factors including their size and functionality (Cuban, 2003). Tablet PCs as modern, mass-market consumer electronics devices are the most recent of these PC devices – the first-generation Apple® iPad™, for example, was only released in 2010 (Apple® Inc, 2010). With their relatively large screen size, functionality, portability and (relative) affordability, it could be argued that tablets have already impacted educational technology more than any of the preceding PC devices (Rossing, Miller, Cecil & Stamper, 2012; Schnackenberg, 2013).

Touted as modern replacements for traditional textbooks, there appears to be a significant amount of support for the adoption of tablets in education both in South Africa (Blom, 2013) and countries such as the United States (BBC News, 2015), with large-scale, high-cost projects to implement tablet usage in classrooms being initiated in the Gauteng Province of South Africa (Falanga, 2015), Los Angeles, California (BBC News, 2015) and elsewhere in the world.

'One-tablet-one-child' projects and related developments follow a more general educational shift towards computer-based and computer skills-centred learning, with the decision by Finnish schools to cease teaching handwriting and cursive in favour of keyboard skills (BBC Monitoring, 2014) being one example of this. The ever-increasing predominance of computers in the modern world is often pointed to as the primary reason for this shift, although additional factors may play important roles as well, varying from context to context.

The use of tablets and other PC devices in education as well as educational technology are controversial topics (Mueller & Oppenheimer, 2014; Ong, 1982), with this controversy extending to a wide range of spheres. The prominence of these topics has also significantly increased since the introduction of (relatively) affordable tablet PCs, which has made the notion of one-device-per-child more feasible for middle- and lower-income communities and countries than ever before. Part of the reason for the scale of this controversy is the sheer number of players and observers involved in the debate. Insights and opinions on PC devices in education as well objections to and support for their use are regularly offered by a wide range of players and observers including those actively working in education, academics, government officials and politicians, commentators, parents, commercial entities, non-governmental organisations and others (e.g. Carr, 2010; Conlon & Simpson, 2003; Cuban, 2001; Hixon & Buckenmeyer, 2009; Kakaes, 2012; Karafiol, 2012), each acting from within a unique set of motivations.

Support for the adoption of tablets in education is, however, by no means universal. The rather high-profile failure of a USD $1.3 billion project involving the distribution of iPads to a large number of schools in Los Angeles, CA (BBC News, 2015) serves as a reminder that many of the questions and criticisms of tablet-based educational technology remain largely unanswered. PC-based educational technology in general is, however, no stranger to controversy.

From the time of their introduction into the classroom criticism has been levelled at pocket calculators (an early PC-based educational technology) by parents and other parties, with a major concern the notion that use of calculators introduces an extrinsic resource which effectively subverts the intrinsic resource that is rote-learned multiplication tables, replacing the activities which ought to be used and which the mind requires to maintain its vitality with a tool that simply enervates the mind (Ong, 1982). Similar charges have been brought against computers and search

engines such as Google™. The rapid proliferation of smartphones and tablets as well as the subsequent increase in average usage of these devices, search engines and other Internet-based resources have only increased these concerns.

1.2. Rationale

Research studies conducted thus far into various aspects of PC-based educational technology have reported a range of findings on performance differences (e.g. Benedetto, 2008; Mueller & Oppenheimer, 2014; Wästlund, 2007), with some results clearer than others. Academic research into the impact and effectiveness of 'screen-based' educational technology (i.e. desktop computers, laptops, tablets and e-readers) has generally investigated performance differences between one or more of these devices and more traditional paper-based tasks for both reading and writing as well as related issues such as visual fatigue caused by paper in relation to screen-based devices. The general consensus thus far appears to be that important differences exist between screen and paper (Jabr, 2013), but that these differences are not yet well-understood (Wells, 2012). Much of this work involves investigating performance differences in reading comprehension between paper and other devices. Although an integral part of the learning process, comprehension is not necessarily a strong measure of learning performance itself – a more ecologically valid measure of learning is required, with Mueller and Oppenheimer (2014) providing an example of such a measure.

Existing research is also largely focused on measurable performance differences and is accompanied by a relative paucity of theoretical work in this area. There is reason to believe that this lack of theoretical work is at least one of the primary reasons for our relatively limited understanding of the reasons for the differences which exist here and that this calls for more sophisticated conceptualisations to accompany and inform further empirical research.

The rationale for this research is thus two-fold. Firstly, our theoretical and conceptual understanding of the differences between the digital and analogue word (i.e. between 'screen-based reading' and more traditional tools like paper and pen) in the educational context is fairly limited. There is, therefore, a need for more research which would contribute to the existing body of knowledge. A theoretical framework will be used to argue that the digital word presents a distinct evolutionary step in the history of the written word, with meaningful differences to the various types of written word which have preceded it. Secondly, it is not clear whether the use of these PC devices (and in particular tablet PCs) as educational tools will in fact enhance educational outcomes and if so, what the extent of their impact will be (whether negative or positive). The digital word has already made significant inroads and continues to spread rapidly within many educational settings. A range of factors and past events suggests (i.e. the ongoing and rapidly increasing proliferation of such technology world-wide) that the use of the digital word will continue to expand regardless of any potentially adverse academic findings. A degree of pragmatism therefore seems the best approach in this setting – utilizing academic research and knowledge-discovery to aid in the more effective usage of the digital word in education (whose significant positive effects and impact on socio-economic development are well-known). Given the substantial financial investment required to implement the use of these devices in classroom settings (particularly on the scale proposed for the Gauteng Province and similar projects elsewhere in the world) and the potential implications of the digital word on educational outcomes and indeed human thought itself, the need to deepen and strengthen our understanding of the effects of these devices is clear, particularly in relation to more traditional tools (such as pen-and-paper based longhand and paper textbooks and other learning materials).

1.3. Research aims and focus of this research project

(1) To better understand the impact on and effectiveness of personal computing device-based educational technology on educational outcomes in comparison to more traditional educational technologies like pen and paper.

(2) To further develop a theoretical framework which aids in better understanding and explaining the impact on and effectiveness of personal computing device-based educational technology on educational outcomes.

1.4. Research questions

(1) Are there differences in learning (incorporating a delay of approximately one week between reading task and test) when text is read (only) on paper compared to when this is done using a tablet PC only?

(2) Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read and notes are taken on paper compared to when text is read and notes are taken using a tablet PC?

(3) What differences exist, if any, between the results of research questions 1 and 2 and what is the nature of these differences?

(4) Are there differences in learning (as measured by test performance) if the delay between reading task and test (research question 2 – note-taking) is reduced from approximately one week to several days?

1.5. Chapter organisation

Chapter 1 provides a brief introduction to educational technology, this research project, its rationale, research aims and research questions and a short list of terms and abbreviations. Chapter 2 is an examination and discussion of relevant existing empirical literature. Chapter 3 details relevant theoretical considerations, leveraging several theories to construct a suitable theoretical framework for this dissertation. Chapter 4 is a methodological overview of the research activities undertaken, while Chapter 5 details the results of these research experiments. Finally, Chapter 6 discusses the results obtained and their implications in light of Chapter 3's theoretical framework, before concluding.

1.6. List of terms and abbreviations

Analogue word – physical text present on physical items, existing such a way that the text and the item form a *de facto* singular entity (e.g. text which is written or printed paper).

AT – Activity theory

CHAT – Cultural-historical activity theory

Digital word – electronic screen-based text, defined chiefly by its physical non-permanence on the screen itself, existing as a projected (where projected refers to any form of electronic display), virtual entity.

GDE – Gauteng Department of Education.

SSIP – Secondary School Improvement Programme

Writing – when used in relation to Ong (1982), the term 'writing' generally refers to the written word in contrast to the spoken word and is more or less interchangeable with the term literacy.

When used elsewhere in this dissertation, the term generally refers specifically to the act of writing, unless otherwise stated.

Chapter 2

Literature Review – Part 1

Existing Empirical Literature

2.1. Introduction and overview

The existing body of literature on empirical studies related to the concept of the digital word, while relatively small in comparison to many other topics, is nonetheless sizeable. It is therefore necessary to more clearly define the scope and focus of this literature review in the context of this dissertation.

Chapter 1 provides an overview of PC devices as educational technology and the need for greater conceptual and practical understanding in this regard. The overarching aim of this dissertation is to better understand the differences which exist between the digital word (and by extension digital devices, particularly tablet PCs) and the analogue (i.e. print and written) word (and by extension traditional learning materials such as paper) in terms of their effectiveness as educational technology and their impact on educational outcomes. In Chapter 2 existing empirical research and related literature which is relevant to the aim will be reviewed. Chapter 3 will then leverage the existing empirical literature of Chapter 2 in conjunction with several theoretical perspectives to generate a useful theoretical framework for the purposes of this dissertation.

2.2. Existing empirical literature

Different role-players in the educational sphere tend to have differing views on the use of technology in the classroom, in particular around the use of personal computing (PC) devices such as laptop computers and tablet computers (e.g. Carr, 2010; Conlon & Simpson, 2003; Cuban, 2001;

Hixon & Buckenmeyer, 2009; Kakaes, 2012; Karafiol, 2012), with a range of academic journals dedicated to research in this area, including *Computers & Education* (Elsevier), *Journal of Educational Computing Research* (Sage), and *Journal of Computers in Education* (Springer). There is much debate on the nature of the differences between various PC (both mobile and non-mobile) devices and more traditional pen-and-paper based learning in the educational context and the significance of these differences in relation to their effect on educational outcomes (e.g. Mangen, 2013a; 2013b; 2016; Mangen & van der Weel, 2016; Mueller & Oppenheimer, 2014; 2016; Spitzer, 2014). One example of this is the disparity between research which suggests that students on average believe that laptops are beneficial overall and serve to enhance educational outcomes (Kay & Lauricella, 2011) and other research which has found that using laptops in classrooms may in fact be detrimental to educational outcomes (Mueller & Oppenheimer, 2014; Spitzer, 2014). The adoption or uptake of e-books in educational settings has also been significantly lower than what was predicted by some and is accompanied by a strong overall preference among many for paper over electronic media, particularly for reading (Feldstein & Martin, 2013). The factors influencing these decisions are also relatively complex and multi-faceted.

Two of the major focus areas pursued when examining the effectiveness of these devices in the educational sphere involve (1) differences between electronic and paper-based reading and (2) differences between paper-based writing (longhand) and other device input methods (keyboard typing and stylus input). First, literature around reading will be discussed, examining findings on (1) reading comprehension, (2) visual fatigue, (3) deep reading, legibility, and mobile devices, (4) linearity and hypertext, and (5) spatial and chronological memory and emotional responses, followed by a brief summary. Secondly, literature around writing and typing will be reviewed,

discussing findings on (1) note-taking strategies, (2) the encoding and external storage hypotheses, (3) handwriting and keyboard typing, (4) note-taking tools and mechanisms, and (5) the neurophysiological basis of writing, followed by a brief summary and then a chapter summary.

2.3. Reading

Reading comprehension

The electronic versus paper for reading debate is not limited to educational research, but occurs more generally in the e-books vs paper books debate. This is a debate which rages on, with studies coming to different and at times conflicting conclusions (see Mangen, 2013a; 2013b; 2016; Mangen & van der Weel, 2016; Noyes & Garland, 2008; Oh, 2013; Wells, 2012).

As Wells (2012) notes, research into the impact of electronic reading on academic performance is limited. Existing studies which have attempted this are limited by factors such as small sample sizes, methodological limitations and lack of sufficiently detailed data to rule out possible confounding variables. Wells (2012) found no substantial differences between e-reading (on a tablet PC) and print both for reading comprehension and levels motivation for reading in U.S. high school and middle school learners and Taylor (2011) also found no significant differences in comprehension between students reading digital- and paper-based texts. Mangen, Walgermo and Brønnick (2013), on the other hand, found that Norwegian high school learners reading from paper performed significantly better on reading comprehension than learners who read from computer screens.

Kretzschmar et al. (2013) conducted a detailed and carefully executed study leveraging both EEG and eye-tracking equipment to examine whether reading text on a tablet PC or an e-

reader required greater cognitive exertion than reading from a piece of paper. No significant differences were observed across all three devices for all of the measures – comprehension, EEG or eye-tracking results, observing only that the improved contrast afforded by the tablet PC screen may be beneficial for older adults whose contrast sensitivity has faded. However, despite the meticulous nature of Kretzschmar et al.'s (2013) experimental setup, its findings are not particularly helpful. Each participant in this study read texts with mean length of only 222 words divided into three short pages, with participants taking approximately 25 seconds to read each page. In addition, participants were required to fixate on a black square in the corner of a blank page in between every page, for all three devices. It is not clear that a reading experiment in which pages take only 25 seconds to read, without any direct physical interaction with the device and with several seconds of staring at a blank screen in between turning/changing pages represents a meaningful or ecologically valid representation of real-world reading. The artificial nature of the experimental setup thus appears to have removed most, if not all, of the factors which differentiate these three types of devices in real-world reading.

Furthermore, assessing text comprehension typically involves testing participants immediately after completing a reading task, which differs from learning. Although learning does involve reading (and is influenced by comprehension), it also introduces a meaningful time-delay between task and testing, thereby recruiting additional processes and abilities not present (or not as strongly present) for comprehension tests alone. A better (i.e. more ecologically valid) measure of learning is required to investigate whether digital- and paper-based texts affect learning (the primary focus of education).

What becomes clear upon more detailed examination is that reading is a complex, multi-faceted construct and that the question of electronic vs paper-based reading can probably not be

answered in a simplistic manner. Oh (2013) points out that reading is not a simple, passive process. Instead, reading is affected by factors such as the medium that is used and by reading habits generally associated with specific generations, among others. Different types of reading occur in different contexts, meaning that a single individual could conceivably benefit more from one reading medium in one particular setting and benefit more from another medium in another setting. The individual also engages with the particular medium that is being used and this engagement is not an entirely static process.

Visual fatigue

As Wells (2012) notes, many studies focus on the usability of electronic devices and associated practicalities, rather than specifically on the impact of these devices on academic achievement or their impact on learning outcomes. Questions around usability and practicality, in addition to being interesting research questions in their own right, are also important for questions around impact on learning outcomes as these practicalities will significantly affect device usage. For example, Benedetto, Drai-Zerbib, Pedrotti, Tissier & Baccino (2013) showed that LCD-based electronic reading results in greater levels of visual fatigue when reading for prolonged periods of time when compared both to paper and to electronic ink (or E-ink). In addition to finding that reading comprehension in high school learners is better when reading from paper than when reading from computer screens, Mangen (2013) also found that students reading from computer screens reported greater levels of stress and tiredness. These results are consistent with findings by other studies such as Clark, Goodwin, Samuelson & Coker (2008), Gunter (2005) and Kang, Wang & Lin (2009). If tablets are to be used in the classroom by secondary school students for a full school day plus additional screen time at home, the issue of increased visual fatigue resulting

from prolonged usage becomes very important. This usability issue would then potentially impact academic performance.

Findings around the issue of visual fatigue appear to be consistent with results obtained by Wästlund, Reinikka, Norlander and Archer (2005; cf. also Wästlund, 2007) who concluded that higher cognitive workloads are required when working with and reading using a computer and that scrolling plays a significant part in this. Although this assertion seems highly plausible, no direct empirical evidence or theoretical grounding was provided to support it. This indicates the need for stronger theoretical and conceptual frameworks along with empirical evidence.

Other studies have struggled to obtain statistically significant results when comparing performance differences using electronic devices and traditional paper-based methods. It must be noted, however, that many of these specific studies are limited by small sample sizes and other methodological shortcomings (Wells, 2012).

Deep reading, legibility, and mobile devices

There is evidence that electronic reading harms ‘deep reading’ and promotes a more superficial type of reading or skimming (Bradford, 2012; Dyson & Haselgrove, 2000; Eveland & Dunwoody, 2002; Liu, 2005; 2012; Wolf, 2008), even for different genres and text types (Wolf & Barzillai, 2009; Wolf, Ullman-Shade & Gottwald, 2012). There is also evidence that learners approach paper-based learning with a more studious attitude than electronic device-based learning. Ackerman and Lauterman (2012) found that students studying a text in a self-paced manner performed worse on computers than on paper but performed equivalently when under time pressure. Furthermore, despite the common belief that preference for paper-based books is largely generational, multiple studies have found that most students still prefer paper-based books to e-books (Roesnita & Zainab, 2013; Walton, 2013; Woody, Daniel & Baker, 2010).

Lin, Wu and Cheng (2013) investigated the effects of screen size, character size and text direction on colour LCD-based e-readers and found that all three factors had an effect on participant word search times. Yeh, Lee and Ko (2013) used EEG to demonstrate that background/font colour combinations affect the legibility of icons. Both these studies, however, used Chinese characters and text, which are substantially different in a number of respects to reading alphabetic scripts. Whether these results will translate for languages which make use of alphabetic script must still be investigated.

Within the sphere of personal computers, there are both mobile (e.g. tablet PCs and smartphones) and non-mobile technologies (e.g. desktop computers). Existing research into the potential differences between mobile and non-mobile PCs is limited, although Morelli, Mahan and Illingworth (2014) showed that there is evidence to suggest that completing online selection assessments on either type of device can be considered equivalent. Questions around mobile vs non-mobile devices in the educational context remain largely unanswered.

Linearity and hypertext

A key aspect of digital reading not addressed by studies such as those conducted by Mangen et al. (2013), Taylor (2011), and Wells (2012) is the impact of text linearity versus non-linearity. The prevalence of non-linear text has been greatly increased by the proliferation of hypertext and hypermedia, a common feature on many PC devices. As Tyrkkö (2011) points out, reading text which uses hypertext requires a paradigmatic shift; not a simple feat. Miall and Dobson (2006) found that hypertext encourages shallower and more superficial reading of literary or narrative text – which could form part of the explanation for Wolf's (2008) assertion that electronic or digital text promotes more superficial reading of text.

Before proceeding, it is necessary to more clearly define text linearity (and non-linearity). Nelson (1992, p. 12) provided one of the first definitions of hypertext, saying that it is "non-sequential writing – text that branches and allows choices to the reader, best read at an interactive screen. As popularly conceived, this is a series of text chunks connected by links which offer the reader different pathways." A linear text could then be defined as text which does not branch and which is designed to offer the reader a single pathway through the text. The degree of non-linearity of a text is therefore contingent upon the degree to which the text branches and to which it offers the reader multiple pathways through the text. It should be noted that non-linearity can also be present in non-digital texts. For example, the extensive use of foot-notes and/or end-notes in a non-digital text would also introduce a degree of non-linearity.

While hypertext's non-linearity has, in the past, been touted as one of its key strengths, it is not clear that this is in fact helpful or even neutral (Mangen & van der Weel, 2015), with research into this area finding that the opposite is true. Niederhauser, Reynolds, Salmen and Skolmoski (2000) demonstrated that students using a browsing strategy which is more linear and sequential performed better on tasks measuring learning than those using a more non-linear variety. While investigating the effect of text type and linearity, Zumbach and Mohraz (2008) found that non-linear text presentation (i.e. text nodes which are associatively linked) of narrative text results in an increased cognitive load and subsequently led to lowered levels of knowledge acquisition. Encyclopaedic text was, however, found to be mostly uninfluenced by the linearity (or non-linearity) of text with regards to knowledge acquisition. Given that narratives are, as Mangen and Kuiken (2014, p. 152) note, by their very nature "based on a chronological ordering of actions and events," the importance of linearity for narrative text makes sense.

Spatial and chronological memory and emotional responses

Existing research within the realm of cognitive psychology has established that spatial memory plays a meaningful role in an individual's ability to mentally reconstruct a text (Mangen et al., 2013; Mangen & Kuiken, 2014; Piolat, Roussey & Thunin, 1997; Wästlund, 2007). Related to this is the tendency of individuals to recall the location on a page and approximate idea of which page/where within the text a piece of information can be found, even if the information itself cannot be fully or exactly recalled – an empirically verified phenomenon known as memory for word location (Rawson & Miyake, 2002; Rothkopf, 1971; Zeichmeister & McKillip, 1972; Zechmeister, McKillip, Pasko & Bespalec, 1975). This ability has been demonstrated for both printed (or already-created) text as well as for text that has been written by the reader (Bigot, Passerault & Olive, 2012).

Mangen, Robinet, Olivier, and Velay (2014) reported that participants reading a fictional story (i.e. narrative text) on an Amazon Kindle E-Ink e-reader performed significantly worse at reconstructing the story's plot than those who read the same story on paper. This study tested participants on various details of the story as well as emotional responses, but only reported significant differences for the plot reconstruction factor, contrary to the authors' expectation that differences would be observed for emotional measures, based on previous findings (Mangen & Kuiken, 2014). Criticism has been levelled at this study for the fact that only two of the fifty participants were experienced Kindle users, implying that device familiarity and novelty influenced the results obtained. If this were true, one would expect at least some measures of recall to be affected. However, the fact that no significant differences were observed for any of the measures except plot reconstruction casts doubt on claims that familiarity and novelty played a meaningful role in the study's outcomes.

Mangen and Kuiken (2014) compared participants reading a text from paper to participants reading the same text from an iPad. Although all participants read the same text, half were told the text was a work of fiction, while the other half were told that the text was non-fiction. Participants in the iPad condition (both fiction and non-fiction) were significantly more likely to report difficulty in using and manipulating the iPad as well as reporting significantly higher rates of losing track of where they were in the text than those in the booklet condition. This effect remained even after researchers statistically controlled for familiarity with an iPad or similar technology. Interestingly, despite these differences, participants in both the iPad and booklet conditions were able to fairly accurately estimate the overall length of the text read (number of pages).

Readers in the 'fiction' condition of Mangen and Kuiken's (2014) study displayed no statistically significant differences across iPad and paper booklet conditions. Readers in the 'non-fiction' condition reading from a paper booklet were more likely to report: (1) what was termed by Mangen and Kuiken (2014, p. 158) as 'narrative coherence' (i.e. both "narrative realism" – the extent to which the story appeared convincing, and "cognitive perspective-taking" – understanding character actions and decisions); (2) 'transportation' (losing oneself in the text, mental closeness or 'sense of presence' to the events of the text, and losing track of time); and (3) feeling sympathy with characters in the story at key moments (Mangen & Kuiken, 2014, p. 159). Paper booklet users did not report greater empathy with characters, however, although a greater likelihood of association between transportation and empathy was reported for paper booklet users.

Summary

Existing empirical literature in this area thus suggests that print-based and digital or electronic text are not equivalent for reading and in fact may be substantially different, with paper (as the much older technology) actually performing better for certain tasks. Noyes and Garland

(2008) take this one step further, asserting that: "while equivalence seems impossible, the importance of any differences appears specific to the task and required outcomes" (p. 1352). An additional consideration is the notion that familiarity and other novelty-related effects may play a role in any observed differences. If true, this would require a more nuanced, perhaps complementarian view of the relationship between print and digital text. The range and types of differences reported by existing literature hint at important, perhaps even fundamental differences, implying that digital text may be more than simply a modern extension of more traditional learning methods. It is therefore imperative that more substantial insights into this field be obtained.

2.4. Note-taking

Note-taking strategies

Reading, while critically important to learning, does not generally exist on its own in the educational context and is often accompanied by note-taking of some kind. Note-taking is among the most common of learning strategies used in the general classroom setting (Kobayashi, 2005) and is widely considered to be an effective learning strategy (Kobayashi, 2005; 2006). Additionally, individuals tend to differ in their use of the reading strategies which they make use of. However, given the prevalence and (arguably importance) of note-taking, the concept of 'reading strategies' includes aspects which could be considered as note-taking, as this is a closer reflection of everyday practice. It is for this reason that the question of electronic vs paper-based reading cannot be answered through relatively simple evaluations of reading comprehension and other related variables.

As mentioned in the previous paragraph, note-taking generally takes place in conjunction with some type of reading as part of a reading strategy. In addition, note-taking may refer to a range of distinct actions or activities. It is therefore necessary to more clearly define which types

of activities will be regarded as note-taking in this dissertation. In her doctoral thesis, Oh (2013, p. 60) identifies eight common reading strategies, namely: (1) *highlighting*, defined as underlining or highlighting text; (2) *note*, defined as writing notes in paper margins or the electronic equivalent; (3) *symbol*, which refers simply to the usage of symbols on the reading medium; (4) *paper note*, which occurs when an individual utilises a distinct piece of paper for note-making; (5) *networking*, which is the reading, re-reading and reviewing of text or documents in order to make sense of it, in particular to make sense of relationships in the document; (6) *jumping based on references*, where the reader moves directly to a different page or place within the text from another place in the text as a result of a reference provided in the latter part of the text; (7) *macro-monitoring*, which occurs when the reader briefly 'steps back' from focusing on the current page in order to examine the textual work in its entirety to determine progress made thus far; and finally (8) *micro-monitoring*, which involves sharpening the individual's focus to a very specific portion of the text for the purposes of information extrication, where a finger, stylus, cursor or similar is physically or virtually directed to a portion of text in order to aid the action of focusing on that specific portion. Of these eight reading strategies listed by Oh (2013), the first four (namely *highlighting*, *note*, *symbol*, and *paper note*) fall under the category of 'annotation.' This research will therefore use these four strategies to categorise traditional note-taking.

The encoding and external storage hypotheses

Much of the (pre-laptops-in-classrooms era) research into note-taking and its effectiveness in the educational context has focused on two hypotheses on the manner in which note-taking affects learning, namely the encoding hypothesis and the external storage hypothesis (DiVesta & Gray, 1972; Kiewra, 1989). The encoding hypothesis "suggests that the processing that occurs during the act of note taking improves learning and retention" (Mueller & Oppenheimer, 2014, p.

1), while the external storage hypothesis focuses on the "benefits of the ability to review material (even from notes taken by someone else)" (Mueller & Oppenheimer, 2014, p. 1). It must be noted that these two hypotheses are not mutually exclusive and can certainly work in conjunction with one another. Kiewra (1985) found evidence to suggest that using both of these aspects is more effective than either one on its own.

Kobayashi (2005) conducted an extensive meta-analytic review on the encoding benefits of note-taking, in which he found that (1) note-taking has a modest positive impact overall and (2) students at lower schooling levels benefited to a greater extent from note-taking than students at higher schooling levels. He also found that a lower proportion of self-generated notes (i.e. more verbatim transcription) serves to lower the encoding effect, a finding which is consistent with Mueller and Oppenheimer's (2014) finding that verbatim content negatively predicts performance on conceptual understanding. Although Kobayashi (2005) did find an overall positive effect of note-taking, the effect itself was relatively weak – weaker than might be expected given the prevalence and popularity of note-taking as a learning strategy. He proposed two possible explanations for this: (1) quality of note-taking – "generative processing" (p. 242) such as summarising and paraphrasing versus copying lectures/lessons verbatim; and (2) the mechanical demands of note-taking by means of pen and paper (such as the time required to physically write and the need to observe one's hand motions and its outputs and the subsequent cost incurred). Brown (1988) was the first to show that proficient typists are able to produce words faster than they are able to write by hand. Typing therefore reduces the amount of time required to input ideas and information. It also reduces cognitive load in observing hand movements and this may lead one to conclude that it is more advantageous to type than write by hand. However, more evidence must first be examined.

Handwriting and keyboard typing

There is a substantial body of research on the topic of note-taking and its effectiveness in the educational context, although most of this research was conducted before laptops came into widespread usage in classroom settings. There are important differences between more traditional pen-and-paper based learning and newer technologies such PC devices (e.g. laptops and tablet computers). The advent of these newer technologies has brought with it new questions around the issue of writing and its various PC-device equivalents and its impact on educational outcomes. One of these differences is the means by which information is transferred to these devices – hand writing for the pen-and-paper and keyboard-based typing of various kinds for the newer technologies.

Although questions around handwriting in comparison to keyboard typing have been under investigation for at least two and a half decades (see Brown, 1988), the existing body of research into this area remains relatively limited. While there is some research involving laptops in the educational setting (e.g. Bui, Myerson and Hale, 2013; Mueller & Oppenheimer, 2014), there is very little involving tablet PCs. One possible explanation for this is that the rapid technological advancement and explosive proliferation of these high-functionality mobile computing devices has made widespread adoption of such devices in the educational setting a reality (where previously it was not) at such a rapid pace that the research community has not been able to yet effectively react. Furthermore, while laptops have been popular, mainstream technological devices for nearly two decades, tablets are generally considered to have only gained significant popularity following the release of the first Apple iPad in 2010 (Park & Burford, 2013).

Mueller & Oppenheimer (2014) found that students taking notes by hand (i.e. via longhand) performed significantly better on conceptual understanding questions than students taking notes

via a laptop. Although students on laptops tended to produce more words than students making use of longhand, laptop students also had a significantly higher percentage of verbatim overlap with the lecture. Number of words positively predicted performance, while verbatim content negatively predicted performance. In the case of students who had taken notes by means of a laptop, the positive external storage effect of the greater number of words in their notes appeared to be offset by the negative encoding effects of the higher verbatim overlap, leaving longhand participants as the highest performance. This result was also seen in cases where students returned a week after the initial lecture to write a test and were allowed to briefly study their handwritten notes before writing. This interpretation does, however, ignore several potential confounding factors and variables such as individual variations in succinctness, level of detail captured in notes (particularly for students with a good grasp of the material being taught), non-textual (e.g. diagrammatic) additions which would be excluded from the word count, among others.

Bui et al. (2013), on the other hand found that transcribing lectures by means of a laptop (i.e. purely verbatim content) was the most effective means in terms of immediate factual recall. Taking organised notes using a computer in an experimental setting was shown to be the highest performing for delayed testing where students were not allowed to study their notes before writing a test on the information that they had learnt, although transcribing using a computer was again the most effective method when participants were allowed to study their notes before writing. Mueller and Oppenheimer (2014), however, point out that this method is not a realistic representation of general student note-taking. It must also be noted that listening to lectures while taking notes is different to reading through a text and taking notes.

Note-taking tools and mechanisms

Another key consideration is the tools and mechanisms by which an individual is able to take notes and the effectiveness of these. Many digital devices offer a word processor or notepad which can be used to make study notes (a commonly-used study strategy in SA secondary schools). Traditionally, study notes are made on separate pieces of paper to the information source (textbook). Some digital devices offer the option of splitting screens or opening two application windows simultaneously, which would offer the ability to read a source (e.g. e-book) and make notes without needed to switch back and forth between applications. On most tablet PCs, the e-reader and word processor/notepad functionalities are provided by two distinct applications or apps, requiring the user to continually switch between apps. Only a few high-end tablet PCs support 'split-screen' or multi-tasking functionality allowing two apps to be used simultaneously. However, even in tablet PCs that do support this functionality, the device's limited screen size/area (a 10" tablet has a screen area less than 50% the size of a standard A4 page, while a 7" tablet has approximately 25% of a standard A4 page) substantially impedes the practicality of this feature. Given the negative effect of hypertext on knowledge acquisition (Zumbach and Mohraz, 2007), particularly due to the distraction and subsequently higher cognitive load it causes, one could reasonably postulate that the distraction caused by having to repeatedly switch between applications when making study notes would also be detrimental to knowledge acquisition.

However, there are also a range of other features and functionalities made possible by mobile PC devices whose potential impact must also be considered. Tablet PCs and some e-readers such as the Amazon Kindle allow users to highlight text and take notes without switching to another app. Some apps even allow for different types of notes and annotations to be made, including recording audio or voice notes. It must be noted that, although both paper and some

electronic devices allow users to perform similar actions (such as highlighting), subtle differences do exist when these actions are performed for the two device categories. For example, when highlighting text on paper, the user must physically mark each word, while users highlighting on electronic devices are able to select and highlight paragraphs without scrolling past each word. That being said, while there are cases where one is not able to make permanent markings in a print-text book (such as in a library book or a loaned textbook), these digital highlighting and annotation options are always available for digital books. Additionally, features such as the ability to record audio notes have no real print or analogue equivalent.

In their experimental setup, Mueller and Oppenheimer (2014) tested understanding and recall by adapting both textual materials and question categories from Butler (2010). Factual text passages were created by Butler (2010) using several online encyclopaedias and written so that each passage was of similar length, divided into the same number of paragraphs, each passage containing four concepts and four facts. Butler (2010) leveraged Bloom's taxonomy of educational objectives to help define these facts and concepts. Questions on Mueller and Oppenheimer's (2014) video lectures which were watched by their participants were organised into one of five categories and this categorisation was used to determine how longhand and laptop note-taking affected particular question types. The five question types or categories derived by Muller and Oppenheimer (2014) from Butler's (2010) work are: (1) fact; (2) seductive detail (i.e. interesting but irrelevant information); (3) conceptual; (4) inferential (same-domain); and (5) application (new-domain inferential). This method of question categorisation serves as a useful means of assessing various facets of understanding and recall in experimental setups like these, which introduce a time delay between textual interaction and testing in order to better measure learning as opposed to reading comprehension.

The neurophysiological basis of writing

The neurophysiological basis of handwriting remains relatively poorly understood, although postulations have been put forward at various times (Planton, Jucla, Roux & Démonet, 2013). The actions of handwriting and typing (a key difference between traditional and PC-based educational technology) are physically very different. Handwriting involves creating letters/characters by hand each time, combining several pen-strokes to form the unique shapes of individual letters while typing involves pressing the correct button or key in order to produce the correct character or symbol. Longcamp, Zerbato-Poudou and Velay (2005) found that very young children (3-5 years of age) who were learning to write performed significantly better in remembering the orientation of newly-learned characters when these characters were handwritten as opposed to being typed on keyboards. This would appear to suggest that the (motor) actions involved in forming individual letters are associated with improved recall (i.e. involving non-motor brain regions) around these letters/characters, particularly when compared to the (motor) actions involved in typing on a keyboard. It is not clear, however, to what extent this effect continues once literacy has been obtained.

Existing studies have shown that practicing letters using handwriting leads to better letter recognition for adults than practicing with keyboards (Longcamp, Boucard, Gilhodes & Velay, 2006). There is also substantial neuroscientific evidence which indicates that the action of writing by hand is neurophysiologically different in its impact when compared to typing. James and Atwood (2009) showed that adults develop functional cortical specialisation for letter- or character-like representations if they have experience writing these representations down by hand. Letter perception is known to involve the pre-motor cortex, but reading does not generally activate the pre-motor cortex (James & Engelhard, 2012). The implication of this is that letters are

processed in different neural regions to words, a finding which has yet to be explained. One hypothesis suggests that part of the reason for this difference in neural processing locations between words and letters could be explained by our experience with writing. Because writing (which is a motor skill) involves writing down one letter at a time (as opposed to reading, which often involves reading entire words at a time), the necessary motor information accompanies the visual information on individual letters (James, 2010; James & Engelhard, 2012; James & Gauthier, 2006; Longcamp, Anton, Roth & Velay, 2003; Longcamp et al., 2006). James and Gauthier (2006) further showed that the action of letter processing automatically recruits an integrated neural network in which the actions of letter perception and letter writing share notable overlap in terms of the neural regions which they involve.

James and Engelhardt (2012) showed that neural activity during letter perception was affected differently by previous handwriting of those letters when compared to tracing or typing those letters. More specifically, letter perception after the experience of hand writing letters recruited the inferior frontal gyrus (pars orbitalis), left anterior cingulate cortex and the fusiform gyrus more so than when typing. Hand writing letters also recruited the posterior parietal cortex and the fusiform gyrus to a greater extent than tracing already-formed letters. James and Engelhardt (2012) go on to note that the inferior frontal gyrus, posterior parietal cortex and the fusiform gyrus are all involved in reading in literate individuals, a finding which indicates that, following hand writing practice, a neural network is activated which serves both reading and writing.

These findings suggest that the action of handwriting is not only qualitatively different to typing, but neurally different too, beyond differences solely in the sensorimotor cortex (where differences would be expected). They show that handwriting activates neural networks and regions

which are associated with both reading and writing (while typing does not). This supports findings by Longcamp et al. (2005) that handwriting practice in very young children leads to better recall of character orientations. These findings also suggest that Mueller and Oppenheimer's (2014) findings that note-taking via longhand is more beneficial when compared to note-taking via laptop may have a neural basis, rather than simply being ascribed solely to the tendency of students to incorporate more verbatim content into their notes when typing on keyboards.

There is some existing literature comparing laptops and longhand. There is relatively little, however, comparing both devices with tablet PCs. Tablet PCs are physically different to laptops in terms of their interfaces, most especially in terms of their keyboards (laptops have physical keys which are depressed for each letter or character, whilst tablets have touchscreens with no physically discernible difference between keys). Laptop and desktop computers make use of graphical user interfaces (GUIs) which require a distinct input device (such as a keyboard or mouse) while tablet PCs make use of touch user interface (TUI), which allows the user to directly manipulate elements on the device screen by means of direct haptic input. Additionally, tablet PCs offer the option of digital pens or styli (*singular* stylus), whose potential is yet to be adequately investigated.

Summary

Note-taking is an important and widely-used tool in the educational context, among others. Existing empirical literature suggests that handwriting and typing are not equivalent, with both psychological experiments and neuroimaging studies providing support for this assertion. Possible reasons for this centre on the sensorimotor activity involved in hand-writing words and letters in comparison to the less-differentiating sensorimotor activities involved in typing. The advantages provided by typing (such as speed and legibility) must therefore be balanced against the

disadvantages which typing engenders, along with the strengths and advantages which handwriting brings with it. It is therefore also imperative that more substantial insights into this field be obtained.

2.5. Summary of existing empirical literature

Questions around the effectiveness and equivalence of personal computing devices in the educational context are complex and multi-faceted. Some findings on the topic of electronic device-based reading vs paper-based reading suggest a degree of equivalency, although device-specific drawbacks such as increased levels of visual fatigue in LCD-based e-reader and digital screen-based reading discouraging deep reading and encouraging superficial reading are important considerations. For the purposes of reading comprehension (without the inclusion of hypertext or hyper-media), existing literature appears to point towards equivalence between reading on paper and E-ink technologies and near-equivalence for LCD-based readers and paper. However, other findings suggest that important and meaningful differences do in fact exist between digital and print-based reading and hint that these differences may even be fundamental.

Studies into the equivalence of the various device input methods (i.e. traditional handwriting when compared to keyboard typing, touchscreen typing and tablet stylus) appear to show significant differences, with some evidence to suggest that handwriting or longhand is superior to typing as it involves multiple levels of encoding. Furthermore, neuroscientific evidence (Planton, Roux, Jucla & Démonet, 2013) adds support to this claim, showing that handwriting is significantly different to typing. It is not clear, however, how similar handwriting is to writing with a tablet stylus.

For both reading and writing, it is clear that a better measure of learning is required in order to more clearly understand the impact of PC device-based educational technology on educational outcomes. Overall, it is clear that, particularly given the very real possibilities of large-scale adoption of personal computing devices in the educational sphere (particularly in the Gauteng Province, South Africa), more insight is sorely needed into the effectiveness and potential impact of these devices on educational outcomes in comparison to traditional print, pen and paper-based learning.

Chapter 3

Literature Review – Part 2

Theoretical Considerations

3.1. Introduction and overview

Theoretical considerations remind us that educational technology is not a new field, with even the written word itself being a tool and type of educational technology. These theoretical considerations also highlight and interrogate a range of important assumptions related to educational technology and the role it plays. Chapter 2's examination of existing empirical literature suggests that assumptions of equivalency around digital and print-based reading as well as hand-writing and typing are largely unfounded. In addition, this existing literature hints at important and even fundamental differences. It is therefore necessary to utilise relevant theory to construct a suitable theoretical framework which allows for a more insightful and careful examination of these research questions, contributing to a better, more comprehensive understanding of these critically important topics.

The overarching aim of this dissertation is to better understand the differences which exist between the digital word (and by extension digital devices, particularly tablet PCs) and the analogue (i.e. print and written) word (and by extension traditional learning materials such as paper) in terms of their effectiveness as educational technology and their impact on educational outcomes. The overarching idea advanced in this chapter is the notion that digital text – i.e. the digital word – is the most recent development in the evolution of literacy and that there are important differences between the digital word and that which came before it. In this chapter,

several theoretical claims and ideas are proffered, supported by a range of existing theoretical perspectives.

The first claim which is explored is the idea that all literacy involves symbolic technologies and that the written word is therefore a technology. Furthermore, it is asserted that literacy creates an external memory field, something which has important advantages and benefits and that literacy has a substantial material cognitive impact. Several theoretical perspectives relating to the notion of the written word as a technology are discussed, focusing primarily on the work of Ong (1982) and Donald (2001).

The second claim is the notion that tools can mediate actions and interactions and that socio-cultural factors play a meaningful role, a central thesis of Cultural-Historical Activity Theory (CHAT). It is argued that tool-person interactions involve more than just those two entities – that a wide range of other factors come into play, particularly socio-cultural knowledge and experience. Noting that most human society has, until very recently, been fundamentally paper-based, it is asserted that both explicit and implicit knowledge of and around pre-digital literate symbolic technologies (such as techniques best to make use of these tools) is relatively well-developed to an extent that is likely not yet true for the digital word.

The third claim explores the notion cognition is grounded or embodied and that affordances (i.e. possibilities for sensorimotor and perceptual engagement (Mangen, 2013a)) therefore matter. In addition to explaining this idea in further detail, this section also examines some important assumptions around the mind, consciousness, and the role of external tools in cognitive processes.

The fourth claim is the thesis of the digital word. The notion of the digital word (i.e. digital text) and the analogue (i.e. non-digital) word as distinct constructs is introduced, using these

concepts/ constructs as tools for understanding engagement with digital and non-digital texts. It is argued that there are fundamental differences between the digital word (i.e. digital text) and the analogue (i.e. non-digital) word, particularly with regards to text-substrate interaction. It is argued that both the digital and analogue each have a specific set of affordances. Because affordances matter (as advanced in the previous section) and can make a difference, it is argued that the digital word is sufficiently discontinuous with previous symbolic technologies so as to make it meaningfully unique.

3.2. Literacy and symbolic technologies

Although educational technology is often associated with electronic, PC device-based tools or 'high-technology,' education has in fact made use of technological tools for millennia. The written word is not only one of the earliest technologies adopted by education, it is also one of the most important, underpinning not only education itself, but modern civilization and even modern-day human thought (Donald, 2001; Ong, 1982).

While tools and technologies may often be physical, tangible items, a substantial body of research has focused on the topic of what are termed symbolic technologies and intellectual tools (e.g. Goody, 1986; Havelock, 1986; Logan, 2007; & Ong; 1982). The written word is an example of both an intellectual tool (Lévy, 2010) and a symbolic technology (Donald, 2001 & Ong, 1982).

As an intellectual tool and symbolic technology, the written word (through literacy) has been and is of enormous importance to human civilization and many of the developments which have accompanied and characterized human advancement (Donald, 2001; Goody, 1986; Havelock; Ong, 1982), permitting the development of "systematically organised knowledge (lists, tables, archives, accountancy, complex hermeneutical procedures) beyond the lore of oral cultures" (Lévy, 2010, p. 72).

Ong (1982, p. 54) counts among the contributions of literacy and literate thought "geometrical figures, abstract categorization, formally logical reasoning processes, definitions, or even comprehensive descriptions, or articulated self-analysis," while Lévy (2010) takes this a step further, asserting that the introduction of an alphabet with roughly 30 signs or characters played a central role in the origination of abstract conceptual thinking (Innis, 1950; Logan, 1986; McLuhan, 1963; 1964). Both Donald (2001) and Ong (1982), among others (such as Hutchins, 1995 & Lévy, 2010) hold that these tools and systems (particularly the written word and the development of literacy) have played and continue to play an active and important role in impacting and moulding cognitive abilities.

The theorists referenced in the preceding paragraphs make strong claims about the importance of the written word and these assertions must be more carefully scrutinised to better ascertain their veracity. Ong's (1982) claims will be discussed in more detail, followed by those of Merlin Donald (2001), after which a theoretical framework known as cultural-historical Activity Theory (CHAT) will be introduced and briefly examined.

Ong (1982)

Literacy has been and is of enormous importance to human civilization and many of the developments which have accompanied and characterized human advancement. As Walter Ong (1982) points out, however, literacy has also had a significant impact on human thought itself and even human consciousness. In his seminal work, *Orality and Literacy: The Technologizing of the Word*, Ong (1982) examines the impact on human thought for cultures which made the transition from primary orality (i.e. those without literacy) to literacy, as well as further transitions to what Ong terms 'secondary orality' (i.e. orality which is conditional on the existence of literacy) ushered in by the electronic age and inventions such as the radio, television and telephone. One of Ong's

key points is the radical impact of the development of literacy and literate- or text-formed thought. As Ong (1982, p. 1) points out:

> Many of the features we have taken for granted in thought and expression in literature, philosophy and science, and even in oral discourse among literates, are not directly native to human existence as such but have come into being because of the resources which the technology of writing makes available to human consciousness.

The sciences and philosophy are not only influenced by writing, but are in fact contingent upon writing for their very existence. Ong explains that these endeavours have their genesis not solely in the "unaided human mind" but instead by the mind "making use of a technology that has been deeply interiorized, incorporated into the mental processes themselves" (1982, p. 168).

Ong (1982, p. 89) makes the claim that sound "exists only when it is going out of existence" in the sense that, when pronouncing a word, by the time one moves onto the next syllable within a word, the preceding syllables no longer exist as spoken words (e.g. when pronouncing 'syllables,' by the time one reaches '-bles', 'sylla-' is gone). The invention of the alphabet "implies that … a word is a thing, not an event" which is "present all at once" and can be discretized. Ong's key assertion here appears to be that that "all script represents words as in some way things, quiescent [inactive] objects, immobile marks for assimilation by vision" (1982, p. 89).

It seems implausible, however, to argue that the invention of the alphabet resulted in the discretization of the word – words are by very definition discrete sounds or combinations of sounds. What could be more reasonably argued is that the written word is more discrete than the spoken word, as the latter is made up of syllables, while the former consists of letters (which then

form syllables). It must still be established, however, to what extent this difference is significant and what its potential impact may be.

For Ong (1982), the 'technologizing of the word' is this act of transforming the word from event to thing. He describes this process as "the reduction of dynamic sound to quiescent space, the separation of the word from the living present, where alone spoken words can exist" (p. 80). The plausibility of this notion, or at least describing it using these terms, requires further examination. It does seem reasonable to speculate that listening to a sentence does involve different sensory modalities compared to when one reads a text. It may be that Ong's (1982) notion of literacy transforming words from events to things has something to do with the changes in sensory modalities involved.

Listening to a story primarily involves the auditory sensory modality, although it can also involve vision (e.g. seeing the speaker, assessing non-verbal cues and other situational information etc.) and other modalities (e.g. haptic – feeling the physical reverberations by the sound waves emanating from the speaker). Reading, however, is primarily visual, generally excluding the auditory modality, although it can involve other modalities such as touch (e.g. feeling and manipulating the pages of a book or following text with fingers) and even smell (such as the smell of a book's pages).

In addition to differences in modalities, there are further fundamental differences between the written and spoken word. When listening with the spoken word, the listener engages with both the content of the speech and the person speaking. In addition to the semantic content of the words spoken, the listener also engages with the speaker's prosody (i.e. factors such as stress, rhythm, tone, and intonation). The level of engagement between listener and speaker can vary greatly (e.g. two close friends meeting face-to-face vs listening to an audio recording of a previously unknown

person), but is still an interaction between listener and speaker (i.e. two people), mediated by the speech. For example, even when listening to an audio recording of a previously unknown person, the listener may notice (whether consciously or subconsciously) details about the speaker, such as their accent, their apparent mood, their fluency, among other details (which would vary based on a whole range of factors). While far less substantial than an in-person conversation, even this still constitutes a substantial degree of social cognition (i.e. cognitive processing required to successfully navigate social interaction).

When reading, however, the person engages with the content of the text and the text plus its substrate (e.g. book) itself. Reading is then an interaction between a person and an object, mediated by the text. This is a very different type of interaction to listening. Although most texts will have a human author, their individual differences (i.e. features which distinguish authors/speakers) are arguably far more discernible in speech than in written text. For example, listening to a 10-word sentence spoken will implicitly provide the listener with information about the author's voice, accent (e.g. possible first language), mood, emotion, among other details, in addition to the content of the sentence. A written sentence would be unable to communicate most of this information implicitly and a 10-word sentence would be unable to communicate much, if any of this information explicitly.

Furthermore, a reader is required to process the visual input of the semiotic markings that constitute the text to imagine or mentally simulate much of the information contained (explicitly and implicitly) within the text, while the listener is presented with much of this information in the form of external stimuli (chiefly auditory, although this can include visual and other stimuli as well).

An objection to the notion that the written word involves an interaction between a person and an object could cite one of the many examples of human interaction which take place via the written word, such as love-letters written from one partner to the other. While this could be considered a person-to-person interaction, there is at least one degree of further separation than an in-person interpersonal interaction would be. It limits the mode of interaction to semiotic markings carried by an object of some sort (e.g. a substrate such as paper), as opposed to the multi-modal interaction delivered in real-time by a real person. It would better be described as a person-to-object-to-person interaction.

One important consequence of the written word being a person-object interaction stems from the fact that objects can generally be manipulated and controlled – theoretically able to serve the person's needs and requirements. The written word can be used to store, represent and manipulate thoughts and ideas in a way that is either very difficult to do in or is simply not possible in biological memory (Donald, 2001). This helps transform the word into a technology/tool which is more accessible, more personal, more functional, and more powerful than the spoken word on its own.

These considerations suggest that Ong's (1982) categorisation of the spoken and written word as events versus things may require some rephrasing. While the spoken word involves interaction between two persons mediated by the speech (i.e. spoken word), the written word involves the interaction between a person and an object, mediated by the text (i.e. written word). Further consideration is required in order to answer a natural follow-on question: does this make any meaningful difference and if so, what?

The work of Donald (2001) and the paradigm of cultural-historical activity theory will now be examined, followed by a discussion of all three notions and further examination of the above question.

Donald (2001)

Merlin Donald (2001) discusses in great detail the role of culture in consciousness and in learning. There are interesting parallels here between Donald's work and the central tenets of Activity Theory (discussed in the following section). Donald (2001) even refers back to an observation of Vygotsky's known as the 'Outside-Inside' principle, which refers to the tendency of children to first display a developmental function interpersonally (i.e. externally) followed by a later display of the same developmental function intrapersonally or internally. Substantial emphasis is placed upon the prepotent role played by enculturation in the development of human cognitive capacity. Chief among the cultural tools discussed by Donald (2001) is the written word and its impact on human thought and cognitive processes.

Although Donald (2001) makes no explicit references to Ong's (1982) work, there are clear parallels and shared sentiments between the two. Donald (2001) refers to words of a spoken language (i.e. oral language) as being a set of internal symbols, while written letters on a page are said to be external symbols, transformed into what he terms symbolic technology, defining it as "the enterprise of manufacturing and crafting external artifacts and devices" (2001, p. 305). Donald further contends that the development of these technologies has allowed for the construction of an immense "cultural storehouse and an external symbolic storage system which serves as group memory," tools constructed specifically to "help us think, remember, and represent reality" (2001, p. 305).

Donald (2001, p. 308) refers to symbolic technologies (when displayed) as having created an "external memory field" accessible to the human mind. These technologies include the written word, but also extend to a range of other symbols from which meaning can be inferred, including ancient cave paintings. According to Donald (2001), this external memory field allows for a vast amount of information and number of ideas to be stored in a stable, accessible, long-lasting state while also enabling for these ideas to be arranged and re-arranged, examined, tested, and refined. Donald (2001) is careful to note that this external memory field does not replace biological or natural memory – the two are instead complementary, working together in tandem.

The impact of this is enormous – enabling the development of most of the technologies which underpin modern civilisation and urban life (Donald, 2001). These technologies include both physical tools such as sextants and clocks as well as intellectual tools such as navigational methods used by European colonial explorers and the accounting techniques which enabled cross-border banking. Donald's (2001) key point here appears to be that just as new technologies are generally developed by utilising existing, older technology, so too the development of many of the physical and intellectual tools we use or benefit from today resulted from an underlying existing technology – symbolic technologies chiefly in the form of the written word.

Donald (2001, p. 307) speaks about written symbols "decontextualiz[ing] ideas and abstract[ing] them from the concrete situations from which they sprang" and that in doing this, enables one to "extract general principles that might otherwise remain obscure." Donald (2001) also notes, however, that symbolic tools are not necessarily able to engender radical cognitive transformation on their own – these tools must first obtain a critical mass of social usage. It is also possible for symbolic tools to hinder cognitive transformation, with the examples of the difficulty of mastering the Chinese writing system impeding the spread of large-scale literacy in region and

the inherent limitations of the Roman numeral system, particularly in the field of mathematics being cited.

There are clear parallels in Donald's (2001) work to the assertions made by Ong (1982) in his focus on the technologizing of the word and its impact on human thoughts, as well as some important differences. Both theorists agree that literacy has fundamentally altered human thought and that it has underpinned much of the technological development which has made possible modern life. Both theorists also agree that the written word enables the manipulation, control and re-arrangement of thoughts and ideas in a way that is simply not possible with the spoken word.

Donald (2001) differentiates between the spoken and written word by referring to them as internal and external symbols. He further asserts that external symbols' power lies within their ability to create an external memory field which the human mind is then able to access and use. Ong (1982), on the other hand, argues that the spoken and written word are fundamentally different entities, terming the former an 'event' and the latter a 'thing,' and that it is the internalisation of the written word which changes human thought and enables progress and development. Further consideration of Ong's (1982) classifications of the spoken and written word cast doubt upon their veracity, although deeper examination of the arguments involved yielded the insight that the spoken word is a person-to-person interaction, while the written word is a person-objection interaction.

Donald's (2001) model of internal and external symbols, with the latter leading to the notion of an external memory field is a clear and simple way of explaining the uniqueness and impact of the written word. It is also, however, heavily computational in its nature and therefore at risk of attempting to apply too simplistic a computational model. The theory's description of

symbolic technologies or tools is reasonably detailed, but proffers only very high-level (i.e. not particularly detailed) descriptions of how these tools are leveraged.

Given the fundamental role that the written word plays in learning, a confluence of ideas and assertions in recognizing the pivotal and far-reaching role played by the written word in the development of human thought and cognitive processes is highly pertinent.

Both Ong (1982) and Donald (2001) view the written word as a technology which has had a major impact on not only human civilisation and existence, but also on human thought itself. Similarly to the notion presented within CHAT, both Ong (1982) and Donald (2001) hold that writing has been heavily internalized and in doing so has radically transformed human consciousness and thought. It does seem believable that many concepts and thoughts which modern-day humankind has were not possible – quite literally unthinkable – prior to the invention of literacy. If the use of an intellectual tool results in previously unthinkable thoughts being made possible, then the notion of internalisation both occurring and impacting human thought does seem a genuinely plausible assertion.

If the written word, as a person-object interaction, is capable of altering human thought to this extent, then the nature of these changes and the impact and effectiveness of the technology (i.e. the written word) is of great importance. Furthermore, if the above is true, then writing is *the* technology which established or commenced what print and subsequently computers merely continue. Educational technology and in this case PC devices in particular should not be viewed as separate tools which exist and function in isolation, but as technologies which are based on and continue the work of the technological invention which underpins (post-literate) education itself – literacy.

Given the impact of certain technologies and their potential impact on human thought, it is unsurprising that a range of criticisms have been levelled against the introduction of various new technologies into the classroom, particularly over the past several decades. The following criticisms, taken from Ong (1982, p. 78), make for interesting reading:

> This technology "destroys memory" – those who use it "will become forgetful, relying on an external resource for what they lack in internal resources." It "weakens the mind." This technology is "inhuman, pretending to establish outside the mind what in reality can be only in the mind. It is a thing, a manufactured product." Thirdly, this technology is "basically unresponsive. If you ask a person to explain his or her statement, you can get an explanation." If you attempt to query this technology, "you get nothing back except the same, often stupid, words which called for your question in the first place." Fourthly, this technology cannot defend itself – it is "passive, out of it, in an unreal, unnatural world." In contrast with the artificiality of this technology, "real speech and thought always exist essentially in a context of give-and-take between real persons."

The criticisms contained in the above paragraph have been levelled against pocket calculators, desktop and laptop computers, smartphones and tablets, search engines and the broader World Wide Web (e.g. Carr, 2010; Kakaes, 2012; Karafiol, 2012). The concerns raised against the introduction of pocket calculators into the classroom (Kakaes, 2012) bear striking resemblance to some of the concerns raised over mobile PC devices and search engines in the early 21st century – i.e. replacing the activities which ought to be used and which the mind requires to maintain its vitality with a tool that simply enervates the mind (Ong, 1982).

An individual reading the indented paragraph above would be forgiven for thinking that the concerns raised therein refer to early 21st century mobile PC devices, rather than being written

in the early 1980s. Although the paragraph admittedly incorporates paraphrasing both by Ong (1982) and myself, these words are in fact those of the Ancient Greek philosopher Plato in the *Phaedrus* (274-7) and in the *Seventh Letter*, composed approximately 2350 years ago, and are expressed against writing – against literacy. According to Ong (1982), these same objections were also raised against print when it was first invented. The similarity of these objections raised against vastly different things and separated by millennia may appear surprising, but are in fact entirely consistent with Ong's key point – all of these tools are technologies based on, contingent upon and in general continuations of the invention that is literacy – the technologizing of the word, which could also be called the externalising of the specific symbolic technology that is the written word, using Donald's (2001) terminology.

Given the critical importance of education and educational outcomes for so many children and families in particular, if digital text – the digital word – has any meaningful differences to print text, then a very clear rationale exists to better understand these differences and their potential impact.

The incorporation of the written word into human mental processes and the subsequent impact on human thought is a prime example of internalization. Internalization, together with the notions of the technologized word as an intellectual tool and symbolic technology, artefacts and mediation, all converge to provide an interesting framework to more closely examine the notion of the digital word. However, before doing this, it is necessary to first examine some important implications of Activity Theory (as will become apparent), as well as the thesis of grounded cognition.

3.3. Cultural-historical Activity Theory (CHAT)

The notion that tools can mediate actions and interactions and that socio-cultural factors play a meaningful role in both is a central idea in Activity Theory (AT). AT is a theoretical framework or paradigm which has its roots in the work of Soviet psychologist Lev Vygotsky and others in the 1920s and 1930s, but which was only successfully propagated beyond the realm of the Soviet Union in the mid-1980s (Engeström & Miettinen, 1999; Roth & Lee, 2007).

Vygotsky, Aleksei Leontiev and Alexander Luria, are considered the founders of both the Soviet cultural-historical school of psychology and activity theory (AT) itself (Engeström & Miettinen, 1999; Roth & Lee, 2007), and the resulting commonalities and overlap have led to the two perspectives being given the collective name of cultural-historical activity theory (CHAT; Kaptelinin & Nardi, 2006).

CHAT is largely non-dogmatic in the sense that it is less prescriptive than many psychological theories and operates instead as more of a descriptive framework or lens through which human activity can be examined than a theoretically-grounded source of predictive outcomes (Engeström, Miettinen & Punamäki, 1999; Roth & Lee, 2007). The paradigm is described as being more focused on real-world practice than abstract theory (Roth & Lee, 2007). CHAT or AT has moved beyond its origins in Soviet psychology to become an international and interdisciplinary endeavour which has substantial influence in a range of disciplines and areas, including child development and education as well as teaching and learning in general (Blunden, 2012; Engeström & Miettinen, 1999; Igira & Gregory, 2009; Roth & Lee, 2007; Yamagata-Lynch, 2010), an area which is highly relevant to the focus of this dissertation.

The complexity of the human mind and human social activities makes scientific (empirical) examination difficult without the introduction of various simplifications and assumptions. One

consequence of these simplifications and assumptions, however, is a reduction in the ecological validity of the research – it becomes less representative of real world circumstances (Engeström et al., 1999). This is the genesis of the long-standing tension within psychology between those who seek to make psychological research and theory more rigorous and empirically verifiable and those who warn against reductionism as a gross oversimplification which effectively overlooks the richness and complexities of human experience (Engeström et al., 1999).

CHAT attempts to reconcile these two viewpoints (at least to some extent) by providing a theoretical framework which addresses both sets of concerns (Blunden, 2012; Engeström et al., 1999; Igira & Gregory, 2009; Roth & Lee, 2007; Yamagata-Lynch, 2010). The theory is, at its heart, an attempt to develop a methodology which better accounts for the complexities of the real world and create a psychology which is, in Blunden's words (2012, p. 244), more "genuinely sensitive to the social and cultural context of [human] interactions."

The theory examines (human) activity, or more specifically, a "system of actions" and accounts for cultural and historical factors, the external environment within which the individual and society exists and operates and the impact of tools or artefacts (Roth & Lee, 2007). One of CHAT's primary strengths is this cultural, historical and contextual focus (Engeström et al., 1999), moving beyond studying the individual in isolation and instead focusing on a broader system of activity and interactions within which individual activity takes place.

It seems clear that social, cultural and historical factors play a meaningful role and are relevant to the study of the human mind and human social activities and that attempting to study individuals in isolation adversely affects ecological validity (Engeström et al., 1999). From the perspective of empirical research (particularly quantitative research), however, incorporating these factors in such a way that they can accurately be systematically quantified presents a number of

very significant difficulties, something which often leaves researchers unable to produce strong empirical research without a great degree of simplification.

CHAT attempts to strike a balance by providing a better 'unit of analysis' that allows for both more comprehensive and more rigorous analysis. A unit of analysis is the "smallest unit of the subject matter which includes all the properties of the process" (Blunden, 2012, p. 246), where 'process' refers to the broader activity system. It is, as the name suggests, the theoretical object which serves as the elementary object. The primary aim of a CHAT-derived unit of analysis is, in conjunction with the more sophisticated account provided by AT's cultural-historical focus, to provide a foundational mechanism for more rigorous study of real world complexities (Blunden, 2012; Engeström et al., 1999).

Yrjö Engeström, a Finnish academic who authored one of the earliest known non-Soviet papers on activity theory, developed a diagrammatic illustration of his own adapted version of Activity Theory, shown below as Figure 1. (adapted from Engeström et al., 1999).

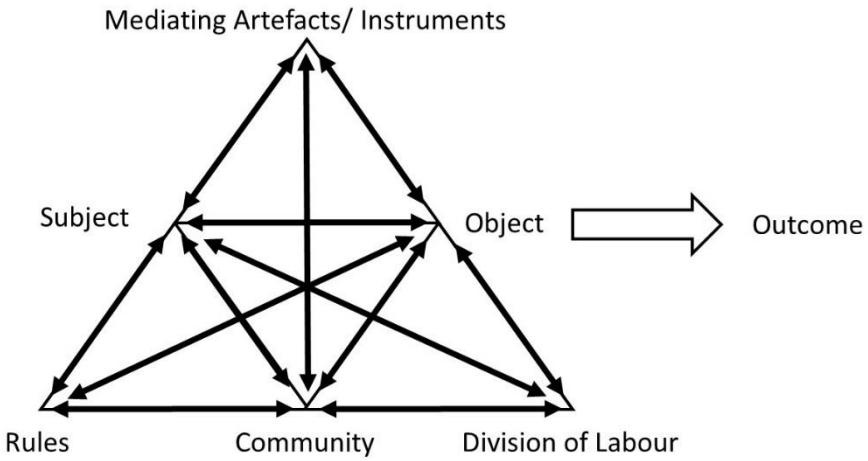


Figure 1. Diagrammatic Representation of Activity System

As can be seen in Figure 1 above, the CHAT model incorporates a number of influencing factors, moving the focus beyond simply the individual and instead including a range of external actors and factors. The subject in the diagram above is the individual or the entity (generally the individual) engaging in an activity which forms part of a broader collective activity. The mediating artefacts or instruments refer to any tool which is used to manipulate the object (the thing that connects the individual's actions with those of the collective) with the aim of inducing a particular outcome. The outcome is the result or output of the activity system. Rules refer to the framework of laws, instructions or similar which govern individual and collective activities. Community refers to the social basis upon which the activity is centred or built, while division of labour refers to and describes the manner in which constituent parts of the collective activity are distributed and carried out (Engeström et al., 1999).

As an example, to illustrate this model in the context of educational technology, let us consider the case of a student who is using an abacus to solve a mathematical task in front of the class in comparison to the same student using tally marks (bars and fences) to complete the same mathematical task. In both cases, the subject is the student, while the object is the mathematical task. In both cases the community or the social basis of the activity consists of the student's classmates and teacher, although this group could be more broadly defined, depending on the context of the activity (e.g. to include role players such as parents). The rules involved include not only the rules governing the use of each of these two tools and the available mathematical methods which can be used to solve the problem, but also school rules, social or societal expectations (both from parents/teachers and peers), among other rules. The division of labour in this case is largely according to age and mathematical ability of the student. The primary difference is in the mediating artefact or instrument – the abacus and the tally count method. Both of these are techniques –

mathematical tools. Factors such as the effectiveness of either technique in solving the posed problem, the student's proficiency with each method and others influence the mediation that takes place. The more effective the mediation, the more likely the chance of reaching the desired outcome.

A broad-reaching theory with a great deal of potential, CHAT remains somewhat underdeveloped (despite its Soviet origin some 90 years ago), having only reached the broader academic world in the late 1980s (Roth & Lee, 2007) and is still in the relatively early stages of its own development in some senses, finding its feet in many respects and with many of its key points still subject to a great deal of debate and critique (Blunden, 2012; Engeström et al., 1999; Igira & Gregory, 2009; Yamagata-Lynch, 2010). Activity theory itself has been applied to a wide range of fields and topics, including childhood development and educational theory (Engeström et al., 1999; Igira & Gregory, 2009; Roth & Lee, 2007), information systems (Yamagata-Lynch, 2010), human-computer interaction (Nardi, 1996), describing personality development, particularly in the former Soviet Union (Roth & Lee, 2007), and workplace theory (Roth & Lee, 2007). A detailed examination of the various schools of thought within CHAT is, however, beyond the scope of this dissertation. Instead, the primary contribution and reason for inclusion in this discussion of CHAT is several key tools and insights which it provides.

Firstly, the inclusion of cultural, historical and social factors in the context of learning is highly useful and in fact critical, particularly in a country as culturally, socially, ethnically and linguistically diverse as South Africa (Fearon, 2003). Secondly, two key insights associated with CHAT (Engeström et al., 1999) link strongly to Ong's insights and will be used to expand the theoretical framework applied in this dissertation – the idea of mediation and the concepts of artefacts and internalization.

Cole (1999, p. 90) defines an artefact or tool as "a material object that has been modified by human beings as a means of regulating their interactions with the world and each other". However, as Cole (1999) further notes, abstract objects such as "imagined worlds" (p. 91) can also serve as artefacts.

Tools bring with them past modifications (whether recent or more ancient past) and are in general built upon these adaptations. They are technologies in varying stages of development, a conceptualization which strongly corresponds to the progressive development of the technologies of writing, print and PC devices, particularly in the educational context (Donald, 2001; Engeström et al., 1999; Ong, 1982). In the case of literacy and the written word, it can be argued that both the externalised symbolic technology of the written word itself, and reading and writing technologies can function as tools within the framework of CHAT.

Cole's (1999) definition also provides an idea of what is meant by the term *mediation* in this context – the regulation or control of the interaction or interplay of humans with both the external (i.e. physical) world and with other human beings. The primary function of artefacts is therefore the act of mediation on behalf of and while in the hands of their human users (Engeström, 1999). The written word can serve to mediate thought and interpersonal interaction.

The third insight is the concept of internalization, something for which Ong provides a helpful explanation. Speaking about the seemingly unceasing reflexivity of intelligence, he observes that "even the external tools that [intelligence] uses to implement its workings become 'internalized,' that is, part of its own reflexive process" (1982, p. 79). Internalization is therefore the process by which artefacts or tools mediating an individual's activity induce permanent change in the thinking or thought process of that individual as a direct result of the incorporation into the individual's (internal) mental processes over time of the modified cognitive functioning caused by

this artefact-human interaction. This tallies with both Ong (1982) and Donald's (2001) assertions that the pre-literate brain is different to the literate brain and that literacy enables thoughts and types of thinking which were previously not possible (an example of the impact of the internalisation of the tool that is the written word).

A significant and important point, which will be discussed in greater detail in Chapter 3, section 3, is that CHAT allows for an embodied view of the mind. A criticism which could be levelled against CHAT, however, is that it is perhaps too broad and far-reaching. It could also be argued that CHAT's lack of prescriptiveness means that it cannot easily be used in isolation and functions more as a paradigm from which to incorporate and utilise other, more normative theories in order to make measurable progress. One of CHAT's most important contributions is its emphasis on the assertion that the individual does not exist in isolation and that cognition does not occur in isolation (Roth & Lee, 2007) and must be analysed in conjunction with the social, cultural, and context within which the cognition takes place. Further criticism (of various kinds) has been levelled against CHAT and AT in general because of its association with Marxism and the very explicitly Marxist viewpoints of Leontiev (Roth & Lee, 2007). Authors such as Langner (1984a, 1984b) address these criticisms in greater detail, while Roth and Lee (2007) simply argue that the tools into which AT categorises various entities and things have little relation to regimes and political systems under which they originated. A full discussion of these arguments is, unfortunately, beyond the scope of this dissertation.

An important thought which can be drawn from CHAT in relation to the written word is centred on the notion that much of human society has, for more than a century and until very recently, been fundamentally paper-based, particularly in the sphere of education. As such, it seems reasonable to assert that a fair amount of explicit and implicit knowledge has been

developed and acquired around the use of this particular symbolic technology (i.e. paper), best practice and techniques for most effective use. By comparison, given its relative novelty, it seems unlikely that there exists a comparable level of either explicit or implicit knowledge for digital text – yet. Given the implications suggested by CHAT's framework, it seems plausible that meaningful differences may exist between pre-digital and digital texts, particularly in the sphere of education. In order to further develop this thought, the notion that cognition is grounded and that affordances therefore matter will be explored.

3.4. Grounded cognition

Cognition as embodied or grounded

Traditional views of cognition have dominated psychology for more than five decades (Barsalou, 2008). These views are generally heavily computational and treat cognitive processing as acting on knowledge seen as information which has been abstracted from its contextual (e.g. perceptual, situational) origin. Barsalou (2008, p. 617) frames traditional views of cognition as "computation on amodal symbols in a modular system, independent of the brain's modal systems for perception, action, and introspection," a view which conceptualises knowledge and the processing thereof as occurring in the form of abstract symbols, using information detached from stimulus or sensory modalities (i.e. making it amodal), with the brain's systems for introspection, perception, and action operating separately and in some senses subordinately to cognition.

Based on a growing body of empirical evidence, another paradigm asserts that cognition in fact operates quite differently. Clark (1997) aptly observes that the notions of thought, action, and perception are interconnected and interrelated in a range of intricate and interpenetrating ways. Barsalou (2008), along with Clark (1997) and others such as Gallagher (2005), Kiefer and Trumpp

(2012), and Mangen (2013a) advocate an embodied or grounded view of cognition, arguing that cognition is underlain by "modal simulations, bodily states, and situated action" (Barsalou, 2008, p. 617) – in other words that it is "critically based on reinstatements of external (perception) and internal states (proprioception, emotion, and introspection) as well as bodily actions that produce simulations of previous experiences" (Kiefer & Trumpp, 2012, p. 16).

The term 'embodied cognition' is thus used to describe the collection of theories which charge that cognition involves the processing of information in conjunction with rather than separately from the brain's systems for perception, action, and introspection. Preferring the use of 'grounded cognition' instead of 'embodied cognition,' Barsalou (2008) points out that using the latter term can lead to the erroneous assumption that bodily states are necessary rather than merely sufficient for cognition and/or that research in this area examines bodily states to the exclusion of other ways in which cognition may be 'grounded' (or underlain by).

As Mangen (2013a, p. 94) puts it, "we do not read only with our eyes and in our heads (not even in the most rigorous experimental settings)" and nor do we write solely with our hands and fingers (even if it may appear that way). According to the thesis of grounded cognition, our engagement with the written word involves far more than merely the visual input of semiotic markings.

As Barsalou (2008) notes, grounded cognition is in fact the view of cognition which has been most dominant for much of the past two and a half millennia. Barsalou (2008) lays the blame for the relative fall in dominance of grounded cognition at the feet of the behaviourists whose viewpoints dominated psychology in the early twentieth century, and more specifically their attacks of the introspection studies of the late nineteenth century as scientifically inadequate. These attacks and their legacy left mental imagery (i.e. mental representations) effectively side-lined

from psychology for at least the first half of the twentieth century, although the available evidence for mental imagery strengthened to such a degree that the concept is now widely accepted as a component of cognition (Kosslyn, Thompson & Ganis, 2006).

Empirical support for grounded theories of cognition continues to grow, with neuroscientific and behavioural research studies leading the charge – comprehensive overviews are provided by Barsalou (2008) and Kiefer and Trumpp (2012). For the purposes of this dissertation, we will focus on several key areas from within this body of literature – specifically, the grounding of reading and writing, memory for events, conceptual memory for objects, knowledge and conceptual processing, and language comprehension.

Grounding of reading and writing:

Grounded cognition suggests that reading will be impacted by the sensorimotor process of handwriting. As Kiefer and Trumpp (2012) point out, handwriting and typing are substantially different from one another, particularly because handwriting requires each letter to be individually form requires the reader/writer to decipher a slightly different, imperfect version of a letter each time it is written, while typing produces a perfect, identical copy of the letter each time and the sensorimotor difference between letters is simply a different place within a rectangular space. There is a meaningful body of empirical neuroscientific evidence which demonstrates that handwriting and letter perception do indeed make use of many of the same neural regions. For a more comprehensive overview, see Chapter 2.4 – The neurophysiological basis of handwriting.

Memory for events:

Events in which we have participated are stored in episodic memory (Tulving, 1972) and when remembered, include not just “abstract-symbolic verbal knowledge” (Kiefer & Trumpp,

2012, p. 16), but also a range of sensorimotor experiences associated with the events themselves (Engelkamp & Zimmer, 1972). These sensorimotor experiences are central to memory (Engelkamp & Jahn, 2003). For example, Engelkamp, Seiler, and Zimmer (2004) found that individuals recall action verbs more accurately when performing associated actions while learning than those who simply learnt the words, while Senkfor, Van Petten and Kutas (2002) found that simply observing others performing the associated actions while reading improved recall, but less so than when participants actually performed the actions themselves. Both Heil et al. (1999) and Senkfor et al. (2002) found neurophysiological evidence suggesting that participants' motor areas activated upon remembering words where they had performed associated actions themselves – this activation was not present otherwise. Further evidence from Ranganath et al. (2004) indicated that recalling the shape of objects (i.e. visual information) resulted in the activation of neural regions associated with vision, while Wheeler, Petersen and Buckner (2000) reported similar findings for audio retrieval. This provides strong evidence for the multi-modal nature of episodic memory.

Conceptual memory for objects:

A key question in grounded cognition is whether concepts, as thought's abstract components, are also grounded in perception and action (Kiefer & Trumpp, 2012). Neuroimaging studies lend support to the assertion that they are (see Kemmerer & Gonzalez-Castillo, 2010; Kiefer & Pulvermüller, 2012; Pulvermüller & Fadiga, 2010), providing evidence that conceptual tasks do result in the activation of sensorimotor-associated neural regions (e.g. Hoenig et al., 2008; Martin et al., 1996; Simmons, Martin & Barsalou, 2005). Kiefer and Trumpp (2012, p. 18) further note that "conceptual and perceptual processing functionally and neuroanatomically overlaps in sensory brain regions" (Kiefer et al., 2007).

Other studies have found that meaningfully-related physical action while encountering new concepts (i.e. physical action which has meaningful connection to the concept itself) leads to activation in visuo-motor associated neural areas that is not present for action which is not meaningfully-related (Kiefer et al., 2008) and that experts such as professional musicians display auditory cortex activation when retrieving musical instrument-related conceptual knowledge – activation not present for musical non-experts (Hoenig et al., 2001).

Knowledge and conceptual processing:

Barsalou (2008) provides a thoroughly comprehensive review of grounded cognition and the evidence which supports it. In one part of this review, Barsalou (2008) focuses on the role of simulation as part of conceptual processing. Noting that simulation (i.e. mental representations or imagery, often based on restatements (i.e. mental reconstructions) of perceptive or proprioceptive experience) has been accepted as integral to working memory for a substantial period time, while yet to gain widespread acceptance as a component of internal knowledge representation, Barsalou (2008) examines three lines of empirical evidence in support of this assertion.

The first is behavioural evidence. Utilising property verification experiments, Solomon and Barsalou (2004) and others found strong evidence to support the notion of simulation during conceptual processing, rather than abstract symbolic computation on its own. The second line is lesion evidence, in which Barsalou (2008) notes multiple lesion studies reporting that damage to specific modalities often leads to deficits in or the loss of concept or object category processing abilities which utilise that specific modality. The third line of evidence comes from neuroimaging, in which Barsalou (2008) details a range of imaging studies which indicate strong links between the mental representation of concepts and conceptual knowledge and the simultaneous activation

of relevant sensorimotor-associated neural regions which are involved in physically perceiving and acting on those concepts.

Language comprehension:

Another section of Barsalou's (2008) extensive and highly detailed review looks at grounded cognition in relation to language comprehension, focusing on four areas. The first is situation models, in which Barsalou (2008) briefly details the long-established body of evidence which indicates that modal representations (i.e. mental reconstructions of modal stimuli), and in particular spatial representations play a significant role in textual comprehension. In the second area – perceptual simulation – Barsalou (2008) briefly outlines empirical evidence such as Zwaan and Madden's (2005) findings to lend support to notion that readers assemble simulations in order to mentally depict text sentences. Barsalou's (2008) third area of examination focuses on motor simulation and briefly details a number of studies which provide strong evidence to suggest that motor simulations are present and play a meaningful role in textual comprehension. The fourth line of evidence examines findings which suggest that a reader will at times simulative affective or emotional states when reading and that it is possible for the individual's affective state to interact with the text's own affective content.

The above five sections provide a very brief overview of the large and growing body of empirical evidence which supports the notion that human cognition does not occur amodally and is in fact grounded in modalities. In his review article, Heuer (2016) examines evidence that the external environment (and in particular technologies) can significantly impact human sensorimotor abilities and skills, providing an additional line of evidence for this thesis. These insights are very important for our consideration of reading and writing, as it means that many related aspects of literacy which may have been overlooked must now be more carefully considered.

As Mangen (2013a, p. 94) asserts, individuals "do not read only with [their] eyes and in [their] heads (not even in the most rigorous experimental settings)" and neither do they write solely with our hands and fingers (even if it may appear that way). Processing a visual scene (such as looking at a page or screen) involves information about not only the visual stimulus (the visible external image), but also proprioceptive information about the viewer's body, ears (i.e. balance), orientation of their head and neck. The process of deriving new insights powerful enough to enable a person to think previous unthinkable thoughts (Donald, 2001) by viewing semiotic markings (i.e. by reading written text) is an extraordinary feat. The lens of grounded cognition helps illustrate that an individual's engagement with the written word is far more complex than simply involving the amodal processing of the visual input of written text – factors such as the physical substrate on which the text is based and the nature of the individual's interaction with that substrate are likely to have an important impact on that individual's reading experience.

There is a substantial degree of convergence between grounded cognition and the lenses provided by Ong (1982) and Donald's (2001) theories and CHAT (which allows for an embodied view of mind), supported by a wealth of empirical evidence, as discussed in both chapters 2 and 3. These lenses frame the written word as a tool or technology which mediates activity and posit the notion of internalisation, while grounded cognition offers a means of better understanding this process. These converging ideas will be used to examine and challenge the assumption that the analogue written word – physical markings stably etched onto distinct physical media – is equivalent to screen-based, digital text – the digital written word. However, given the range of important questions raised by the preceding theoretical considerations and empirical evidence, it is necessary to first briefly examine some important assumptions around the mind, consciousness,

and the role of external tools in cognitive processes, before moving onto discussing the digital word.

The brain, extended mind, and consciousness

The implications of Ong (1982) and Donald's (2001) conceptualizations of the technologizing of the word and its impact on human thought and perhaps even human consciousness are profound. It would seem to imply that it is possible that the use of external tools can, in certain cases, lead to meaningfully impact the cognitive processes that constitute thought, allowing for new types of thoughts to be thought, a process which Activity Theory postulates involves the internalisation of a mediating artefact or tool over time. Grounded cognition indicates that the external environment plays a significant role in cognitive processes – or at least the individual's perceptual and proprioceptive experience of the external environment.

Given the potential ability of technology and tools to effect change, it is clearly important to better understand the potential impact of educational technology on both educational performances and on human thought. However, this point raises several important questions. If tools it is possible for tools to interact with and in some sense be internalized by the mind, at what point does this internalization take place? What constitutes the boundary of the mind? These questions lead to further, even more fundamental questions such as what is the mind and what is consciousness? While a comprehensive discussion of the mind and consciousness is far beyond the scope of this dissertation, it does seem necessary to briefly examine some important assumptions around the mind and the role of external tools in cognitive processes.

In his book entitled '*Out of Our Heads: Why You Are Not Your Brain and Other Lessons From The Biology Of Consciousness*,' Alva Noë (2010) examines and challenges a number of foundational assumptions present in the study of consciousness, the mind and the brain. One of

the most critical assumptions that Noë challenges is the notion that consciousness (and the mind) emerges in the brain, arguing that the seat or centre of consciousness is not located within. Instead, Noë (2010, p. 24) contends that consciousness is not "something that happens inside us: it is something that we do, actively, in our dynamic interaction with the world around us."

There are a number of important implications that follow from this, which Noë (2010) explores in greater detail. The most pertinent of these relates to the conceptualization of the mind. There exists a tendency within some areas of cognitive science to view the mind as a type of software which runs on the organic computer-like hardware that is the brain. Noë (2010) claims that computers and indeed brains cannot think in the same way that construction tools cannot build a structure on their own. People think and have minds – brains and computers do not. Brains (and computers) are instead tools which humans use in order to think. The brain certainly plays a critically important role in the process of thinking and is the primary tool used, but it is the person acting within and interacting with the external world who does the thinking. Building on this conceptualization, it is now possible to view other processes, objects, techniques etc. as tools which can act in conjunction with the primary tool (i.e. the brain) for the purposes of thinking.

A similar theoretical conceptualization of this idea is found in the notion of the extended mind. In their seminal work in the field of extended cognition, Clark and Chalmers (1998) propose the notion of the 'extended mind' by means of a concept called active externalism, which argues that there is no good reason for the mind to be said to be contained only within the boundaries imposed by the skull and that external objects (i.e. external to the skull) can be said to operate as part of the mind. According to this hypothesis, the mind, the body, and the external environment (when acting in tandem as part of a coupled cognitive system) should not be seen as distinct or separate, but instead as part of a single extended mind.

> The human organism is linked with an external entity in a two-way interaction, creating a *coupled system* that can be seen as a cognitive system in its own right. All the components in the system play an active causal role, and they jointly govern behavior in the same sort of way that cognition usually does. If we remove the external component the system's behavioral competence will drop, just as it would if we removed part of its brain. (Clark & Chalmers, 1998, p. 8).

Clark and Chalmers (1998) make use of a thought experiment to further explain their point, in which two characters named Inga and Otto are both travelling to the same location – the Museum of Modern Art on 53rd Street. In this thought experiment, Inga is said to have 'normal' memory, while Otto is said to have Alzheimer's disease and therefore suffers from memory loss. In attempting to navigate to the Museum, Inga is able to recall the location and/or directions to this location using her (internal) memory, while Otto has this information written down in a notebook which he carries around with him. Clark and Chalmers (1998) argue that both Inga and Otto have a belief that the Museum is located at that specific point before consulting internal memory or the notebook (respectively). They further add that Otto makes frequent use of his notebook and that it is consistently readily available, much like Inga and her (internal) memory. On this basis, the argument is made that there is no principled distinction between Inga's memory and Otto's notebook – both serve the same function to the same end. Otto's mind has therefore in fact undergone an extension beyond the boundaries of his skull to include the notebook, which serves as his memory.

Clark and Chalmers' (1998) thesis is an interesting and useful consideration as it reframes debates around the use of educational technology in a new perspective. However, the analogy appears to be heavily computational in its construction, in the sense that it seems to include an

inherent assumption that (human biological) memory is highly and very discretely modularized, similarly to how modern computers contain memory modules. It is not clear that this is an appropriate analogy to describe human memory (as well as much of the brain), as the reality of memory in the human brain appears to be somewhat more complex than this (Ward, 2010).

It must also be noted that while there certainly are conceptual similarities between Otto's notebook and Inga's internal memory, there are also important differences. The implied assertion that Otto's notebook acts as a replacement for his memory is slightly misleading - he is in fact making use of both his own internal memory and his notebook. Although the notebook is clearly a tool acting in conjunction with the brain to enable Otto to think, the foundation and driver of Otto's thinking and cognition remains his brain and the multitude of functions which it is still able to perform. Although he is impacted by his Alzheimer's disease, in order to function as he does in this example, Otto must still be able to remember a vast number of things using his internal memory, including reading, writing, what art is, why he would want to visit a museum, what his notebook is and how to use it. Otto's behavioural competence will drop if his notebook is removed from him, but will cease completely if his internal memory were to be removed.

A key point here is that even if the embodied mind-brain and a notebook are both viewed as cognitive tools, not all tools are equal. As has been implicitly asserted by every theorist discussed thus far, the brain is the primary and pre-eminent tool used by humans for thinking. All other tools are contingent upon being co-opted and used by a person driven by a functioning brain in order to play any cognitive role, while the converse is clearly not true. Although potentially limited in capacity and wont to make use of other tools to overcome such limitations, the brain remains the foundational requirement in any cognitive occurrence. For example, a basic level of internal (i.e. traditional biological) memory is clearly necessary for a person to function and make

use of external tools, even in the presence of external memory storage tools such as notebooks, as was inadvertently affirmed by Clark and Chalmers' (1998) thought experiment involving Otto and Inga.

As such, the impact of any educational technology on the embodied mind-brain and its vitality is therefore a critically important factor when considering that technology's value and effectiveness as educational technology. We have good reason to believe that a technology (i.e. the written word) fundamentally impacted human thought (e.g. Ong, 1982; Donald, 2001) and that the external environment is able to significantly impact human sensorimotor abilities and skills (Heuer, 2016). If there are meaningful differences between traditional analogue text and digital text, then the notion that the digital written word is able to impact human thought cannot yet be dismissed.

3.5. The digital word

Since its beginning in the Ancient Near East (Robinson, 2011), writing has taken an array of different forms, from engravings chiselled out on clay or stone tablets, to ink markings on papyrus and paper, and later machine-set ink imprints on printed paper, to chalk markings on school blackboards, microfiches, and most recently to electronically displayed texts on a screen of some sort. However, despite the diversity of this array of device technologies, an important fundamental feature underlies each one – save for electronically displayed texts. In this section, it will be argued that electronically displayed text, or *the digital word*, is sufficiently unique compared to traditional print and handwritten text (*the analogue word*) to constitute a distinct step in the evolution of literacy, followed by an argument for why this might matter for learning and educational outcomes.

Different reading and writing devices utilise different interfaces and contain important technical, physical, and/or ergonomic differences (Mangen, 2008, 2013a; Mangen & Velay, 2010). For example, the action of writing with a pen on paper involves the writer using a physical tool (the pen) to directly alter the substrate by leaving semiotic markings (text), where these markings and the position of the tool as directly controlled by the writer map directly onto one another. A laptop computer, on the other hand, involves several interconnected tools. Typing on a laptop computer involves pressing down on a specific part of one tool (the keyboard) and then relying on other tools (as part of this chain) to interpret this action (the job of the computer's processing hardware) and send the relevant commands to a third tool (the screen) to display the appropriate semiotic markings. The tool controlled by the writer is separated from the semiotic markings by several degrees and does not directly or permanently alter the text substrate (the screen).

These differences provide users with an array of what Gibson (1979) terms *affordances*, referring to potential possibilities for sensorimotor and perceptual engagement (Mangen, 2013a). If reading and writing were cognitively or intellectually abstract activities, these differences may not make all that much difference. However, as Mangen (2013a) notes, reading and writing are not cognitively or intellectually abstract endeavours – they are grounded in sensorimotor and other embodied elements of human experience (Mangen, 2008; Mangen & Schilhab, 2012; Mangen & Velay, 2010; cf. Chapter 2.3.5., Chapter 2.4.5., & Chapter 3.3. of this dissertation).

Electronically displayed texts, or the *digital word*, represent the first time in the history of literacy that the semiotic markings (text) are ontologically unstable (in the sense that they are impermanent and fluid) and materially disconnected from the substrate which supports them (Liu, 2008; Mangen, 2008, 2010, 2013a). This is true for all electronically displayed text, whether it be a full-colour LCD/LED-based iPad or computer screen or e-ink-based e-reader such as an Amazon

Kindle or Kobo reader. When reading the analogue word, the text becomes a feature *of* the object (piece of paper, stone, vellum etc.) rather than simply a feature *on* an object. The tangibility and material connectedness of both medium/substrate and word results in the creation of a *de facto* singular entity or tool with which the individual interacts. Reading the analogue word is therefore not just engaging with symbolic representations that convey information, but also engaging with physical objects that contain a wealth of spatial, textual, tactile and other types of information, all of which provide a richer context to the information and add to the levels of processing which accompany its imbibing. Mangen's (2013a, p. 95) elaboration of this deserves to be quoted at length:

> When reading digital texts, our sensorimotor (haptic and tactile) interaction with the reading device is experienced as taking place at an indeterminate distance from the actual text, whereas when reading print text we are physically and phenomenologically in touch with the material substrate supporting the text… The book… is a physically and functionally unitary object in which the content cannot be distinguished from the material platform of substrate. Such a detachment [as occurs for digital text] might plausibly have important implications for the reading experience, and it calls for a substantial understanding of the role of the physicality and tangibility of the document and, as a corollary, the fixity of the text during reading.

One potential explanation for why the fixity of text may be important comes from researchers such as Zeichmeister et al. (1975) and Kennedy (1987, 1992, 2000, Kennedy, Brooks, Flynn, & Prophet, 2003; Kennedy & Murray, 1987), who argue that mental depictions of linguistic components have a strong spatial component which is used to aid in certain cognitive activities. Kennedy and Murray's (1987; cf. Kennedy 1992) hypothesis contends that, when reading, an

individual attaches values of a spatiotopic nature to various components of language such as letters, words and phrases (Inhoff & Weger, 2005). These indexed spatiotopic values serve the function of making the text spatially searchable, adding an additional dimension to the textual interaction.

There is a range of empirical evidence supporting Kennedy and Murray's (1987) hypothesis, including Zeichmeister and McKillip (1972) and Zeichmeister et al.'s (1975) work on memory for word location, discussed here in chapter 2.3. Further empirical support comes from Carpenter and Daneman (1981), Christie and Just (1976), Ehrlich and Rayner (1983), Frazier and Rayner (1982), Rayner and Frazier (1987), and Baccino and Pynte (1994), as well as empirical support from experiments conducted by Kennedy et al. (2003) and Kennedy and Murray (1987) themselves.

A key implication of this hypothesis is that the page layout (whether digital or analogue) then becomes a type of external memory (Inhoff & Weger, 2005; Kennedy et al., 2003), which is consistent with Donald's (2001) conceptualisation of external symbols and the external memory field. So, not only the symbols themselves, but also their spatial location can become part of the external memory field.

Kennedy and Murray's (1987) hypothesis implies that when an individual interacts with an object for the first time, a process of sensory and cognitive familiarization occurs where the individual experiences and takes note of important physical features which characterize that object. Much in the same way, an individual reading a page of text for the first time not only interacts with a symbolic representation which conveys information (i.e. the text itself), but also with a physical object – a person reading text on a page processes the textual information as well as things like the location of the text on the page and other physical characteristics such as colours. These ideas will now be used to help contrast the analogue and digital word for reading and then for

writing, two skills which underpin the modern education system. Given their prominence, differences between the digital and analogue for reading, writing or both would have important educational implications.

In the case of the analogue word, the reader is able to interact directly with both the semiotic markings and the substrate, which (in this case) form a *de facto* single object (Kennedy & Murray, 1987; cf. Chapter 2.3.5), enabling the user to assign spatiotopic values to various parts as a component of their interaction with the text. Many of the physical characteristics of the substrate and the semiotic markings are relatively fixed, in the sense that any changes to the text will involve the user physically (and directly) effecting these changes on a near character-by character basis. Even in the case of a 'less permanent' medium such as chalk on a chalkboard, erasing still requires the user to erase each character by hand – the text is not erased near instantaneously as is the case for many screen-based technologies. This (relative) stability of word position may be advantageous if it enables the reader to leverage it as an additional 'memory tool', potentially enabling an additional level of encoding to the reader's engagement with the text. However, other factors such as the inability to alter text size (through zoom) to the individual's preferred size for their unique requirements may prove disadvantageous. Another important factor will be the nature of both the text itself and the task motivations for reading. For example, a person marking an essay or a magazine article is unlikely to need to read that text or meaningfully recall its content at a later stage and is therefore less likely to be negatively impacted by the lack of a spatiotopic extra level of encoding. However, a person studying for an exam from a textbook is more likely to be affected by this, provided meaningful effects actually do exist.

In the case of the digital word, however, the interaction is more complex. The substrate (i.e. the screen) functions as an intermediary between the user and the text, simulating both the

text and a virtual substrate and mediating the user's interaction with the text and virtual substrate. There are important implications both for reading and writing. First, we will consider reading.

As noted earlier in this section, a primary distinction between the analogue and digital word is that the latter is ontologically unstable or impermanent and materially disconnected from its substrate (Liu, 2008; Mangen, 2008, 2010, 2013a). This instability and disconnectedness is what allows digital texts to act as a portal, capable of displaying a vast array of different sources – books, essays, articles etc. – on demand, in comparison to printed text's singular source permanence. This ability is greatly advantageous in many respects. However, this impermanence also removes (to some extent) the spatial location or spatiotopic values which can be assigned to the analogue word (a potentially useful 'memory tool'), although this can be mitigated to some extent by simulating a virtual substrate. In cases like this, the reader is effectively viewing a virtual print text page (with fixed position text) through the portal or intermediary of a digital screen. However, digital text does not necessarily emulate spatial and contextual features of printed text and in some cases, removes this spatial contextual information almost entirely, removing this aspect of the external memory field. In addition, print text still retains important contextual markers such as visual indicator of book size, thickness of pages remaining, etc. (Mangen, 2013a, 2013b, 2016) which the digital word is not yet able to emulate.

As implied by Kennedy and Murray's (1987) hypothesis, when reading a text (particularly when reading it for the first time), an individual can be said to form 'couplings' – mental associations between specific words, points or sentences (i.e. the text) and physical points on the page. The analogue word involves stable one-to-one couplings – each part of the physical space of the medium maps to one part of the text or semiotic marking and this coupling, once set, remains stable. If these spatio-contextual markers are largely absent from a digital text, then reader

performance may suffer, particularly for tasks which require repeated engagements with the text and recall. However, if the digital word successfully emulates a virtual print text page (with fixed position text) in such a way that enables the reader to discern the spatial and contextual features that would be discernible for printed text, there it seems plausible that the interaction would be fairly similar, allowing the reader to form and retain the mental couplings.

For cases where the presentation of the digital word contains spatial and contextual features such as page layout which are less easily discernible, it is unclear whether the mind would either form far fewer couplings or form and reform couplings every time text size and position changes. Zumbach and Mohraz's (2008) finding that reading hypertext increases cognitive load suggests the latter, although Mangen and Kuiken's (2014) findings suggest this increase in cognitive load could be at least partly due to chronological order effects. More research is needed to answer this question.

As illustrated above, there appears to be good reason to believe that meaningful differences exist between reading the analogue word and the digital word. Both conceptual considerations and empirical evidence suggests that there is good reason to believe that even stronger differences exist between the acts of writing the analogue word and the digital word. While reading's primary tasks are reception and processing of existing material, writing involves expression and production – the formation of semiotic markings from within a predefined textual or alphabetic structure in a coherent manner consistent with an array of linguistic requirements. Neurophysiological and experimental evidence indicates that important differences exist, for example, finding that handwriting activates areas of the brain associated with reading and writing, while typing only activates regions associated with the latter (James, 2010; James & Engelhard, 2012; James & Gauthier, 2006; Longcamp et al., 2003, 2006) and that recall is better for handwriting than typing

(Longcamp et al., 2005, 2006; Mueller & Oppenheimer, 2014). Further evidence indicates that differences exist in hand-eye sensorimotor integration and that cross-modal couplings exist for handwriting (Alamargot et al., 2006; Caporossi, Alamargot & Chesnet, 2004) and typing (Inhoff & Gordon, 1997; Wengelin et al., 2009).

Similarly to reading, hand-inscribing the analogue word allows the writer to directly interact with the substrate and physically (tangibly) alter it. The sensorimotor skills involved in writing are also different to those involved in typing (Heuer, 2016). The handwritten analogue word requires the individual to physically form shapes (e.g. letters) which correspond to an existing alphabet or predefined required shape and structure (while also being able to recognise the litany of slight variations of each letter's print shape, and handwritten shape both within an individual's own handwriting and across different individuals' handwriting). There is also a high degree of consistency between the motoric output (i.e. the shapes drawn and associated hand movements when writing letters) and what is processed visually, supported by Longcamp et al. (2005, 2006) and James and Engelhardt's (2012) findings. This greater degree of visuo-motoric consistency may enable an additional level of encoding, which may help explain Mueller and Oppenheimer's (2014) findings.

Typing, on the other hand, involves a strongly mediated interaction, where the user is unable to directly interact with the substrate and is not able to physically (i.e. permanently) alter the scree. There is a significantly lower degree of visuo-motoric consistency, for two reasons. Firstly, the writer's motoric input is directed at another tool which then interacts with other tools to modify the substrate, rather than being able to interact directly with the substrate itself (as is the case for the analogue word). Secondly, typing does not require the writer to form each letter by hand, with the shapes drawn and hand movements made corresponding strongly to the output on

the substrate. Instead, each character is associated with a spatial location within the confines of the keyboard space. Reaching this spatial location with one's finger is both less consistent with the shape of each letter (than writing) and less differentiable from the actions required to produce other letters.

However, the assigning of spatiotopic values still takes place for typing, as evidenced by the existence of touch typists – individuals who are able to type without needing to look at the keyboard to recall which letter-buttons are situated where. This is an example of the phenomenon known as implicit or 'muscle memory' (Shusterman, 2011). Anecdotal evidence suggests that it is possible to form implicit representational memories for typing which are not consciously available and can only be accessed by repeating the typing action. An example of this is an individual who is unable to consciously remember their e-mail password, but who is able to recall it by typing it out on a keyboard. This suggests that spatiotopic value-assigning still takes place for typing, but at a lower rate or level than for handwriting (as individuals are generally able to mentally simulate written letters far better than mentally simulating keyboard key positions). A further question is whether the greater number of levels of perceptuomotor/spatial encoding for handwriting make a difference.

3.6. Summary of theoretical considerations and literature review

Individuals and entities from various spheres have, at various points in time, supposed that newer technologies like the tablet PC would replace older technologies such as printed text (Mangen, 2013a, Marshall, 2005; Sellen & Harper, 2002), However, as this chapter has illustrated, important differences do exist between the analogue and digital word and there is reason to believe that these differences may have important implications, particularly for learning. Using theoretical contributions from Ong (1980, 2011), Donald (2001), and others from the field of cultural-

historical activity theory, it has been demonstrated that the written word is a tool and technology which played a pivotal role in the development of human civilisation and has even altered human thought. Insights and evidence from theorists and researchers in the field of grounded cognition helped illustrate the embodied nature of cognition and the important role played by perception, proprioception, bodily states, simulation and other modal factors. Following this, contributions from several theorists and researchers were used to briefly examine relevant questions around the brain, extended mind, and consciousness. Finally, this body of literature (in conjunction with empirical evidence cited in chapter 2) was used to argue that the electronically displayed text – the digital word – has important features which distinguish it from the more traditional analogue word.

The considerations detailed in previous sections suggest that the digital and analogue word do offer different affordances. While there is evidence to suggest that the analogue word does offer important affordances which the digital word does not, it must be noted that the digital word also offers affordances which the analogue does not. Disparities may also narrow as socio-cultural knowledge (both implicit and explicit) around the digital word grows. It seems reasonable to suggest that the introduction of these new digital technologies, rather than replacing paper, may instead allow us to expand the usefulness of the written word, enabling new ways of using and interacting with the written word. It is in this that the strength of the digital word lies – in its ability to expand and complement and not necessarily replace print text or the analogue word.

Many important questions are raised by these considerations. Given that the core focus of this dissertation is on the role of the digital word and its various interfaces and its impact on educational outcomes, the most appropriate focus questions appear to be those centred on learning and in particular the impact of these various devices on learning. The next chapter will now detail

the experimental methodology utilised to conduct the research experiments which are the focus of this dissertation.

Chapter 4

Methods

4.1. Overview

When used in the educational context, tablets are often used to replace traditional paper-based textbooks with electronic or e-textbooks. This experiment examined whether performance differences exist when learners performed the same reading task using either traditional pen and paper or using a tablet PC. Participants either performed a reading-only or reading and writing task which was followed one week later by a multiple-choice test on the passage read. This study involved both repeated measures (i.e. within subjects) participants who performed either the reading-only or reading and writing task on both paper and tablet as well as participants who completed only one of these conditions (i.e. between subjects). The tests used contained both factual and conceptual (i.e. higher-order, applied) questions.

4.2. Aims and objectives of this experiment

This experiment examined whether performance differences exist when South African secondary learners performed ostensibly the same reading-and-writing based learning tasks using either traditional pen and paper or using a tablet PC. Learning performance (as opposed to reading comprehension) was measured by introducing a meaningful time-delay between the task itself and the test conducted. Differences were further explored through the comparison of ostensibly identical tasks on paper and tablet (i.e. reading only) as well as ostensibly similar tasks on paper and tablet (reading and note-taking), both tasks or activities which provide a reasonable approximation of real-world learning.

4.3. Rationale for experimental design

Arguably the most common use of tablets in the educational setting is replacing traditional paper-based textbooks with electronic or e-textbooks. Existing literature is yet to reach a definitive conclusion on what differences, if any, exist between reading from paper and from tablet PC screens, although most existing studies effectively tested reading comprehension (since participants were tested almost immediately after completing the reading tasks) rather than learning (by introducing a meaningful time-delay between task and testing). Despite a lack of definite clarity, however, it is the more recent of the studies reviewed which indicate that meaningful differences may exist. Furthermore, these studies cast doubt on the assumption that the fundamental task of reading is device-agnostic, with differences in levels of visual fatigue, comprehension etc. It is therefore imperative to examine whether meaningful performance differences in learning exist when using these two different media (digital and analogue). The most sensible place to begin would appear to be examine whether learning performance differences exist for reading only (a fundamental task which is not dependent on device-familiarity) and for reading and note-taking (a commonly used learning strategy among secondary and tertiary learners).

A one-week delay between reading task and test adds to the logistical complexity of the experiment and increases the risk of attrition. A further component was added to this experiment after data was collected by partitioning out a sub-sample of participants who had a two-to-three-day delay between reading task and test (as opposed to the approx. one week delay for all other participants), with the aim of establishing whether this shorter delay still provides as ecologically valid a measure of learning as a one-week delay.

4.4. Research questions

(1) Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read (only) on paper compared to when this is done using a tablet PC?

(2) Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read and notes are taken on paper compared to when text is read and notes are taken using a tablet PC?

(3) What differences exist, if any, between the results of research questions 1 and 2 and what is the nature of these differences?

(4) Are there differences in learning (as measured by test performance) if the delay between reading task and test (research question 2 – note-taking) is reduced from approximately one week to several days?*

4.5. Hypotheses

(1) Statistically significant differences will exist between the paper and tablet reading-only conditions.

(2) Statistically significant differences will exist between the paper and tablet reading-and-note-taking conditions.

(3) The differences between conditions for research question 1 will not be the same as those observed for research question 2.

(4) Statistically significant differences will not be detected between participants with one week or 2-3 day delays between reading task and test.

4.6. Sample

A volunteer, convenience sample was used for this experiment. Participants were recruited from six sites, all within the Gauteng area, all of which hosted secondary school students in grades 11 and 12. These six sites represented different parts of the demographic spectrum in terms of socio-economic status and mother tongue/home language spoken, among other factors, strengthening the external validity of this study. Participants completed their assigned experimental tasks on one or more of paper, a tablet PC, laptop/desktop PC, or an e-ink e-reader. A more balanced designed across a number of conditions was originally intended, but recruitment and other practical challenges made this unachievable Because of the very small number of respondents in every condition except paper and tablet, as well as the fact that the primary focus of this experiment is comparing these two devices, only the paper and tablet conditions are examined here. Table 1 below provides an overview of participant distribution across the various conditions.

Table 1. Participant numerical distribution across various conditions

Type	Condition	Paper (N)	Tablet (N)
Between-subjects (one-week delay)	Reading-only	33	12
	Reading & note-taking	59	26
Within-subjects	Reading-only	27	27
	Reading & note-taking	42	42
Between-subjects (two-to-three-day delay)	Reading & note-taking	16	9

As illustrated in Table 1 above, the data is partitioned into three distinct samples – between-subjects (one-week delay between reading task and test), within-subjects, and between-subjects (two-to-three day delay between reading task and test). Apart from three cells, the sample sizes obtained compare favourably (either similar or larger) with those obtained for similar experiments such as Mueller & Oppenheimer (2014), whose sample size averaged approximately 27 per cell.

Basic sample characteristics for each of these three partitions are provided below; more detailed presentation of demographic information is provided in Chapter 5 – Results.

Between-subjects (one-week delay)

Table 2 below provides an overview of participant demographic information for the paper and tablet between-subjects (one-week delay between reading task and test) condition which will be analysed as part of this experiment.

Table 2. Between-subjects (one-week delay)

	Reading only		**Note-taking**	
	Paper	**Tablet**	**Paper**	**Tablet**
Total number (N)	33	12	59	26
Average age (years)	18.2 [25]*	18.4 [7]*	17.0 [49]*	17.7 [21]*
Number of male participants	12[a] (39%)	4[b] (44%)	23[c] (42%)	9 (35%)
Number of female participants	19[a] (61%)	5[b] (56%)	32[c] (58%)	17 (65%)

N in brackets. Variable N's are the result of missing demographic data.

[a, b, c] 2, 3, & 4 participants did not answer, respectively

Within-subjects

Table 3 below provides an overview of participant demographic information for the paper and tablet within-subjects condition which will be analysed as part of this experiment.

Table 3. Within-subjects

	Reading only	**Note-taking**
Total number (N)	27	42
Average age (years)	16.45 [1]	16.75 [2]
Number of male participants	8 (30%)	24 (57%)
Number of female participants	19 (70%)	18 (43%)

[1] 7 participants did not answer – calculated using remaining 20

[2] 1 participant did not answer – calculated using remaining 41

Between-subjects (two-to-three-day delay)

Table 4 below provides an overview of participant demographic information for the paper and tablet between-subjects (two-to-three-day delay) condition which will be analysed as part of this experiment.

Table 4. Between-subjects (two-to-three-day delay)

	Note-taking	
	Paper	**Tablet**
Total number (N)	16	9
Average age (years)	16.8	16.7
Number of male participants	3 (19%)	2 (22%)
Number of female participants	13 (81%)	7 (78%)

4.7. Instruments

A range of instruments were used to conduct this experiment, including electronic hardware (devices), text passages and related test questions and a demographic questionnaire, among other instruments.

Devices

The devices which were used in this study are: touchscreen tablet computers, pens and A4 paper with printed text. In cases where participants did not have a tablet of their own, one was provided by the researchers. At three of the six sites, most participants were in possession of tablet computers which they made use of on a daily basis as part of their academic activities, many of whom had done so for three years. This implies a high degree of device and app familiarity both in general and more specifically for use in the classroom setting. Although allowing participants to make use of their own devices to participate in the experiment would result in a lack of standardisation, particularly in terms of screen size and performance, this disadvantage is substantially outweighed by the potential improvements in ecological validity which could be obtained. Participants were therefore allowed to make use of their own devices to complete the assigned experimental tasks. The models of tablet used by these individual participants varied significantly and screen sizes of these tablets varied from 7” to 10” measured diagonally.

Demographic Questionnaire

Each participant completed a demographic questionnaire consisting of three parts. The first part contains items which established participant age, grade, gender and school subjects taken at grade 10 – 12 level. The second part focused on the participant’s language experience and proficiency. This section is a shortened, adapted version of the Language Experience and Proficiency Questionnaire (LEAP-Q), a well-established measure of language proficiency

developed by Marian, Blumenfeld and Kaushanskaya (2007). South Africa is a highly multi-lingual society and English is only spoken as a home language by a small proportion of South Africans (Statistics South Africa, 2012). The primary focus of this section, therefore, was to gain a measure of insight into the participant's experience and proficiency with the English language. The final section of the demographic questionnaire contains two questions which addressed participant access to electronic devices (specifically laptop, desktop PC, tablet, smartphone and e-reader) and frequency of use. The demographic questionnaire is included as Appendix A.

Reading Material

The four texts used for this experiment were adapted from materials used by Mueller and Oppenheimer (2014). Prior to conducting these research experiments, a pilot study was conducted using one of four texts from Mueller and Oppenheimer (2014) as well as an extended factual article taken from British Broadcasting Corporation (BBC) News service of similar length (BBC News, 2015b). Based on the results of this pilot study, the four texts used by Mueller and Oppenheimer (2014) were chosen for use in the full-scale experiment and were adapted to make the texts more appropriate for South African grade 11 and grade 12 learners. These adaptations were implemented by the research team incorporating the principal researcher and research assistants, all of whom are postgraduate psychology students. Each text is approximately 1150-1200 words long and is centred on either bread, bats, respiration or vaccines. All four texts are included as Appendices D, E, F, and G.

Multiple Choice Tests

Approximately one week after reading/studying these texts, participants completed a 10-item multiple choice test based on the text they had read. All four tests were adapted from materials used by Mueller and Oppenheimer (2014). Each test consisted of five levels of or types of question

and each test contained two questions belonging to each of the five question types/categories. Table 5 below lists each question type and provides an example question for illustration. Participants were given four possible answers to each question and were required to select the correct option (i.e. standard multiple-choice answer format). The questions used were taken from Mueller and Oppenheimer (2014), while the research team created the four possible answers for each question. All four tests used in the full-scale experiment are included as Appendices L, M, N, and O.

Table 5. Examples of question types used

Question type	Example of question type
Factual	What compound will form when calcium and chlorine react with one another?
Conceptual	If a person's larynx is not working properly, what will the mostly likely result be?
Inferential	"Sometimes bats die while they are sleeping. What will happen if a bat dies while it is hanging upside down?" (Mueller & Oppenheimer, 2014, p. 6)
Application	"Psychologists have investigated a phenomenon known as "attitude inoculation,' which works on the same principle as [medical] vaccination and involves exposing people to weak arguments [which are] against a viewpoint [that] they hold. What would this theory predict would happen if the person was later exposed to a strong argument against their viewpoint?" (Mueller & Oppenheimer, 2014, p. 6)
Seductive Detail (i.e. interesting but irrelevant information)	What were the names of the two sheep which were cloned at the University of Istanbul in Turkey in November 2007?

4.8. Procedure

After Departmental and Faculty review of the research proposal, an application for ethics clearance was submitted the Wits Human Research Ethics Committee (non-medical) – HREC (non-medical). In parallel, a research approval request was submitted to the Office of Knowledge Management and Research, Gauteng Department of Education (GDE). Approval was granted by the GDE (ref. no. D2016 / 178 GA) and ethics clearance was subsequently granted by the HREC (non-medical) – protocol number H15/05/41 to conduct this research. As stipulated in the GDE research approval letter, this letter was forwarded to the relevant district directors via the district co-ordinators of the Secondary School Improvement Programme (SSIP).

A pilot study with a small number of participants was then conducted at a science centre with students participating in an enrichment programme run by the centre. Permission for this was first obtained from the CEO of the centre. Feedback from this pilot study was incorporated and necessary changes were made to the instruments and the experimental procedure.

At all six sites where these experiments were conducted, researchers were allocated a classroom space to make use of. All of these classrooms were largely similar in terms of their size, lighting, types of desks and chairs, environment (i.e. temperature and humidity) and external noise level (low to moderate) – representative of real-world learning conditions.

At sites 1-5 participants were assigned to a device and reading/note-taking condition and given 30 minutes to study the text passage assigned to them. Before beginning their assigned task, participants first completed the demographic questionnaire. Approximately one week later, participants returned, were given 5 minutes to revise the text and/or their notes, followed by a 10-minute test on the text passage. For participants who completed only one device condition, this marked the end of their research participation. Participants completing multiple conditions,

immediately after completing their first test, were then assigned to another device condition and the same reading/note-taking condition and given 30 minutes to study a different text. These participants then returned approximately one week later, were given 5 minutes to revise the text/their notes followed by a 10-minute test.

Participants at site 6 followed a nearly identical procedure to the one device only sample. The only difference was that half of site 6 participants were given 2 days between initial studying of text and test, while the other half were given 3 days. This was enforced by logistical limitations – this was the only available time frame which could be allocated by the organisers of the site 6 timetable and compares to the approximately one week between initial reading and test that occurred at the other five sites. At all six sites, each experimental session lasted approximately 50 minutes, both for participants only completing one device condition and for those completing two or more device conditions.

Two of the six sites where experimental data was collected are SSIP participants and are located in two separate Gauteng townships. This programme is structured so that pupils from approximately two to three schools (with this number depending on a range of factors) attend classes at one of those schools on Saturdays and during school holidays. Although primarily targeted at underperforming schools, many schools on this programme have seen dramatic performance improvements in a short space of time and are no longer considered underperforming. The two SSIP schools where experiments were conducted both have matric pass rates of 90%+ and are therefore considered to be fairly high performing institutions.

At both these SSIP sites, research was conducted on Saturday mornings, over a period of two Saturdays at one site and four Saturdays at the other. In both cases preparations were made with the relevant SSIP site manager beforehand. Learners who had free slots in their Saturday

morning class timetable were invited to participate in the research. The SSIP programme involves matric learners and participants from these two sites were 18 years or older, allowing participants to give informed consent themselves, without requiring informed consent from their parents or legal guardians. This approach was requested by district officials to avoid researchers having to approach learners during the week. The site managers allocated an empty classroom for use by the researchers. At site 5 participants were assigned both to a device condition and a particular text passage on the first Saturday morning – all participants completed the reading only condition. At site 3, participants had each been provided with a tablet by the GDE and as such learners were allowed to use their own devices. Therefore, on the first Saturday morning at site 3, all participants completed the paper note-taking condition using the same text and the following week, participants all completed the tablet note-taking condition, using a different text, but with all participants using the same text. Due to a number of factors, including an alternate week subject scheduling on learner timetables, relatively high rates of attrition were experienced at this site, necessitating two additional sessions at site 3. Despite four sessions, very few participants successfully completed two conditions, leaving most of the data collected from both these sites as one device condition only.

Sites 2 and 4 are both suburban secondary schools, while site 1 is a private urban school. Research at these schools was conducted during the week, at times allocated by the school management. At all three schools, grade 11 learners were addressed as a single group and invited to participate in the research. Participant information sheets and consent/assent forms were also handed out to learners. The researchers then returned approximately one week later and began conducting the research experiments over a number of weeks. Participants at sites 1 and 4 completed the paper condition first followed by the tablet condition a week later, primarily due to

practical limitations. Participants at site 1 all completed the same text passage during the first session and participants all completed the same text (different to the first week's) during the second session. However, the majority of participants at this site did complete two device conditions, allowing for comparisons to be made within samples. Participants at site 2 completed the same text passage each week, but were 'quasi-randomly' assigned to device conditions, leading to a fairly balanced distribution of device conditions and text passages.

4.9. Research design

The research questions addressed by this experiment were investigated by means of both between and within-subjects quasi-experimental designs with contrast groups and without bona fide random assignment. The implementation of a within-subjects research design was attempted wherever possible, but where practical and logistical factors prevented this, a between-subjects research design was implemented instead. The fundamental design for each participant remained the same, with relatively minor variations across samples.

A range of largely practical factors determined whether (and to what extent) the between- or within-subjects designs were implemented. Among the most prominent of these factors were willingness to participate in more than one condition, availability of time slots at individual venues, and logistical and technical difficulties experienced while conducting the experiments. The extent and effect of these factors varied across sites and even across times, leading to only the between-subjects design being implemented at sites 5 and 6 and both the between- and within-subjects designs being implemented at sites 1, 2, 3 and 4.

At sites 2, 5 and 6 participants were 'quasi-randomly' assigned to a device condition (i.e. the research team assigned participants to device conditions, but without the aid of a mathematical tool to ensure randomness). At sites 1, 3 and 4, participants all completed the paper condition first,

followed by the tablet condition a week later. Although this introduces the potential of order effects, it was not practically possible to balance device conditions at these particular sites. It was intended that all participants at these sites (1, 3 and 4) would complete two device conditions; however, attrition meant that a significant number of participants ended up completing only one of these conditions, thereby falling into the between-subjects design by default. Practical realities made random assignment difficult and this was therefore not successfully implemented. These various device conditions and reading/note-taking conditions represent contrast groups rather than control groups, further reiterating the quasi- rather than true experimental nature of this experiment. That being said, however, it is not clear and certainly not obvious whether a practically feasible control group condition is possible in this context. Furthermore, these contrast groups strongly correspond to real-world learning experiences, with many learners making use of one or more of these device- and reading/note-taking conditions as part of their regular academic activities.

4.10. Ethical considerations

An application for ethics clearance was submitted the Wits Human Research Ethics Committee (non-medical) – HREC (non-medical). In parallel, a research approval request was submitted to the Office of Knowledge Management and Research, Gauteng Department of Education (GDE). Approval was granted by the GDE (ref. no. D2016 / 178 GA) and ethics clearance was subsequently granted by the Wits HREC (non-medical) to conduct this research (protocol number H15/05/41). Four of the sites are public secondary schools. One of the stipulated conditions of the GDE research approval is that the GDE research approval letter be sent to the directors of these four districts. This was done via the district SSIP co-ordinators. Permission to

conduct research was obtained from the principals or site managers at each site. One of the sites is a private school – written permission was obtained from the school principal.

Informed consent and assent.

Informed consent to participate was obtained prior to conducting research for participants above the age of majority (i.e. 18 years of age). School/site management and teachers at all six sites were informed of the need to obtain informed assent and consent (from parents if participants were younger than 18 and from the participants themselves if 18 years or older) to participate for learners below the age of 18 years. Researchers worked in conjunction with school/site management and teachers through available channels to distribute the necessary assent and consent forms to learners who wished to participate in the research. Learners were instructed to return them either to the researchers themselves upon their next visit to the site/school or to their teachers. Learners were given regular reminders both by the school, teachers and the researchers themselves to return these forms should they wish to participate in the research. In addition, participants were regularly reminded that they were under no obligation to participate in the research and that both consent and assent (if under the age of 18) was required for their participation in the research.

No disruption of teaching and learning.

The researchers involved in this project worked closely with school management and teachers at all six sites to structure and carry out this research so as to ensure that it caused no disruption to ordinary teaching and learning at any of these schools. In all six cases, the researchers made it clear to teachers and school management that one of the researchers' obligations was to not disrupt ordinary teaching and learning and that teaching and learning were required to take precedence over the research experiments. In order to ensure the optimal use of time and resources

(from the perspective of schools and learners), the researchers deferred to and were guided by school/site management and teachers in each case with respect to the timing and location of the research experiments.

Anonymity

The right to anonymity of all participants was protected as far as practically possible. All personal or identifying data which was captured as part of this research is stored on a password-protected laptop computer belonging to one of the researchers. Access to this information has been strictly limited to the researchers. Both the analysis and write-up of results is entirely anonymous, with all personally identifying data removed. The original data has been safely stored and will be destroyed after a period of 5 years has elapsed following the completion of the primary researcher's Master's thesis.

The nature of the research design used required participants to return after a period of one week in order to complete the experiment, which required a means of identifying participant notes/documentation. A labelling system using a unique anonymising code was developed for each participant, which is relatively easy for participants to generate and remember, allows identification of documentation as necessary while protecting participant anonymity. This code is based on the last three letters of participant's first name, the last three letters of the participant's surname and the participant's grade (i.e. year of school study). This anonymizing system was implemented at sites 2, 3 and 5. This labelling system was altered slightly for site 6 by replacing the last three letters of the participant's name/surname component with participant seat row and number. This was done for primarily practical reasons, although it also strengthened participant anonymity. At sites 1 and 4, participants struggled to properly implement this labelling system and

as such some participants instead wrote their names or names and surnames on their notes and tests instead of the anonymising code. A number of steps were taken by the research team to ensure that the original documents (notes, tests etc.) were securely stored and transported so that only the research team was able to access and view these documents. During the process of data capturing, all participants (whether they had made use of the anonymising code system or had simply written down their names) were assigned a numerical code which allowed for the anonymous analysis of captured data.

Debriefing

Participants were made aware by means of the participant information sheet handed out that they would be able to direct any queries about the research to the principal researcher, whose e-mail address was provided on the sheet itself. Participants were also given the opportunity to ask questions at any point throughout the experimental process.

Right to withdraw at any time without penalty

Participants were made aware of their right to withdraw from participating in any of these studies via the participant information sheet and could withdraw at any point during the study without penalty.

4.11. Data analysis

Each valid participant response involved a completed 10 item test score. As described in Chapter 4.7., four different text passages (and accompanying texts) were utilized in this experiment. In order to account for perceived and actual differences in difficulty across these four text passages, all test scores were standardised to z-scores, with each of the four text passage

groupings being normalized separately. These standardisations were conducted across the whole sample, rather than separately for smaller groupings/sites.

Research Question 1

Reading-only condition: a non-parametric Mann-Whitney U test is used to analyse between-subjects (one-week delay) data, while a parametric paired-samples t-test is used to analyse within-subjects data. Independent variable (IV): device condition; dependent variable (DV): test scores

Research Question 2

Reading and note-taking condition: a non-parametric Mann-Whitney U test is used to analyse between-subjects (one-week delay) data, while a parametric paired-samples t-test is used to analyse within-subjects data. IV: device condition; DV: test scores

Research Question 3

For both the between-subjects (one-week delay) and within-subjects conditions, the results obtained for research questions 1 and 2 are compared and contrasted.

Research Question 4

Data from the between-subjects (two-to-three-day delay) condition are compared to data from the between-subjects (one-week delay) condition.

Supplementary Analysis

A supplementary analysis is conducted to evaluate the impact self-report English proficiency on test results. A second supplementary analysis is conducted to evaluate whether any performance differences exist for gender.

Chapter 5

Results

5.1. More detailed participant demographic information

More detailed participant demographic information is presented below, focusing on English language background and self-report proficiency (as the language in which the experiment was conducted), and is split into three sections – between-subjects (one-week delay), within-subjects, and between-subjects (two-to-three-day delay). The 'English Home Language' and 'First Additional Language' in each table refers to the level at which participants study English as an academic subject. The majority of South African secondary school learners do not speak English as their home language, although a significant proportion of these learners still study English at home language level (Statistics South Africa, 2012), necessitating additional items to build a better picture of language background and self-report proficiency.

(a) Between-subjects (one-week delay)

Table 6. Between-subjects (one-week delay) demographic information

	Reading only		**Note-taking**	
	Paper	**Tablet**	**Paper**	**Tablet**
Total number (N)	33	12	59	26
Average age (years)	18.2 *[25]* *	18.4 *[7]* *	17.0 *[49]* *	17.7 *[21]* *
Number of male participants	12[1] (39%)	4[2] (44%)	23[3] (42%)	9 (35%)
Number of female participants	19[1] (61%)	5[2] (56%)	32[3] (58%)	17 (65%)
English Home Language (subject)	21 (64%)	7 (58%)	57 (97%)	14 (54%)
English First Additional Language (subject)	12 (36%)	5 (42%)	2 (3%)	12 (46%)
Average estimated percentage of time participant is exposed to the English language (%)	40.9% *[24]* *	36.4% *[7]* *	49.7% *[47]* *	37.3% *[19]* *
English most dominant language? (% of participants)	64% *[25]* *	57.1% *[7]* *	71.4% *[49]* *	42.1% *[19]* *
English as first language of acquisition (%)	28.0% *[25]* *	0% *[7]* *	28.6% *[49]* *	5.3% *[19]* *

* Figure in brackets shows N used to calculate. Variable N's resulted from missing demographic data

[1, 2, 3] 2, 3 & 4 participants did not answer, respectively

The average age of participants ranges from 17 to 18.4 years of age, while the gender distribution across cells is skewed in favour of females, with female to male ratios of approximately 1.6:1 for the paper reading-only condition; 1.25:1 for the tablet reading-only condition; 1.4 for the paper note-taking condition; and 1.9:1 for the tablet note-taking condition. A higher proportion of participants report taking English at home language level than at the level of first additional language, with slightly more taking English home language for the tablet reading-only (58%) and note-taking (54%) conditions and substantially more for the paper reading-only (64%) and note-taking (97%) conditions.

No more than 29% of respondents in any cell listed English as their first language of acquisition and for no condition did the participants (on average) estimate that they were exposed to the English language more than 50% of the time. Despite this, however, a much larger proportion of students listed English as their most dominant language. Although this may seem somewhat strange at first, when one considers the ever-increasing prevalence and predominance of the English language in various aspects of modern life, particularly among younger generations combined with the prevalence of learning English at the level of home language already displayed in this sample, this very high proportion of participants listing English as being their most dominant language seems not only plausible, but very possible that these statistics are fairly close to being representative of national demographics for this age group.

(b) Within-subjects

Table 7. Within-subjects demographic information

	Reading only	**Note-taking**
Total number (N)	27	42
Average age (years)	16.45 [1]	16.75 [2]
Number of male participants	8 (30%)	24 (57%)
Number of female participants	19 (70%)	18 (43%)
English Home Language (subject)	27 (100%)	40 (95%)
English First Additional Language (subject)	0 (0%)	2 (5%)
Average estimated percentage of time participant is exposed to the English language (%)	53.3%	65.5%
English most dominant language? (% of participants)	80% [1]	80.5% [2]
English as first language of acquisition (%)	15% [1]	41.5% [2]

[1] 7 participants did not answer – calculated using remaining 20

[2] 1 participant did not answer – calculated using remaining 41

The average age of participants in each sample group (reading only and note-taking) is within the expected 16-18-year age range. All of the participants in the reading-only sample study English at home language level, while the vast majority of those in the note-taking sample (40 out of 42 participants) study English at home language level. However, this is not a good measure of home language or level of multilingualism, as demonstrated by the statistics in Tables 7 and 8. A very high proportion of participants claimed to be able to speak two or more languages, with English being the first language or home language of only a small proportion of participants,

particularly for the reading only sample (15%) and to a lesser extent for the note-taking condition (41.5 %). The former is consistent with national demographics, while the latter is significantly higher than general population statistics (Statistics South Africa, 2012). In the reading-only sample, participants (on average) estimated that 53.3 % of their general language exposure was to English, with this figure being 65.5% for the note-taking sample. Given the ever-increasing prevalence and predominance of the English language in various aspects of modern life, particularly among younger generations, it seems possible that these statistics are fairly close to being representative of national demographics for this age group. Finally, for gender, the reading only condition has a markedly skewed distribution, with more than twice as many female participants compared to male participants (a ratio of approximately 3 males to every 7 females or 1:2.3), while the note-taking condition contains a somewhat less skewed (albeit still uneven) gender distribution, with males outnumbering females at a ratio of approximately 4 males to every 3 females (or 1.33:1).

(c) Between-subjects (two-to-three-day delay)

Table 8. Between-subjects (two-to-three-day delay) demographic information

	Note-taking	
	Paper	**Tablet**
Total number (N)	16	9
Average age (years)	16.8	16.7
Number of male participants	3 (19%)	2 (22%)
Number of female participants	13 (81%)	7 (78%)
English Home Language (subject)	3 (19%)	3 (33%)
English First Additional Language (subject)	13 (81%)	6 (67%)
Average estimated percentage of time participant is exposed to the English language	32.3%	45.7%
English most dominant language? (% of participants)	25%	55.6%
English as first language of acquisition (%)	0%	0%

The average age of participants in this sample is very uniformly distributed at 16.7–16.8 years of age across both device conditions. The gender balance is, however, very heavily skewed in favour of females. This sample is the only one of the three where a greater number of participants study English at the level of first additional language rather than at home language level. None of the participants in this sample had acquired/learnt English as their first language. Both these are more (although not fully) representative of national demographics than the previous two sections (Statistics South Africa, 2012). The average estimated percentage of time that participants are exposed to the English language is fairly similar to the proportions reported in the one device only

section. Given that none of the participants in this sample are English first language speakers, the percentage of participants listing English as being their most dominant language is also comparatively large. As discussed in the previous subsection, when one considers the ever-increasing prevalence and predominance of the English language in various aspects of modern life, particularly among younger generations combined with the prevalence of learning English at the level of home language already displayed in this sample, this very high proportion of participants listing English as being their most dominant language seems not only plausible, but very possible that these statistics are fairly close to being representative of national demographics for this age group. It must be noted, however, that the sample sizes in the sub-section are very small.

5.2. Overview of test results

As described in Section 4.7., each of the four tests used in these experiments contained 5 question types or categories, with each test comprising a total of 10 items, with two items per question category. The 5 question categories are: Factual, Seductive Detail, Conceptual, Inferential, and Application. However, given the relatively small number of participants in some of the samples, that each question category is served by only two items, and that there are meaningful similarities between the question categories, it was decided to collapse these five categories into two, as detailed in the next sentence. For this analysis, these 5 question categories were collapsed into 2 groups, namely ‘Factual’ questions (comprising the Factual and Seductive Detail categories) which involve recall of information without a significant degree of application or conceptual understanding and ‘Conceptual’ questions (comprising the Conceptual, Inferential, and Application categories) which involve a significant degree of application and conceptual understanding. The scores for the Factual and Conceptual groups were calculated by averaging the standardised scores of the constituent question categories for each group.

5.3. Research question 1

(1) Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read (only) on paper compared to when this is done using a tablet PC?

(a) Between-subjects (one-week delay)

Due to the small number of participants in the tablet condition (n = 12) and the imbalance between tablet and paper, non-parametric, independent-samples Mann-Whitney U tests were conducted on the scores obtained by the 45 participants who completed the reading only condition using either paper (n = 33) or tablet (n = 12). Separate tests were conducted for the Factual and Conceptual question groups. Table 9 below details the results obtained.

Table 9. Between-subjects (one-week) reading only condition

Question Group	Device	N	Mean	SD	Mean Rank	Sum of Ranks	Mann-Whitney U	Exact Sig.	Effect Size
Factual	Paper	33	.271	.68	25.79	851	106	.017	.69
	Tablet	12	-.204	.71	15.33	184			
Conceptual	Paper	33	-.139	.70	23.53	776.5	180.5	.658	.04
	Tablet	12	-.163	.47	21.54	258.5			

For factual questions, participants who used paper performed significantly better than those who used tablets (sig. = .017), similarly to the pattern seen in participants in the corresponding paired-samples section. For conceptual questions, however, the means are almost

identical and there is therefore no statistically significant difference between the two distributions.

(b) Within-subjects

The relevant parametric assumptions were met and a matched-pairs or paired-samples t-test was conducted on the scores obtained by the 27 participants completed the reading only condition using both paper and tablet. Separate paired samples t-tests were conducted on both the Factual and Conceptual question groups. A positive mean indicates that paper-device scores are higher than those for tablets. The obtained results are listed in Table 10 below.

Table 10. Within-subjects reading only condition

Question Group	Means (Paper/ Tablet)	Mean Diff.*	Stand. Dev.	Std Error Mean	95% CI of Difference		t	df	Sig. (2-tailed)	Effect Size (Cohen's d)
					Lower	Upper				
Factual	.31 –.20	.51	.96	.18	.132	.89	2.78	26	.010	0.65
Conceptual	.01 –.23	.24	.63	.12	-.004	.49	2.02	26	.054	0.33

* Positive mean indicates that paper-device scores are higher than those for tablets; N = 27

For the Factual group of questions, with a statistical significance of 0.01 and moderate-to-large effect size of 0.65, participants performed significantly better when they used paper compared to when they used tablets. For the Conceptual group of questions, the mean difference is also positive, indicating that participants tended to perform better when using paper compared to when using tablets for reading. The statistical significance of this difference is 0.054, which is

very marginally above the widely-used level of significance of $\alpha = 0.05$, while the effect size is small-to-moderate at 0.334. This suggests the possibility of weak but real effects on performance for higher order conceptual questions, but the evidence is inconclusive given the failure to achieve significance.

5.4. Research question 2

(2) Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read and notes are taken on paper compared to when text is read and notes are taken using a tablet PC?

(a) Between-subjects (one-week delay)

Despite the number of participants in the paper-device condition (56) exceeding the rule-of-thumb 30 advocated by the Central Limit Theorem (Boston University School of Public Health, 2015; Siegrist, 2015) and the tablet condition (26) nearly reaching it, a Shapiro-Wilk test for normality returned significant results for both paper and tablet (.005; .008), while a Kolmogorv-Smirnov test for normality returned a significant result for paper (.001) and a non-significant result of .059 for tablet, indicating a non-normal distribution. Given that a normal distribution is a base parametric assumption, a non-parametric Mann-Whitney U test is used instead. The obtained results are listed in the table below.

Table 11. Between-subjects (one-week) note-taking condition

Question Group	Device	N	Mean	SD	Mean Rank	Sum of Ranks	Mann-Whitney U	Exact Sig.	Effect Size
Factual	Paper	59	-.02	.77	41.68	2459	689	.45	-.07
	Tablet	26	.03	.69	46.00	1196			
Conceptual	Paper	59	-.01	.69	42.27	2494	724	.68	.03
	Tablet	26	-.03	.51	44.65	1161			

For both factual and conceptual questions, no statistically significant differences between the paper and tablet device conditions were found, with effectively non-existent effect sizes.

(b) Within-subjects

The relevant parametric assumptions were met and a matched-pairs or paired-samples t-test was also conducted on the scores obtained by the 42 participants completed the note-taking condition using both paper and tablet. Separate paired samples t-tests were conducted on both the Factual and Conceptual question groups. The obtained results are listed in the Table 12 below.

Table 12. Within-subjects note-taking condition*

Question Group	Means (Paper/ Tablet)	Mean diff.*	Standard Deviation	Std Error Mean	95% CI of Difference		t	df	Sig. (2-tailed)	Effect Size (Cohen's d)
					Lower	Upper				
Factual	-.05 .07	-.115	.963	.149	-.415	.185	-.775	41	.443	-.158
Conceptual	.19 -.12	.306	.862	.133	.038	.575	2.305	41	.026	.476

* Positive mean indicates that paper-device scores are higher than those for tablets; N = 42

In a reverse of the reading only condition, participants in the note-taking condition performed marginally worse using paper than they did using tablets for the Factual group of questions, although this difference is not significant (sig. = 0.443). For the Conceptual group of questions, however, participants using paper performed significantly better than they did using tablets, with a significance of 0.026 and a moderate effect size of 0.476.

5.5. Research question 3

(3) What differences exist, if any, between the results of research questions 1 and 2 and what is the nature of these differences?

(a) Between-subjects (one-week delay)

For factual questions, participants in the reading-only condition performed better when using paper compared to when tablets were used, with a statistical significance of $p = 0.017$ and a large effect size of 0.69. This result was not repeated in the note-taking condition. Instead participants using paper performed marginally worse than those using tablets. This difference is,

however, not statistically significant (p = 0.45) and the effect size is effectively non-existent (-0.07).

For conceptual questions, participants in the reading-only question performed approximately equally regardless of the device used, with a highly non-significant result (p = 0.658) and an effectively non-existent effect size (0.04). Participants in the note-taking condition who used paper performed marginally better when compared to participants who used tablets, although this result is also not significant with p = 0.68 and a near non-existent effect size (0.03).

(b) Within-subjects

For factual questions, participants in the reading-only condition performed substantially better when using paper compared to when they used tablets, with a significant result (p = 0.01) and a moderate-to-large effect size of 0.65 being observed. Participants in the note-taking condition, however, performed slightly worse (for factual questions) when using paper compared to when using tablets, although the non-significant result and very small effect size suggest that performances were in fact approximately equal (p = .443, E.S. = -.158).

For conceptual questions, participants in the reading only condition performed better when using paper compared to when they used tablets. However, these differences are non-significant (p = 0.054) and a small-to-moderate effect size (0.33) was observed. It is possible that a real, but weak effect does exist, but these results do not provide adequate evidence to support such an assertion. Further research is required. Participants in the note-taking condition also performed better (for conceptual questions) when using paper compared to tablets, with these differences returning a significant result (p = 0.026) and moderate effect size of 0.48 suggesting real, but moderate effects.

5.6. Research question 4

(4) Are there differences in learning (as measured by test performance) if the delay between reading task and test (research question 2) is reduced from approximately one week to several days?

The relevant parametric assumptions were met and independent-samples t-tests were conducted to compare the obtained means for participants in the between-subjects (one-week delay) and between-subjects (two-to-three-day delay) samples. A total of four tests were conducted, comparing means for questions which tested factual recall (both for paper and for tablet conditions) as well as for questions which tested conceptual understanding (both for paper and for tablet conditions). The results for the paper condition are detailed in Table 13 below.

Table 13. Between-subjects (one-week vs two-to-three-day delay) – Paper condition

Question Group	Delay time	N	Mean	SD	95% CI of Difference		t	df	Sig. (2-tailed)	Effect Size (Cohen's d)
					Lower	Upper				
Factual	2-to-3	16	.10	.57	-.29	.54	.598	73	.552	.18
	One-week	59	-.02	.77						
Conceptual	2-to-3	16	-.27	.73	-.66	.12	-1.37	73	.176	.37
	One-week	59	-.01	.69						

No statistically significant differences were detected between participants in the paper condition for factual or conceptual questions. The results for the tablet condition are detailed in Table 14 below.

Table 14. Between-subjects (one-week vs two-to-three-day delay) – Tablet condition

Question Group	Delay time	N	Mean	SD	95% CI of Difference		t	df	Sig. (2-tailed)	Effect Size (Cohen's d)
					Lower	Upper				
Factual	2-to-3	9	.64	.46	.10	.25	2.4	33	.02	1.04
	One-week	26	.03	.69						
Conceptual	2-to-3	9	.02	.44	-.34	.44	.24	33	.808	0.11
	One-week	26	-.028	.51						

A statistically significant difference between participants in the tablet condition was detected for questions which tested factual recall, with $p = .02$ and a very large effect size of 1.04, implying that the difference which exists is greater than one standard deviation. No difference was detected for questions which tested conceptual understanding, with a highly non-significant result and a very weak effect size.

5.7. Supplementary analysis

A supplementary analysis was conducted to examine two additional factors, namely: (1) the impact self-report English proficiency on test scores (given the highly multilingual nature of the samples obtained) and (2) due to the gender imbalances observed in some sample groups, whether any significant differences are observed for gender.

(1) Impact self-report English proficiency on test scores

Bivariate correlation analysis was used to determine whether any statistically significant correlations exist between the self-report English proficiency and test scores. Analyses were conducted both for participants in the between-subjects (one-week delay) and within-subjects sample groups. Self-report English proficiency scores were calculated using three self-report items from the adapted LEAP-Q –estimated percentage of time exposed to the English language, most dominant language, and order of language acquisition (i.e. whether English was acquired as a first, second, third etc. language).

Table 15. Between-subjects – impact of English proficiency on test scores

	N	**Pearson Correlation**	**Sig.**
Reading-only			
Factual	31	.005	.979
Conceptual	31	.082	.662
Reading and note-taking			
Factual	66	.260	.035*
Conceptual	66	.254	.040*

* significant result

Participants in the reading-only condition showed no statistically significant correlation between self-report level of exposure to English and test scores for either question type. Participants in the reading and note-taking condition did, however, show stronger correlations which are statistically significant for both question types. Table 16 below shows the results for participants in the within-subjects sample group.

Table 16. Within-subjects - impact of exposure to English on test scores

	N	Pearson Correlation	Sig.
Reading-only			
Factual	38	-.084	.734
Conceptual	38	.207	.395
Reading and note-taking			
Factual	82	.284	.072
Conceptual	82	.318	.043*

* significant result

Similarly to participants in the between-subjects (one-week delay) reading-only sample group, participants in the within-subjects reading-only group showed no statistically significant correlation between self-report English proficiency and test scores. However, for participants in the reading and note-taking group, a statistically significant correlation was observed for conceptual questions.

Given the correlations observed in both the between- and within-samples groups, a covariate analysis of variance was conducted to examine the impact of language proficiency. These results are included as Appendix O. When this set of tests was conducted, the following results were observed:

- All previously non-significant results remain non-significant.
- The previously statistically significant results for participants in the reading-only factual questions condition from both between- and within-subjects disappear.

- The previously statistically-significant result for participants in the within-subjects conceptual questions note-taking condition remains.

However, incomplete data from some participants results in the further reduction of sample sizes for this covariate analysis when compared to the previous analyses (which did not look at language). This sample size reduction results in already-small samples such as the between-subjects reading-only condition (N=33, 12) becoming even smaller (N=24, 7). This renders the between-subjects reading only analysis non-parametric, which suggests the ANCOVA is not useful for this particular data subset. Further assumptions required to conduct an ANCOVA include the dependent and covariate variables being continuous (met), that the independent variable be categorical (met) and homogeneity of variances - met (Glass, Peckham & Sanders, 1972). Additionally, the composite measure of English proficiency is still not a bona fide measure of English language proficiency. Meaningful conclusions can therefore not be drawn on the impact of English language proficiency – further research is required. This suggests that further caution need be applied in interpreting the original analyses as well.

(2) Gender differences

Given the gender imbalances observed in some of the analyses conducted in this chapter, a series of independent-samples t-tests were conducted to determine whether any statistically significant differences exist between male and female participants for the various cells. Table 17 below shows the means for these various cells, with the asterisk (*) marking corresponding means which are statistically significantly different from one another.

Table 17. Gender differences in mean test scores

	Between-subjects (one-week) Mean (N)		Within-subjects Mean (N)	
	Male	**Female**	**Male**	**Female**
Reading-only				
Factual	.19	.06	.09	.05
	(16)	(24)	(16)	(38)
Conceptual	.07	-.20	.2	-.24
	(16)	(24)	(16) *	(38) *
Reading and note-taking				
Factual	-.17	.10	-.07	.12
	(32)	(49)	(48)	(36)
Conceptual	-.06	.06	.06	.001
	(32)	(49)	(48)	(36)

* statistically significant difference; p = .037

While differences in mean scores were observed in all cases, only one statistically significant difference was observed – male participants in the within-subjects reading-only

condition performed statistically significantly better than their female counterparts for questions which tested conceptual recall.

Chapter 6

Discussion

6.1. Research question 1

Research Question 1: Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of approximately one week between reading task and test) when text is read (only) on paper compared to when this is done using a tablet PC?

For the purposes of comparing various device interfaces, the reading-only condition is arguably the most evenly-balanced or equal of the conditions used in these experiments, as it substantially reduces potential confounding variables such as device familiarity and technological proficiency. That statistically significant differences were shown to exist for both the between-subjects and the statistically more powerful within-subjects samples adds further support to the notion that, rather than being approximately equivalent activities, important differences in fact exist between reading from a tablet (i.e. computer screen) and reading from paper. The small sample size obtained for participants in the tablet condition of the between-subjects group is a potentially confounding variable. It must be noted that other potential confounding variables such as zoom level, head and neck position, and others are not necessarily eliminated by reading only and must be controlled for in other ways. However, it must also be noted that the vast majority of participants indicated strong (and well-established) general tablet device proficiency on the

relevant items contained in the demographic questionnaire (Appendix C) Additionally, the majority of participants had been using tablet PCs in the classroom for approximately 3 years, decreasing the likelihood that details such as these acted as significant confounding variables.

The finding of both sample groups (with moderate-to-large effect sizes) that participants in the paper condition performed better on factual questions lends weight to the assertions of Wolf (2008), Wolf and Barzillai (2009) and Wolf et al. (2012) and others that electronic screen-based reading promotes more superficial reading of textual content, resulting in participants either recalling factual details less clearly when tested or possibly engaging less strongly with these factual details while actually reading the text.

However, this assertion struggles to explain the non-significant differences observed for questions teaching conceptual recall. The result for the statistically more powerful within-subjects condition was non-significant and its effect size was substantially smaller than the effect size observed for factual questions. One possible explanation for this is that the type of skimming or shallow(er) reading which is encouraged by the digital word (or at least some iterations of it) involves the reader aiming to ascertain the gist of the text and its content, without paying as much attention to many details, in the same way as some individuals often tend to remember the gist of a news story without remembering any of the names of the people, companies or things involved, or in the same way as individuals may tend to remember what a product does/how it works (in terms of key selling points) without remembering details such as its official name. This would allow tablet readers to gain a general idea of how concepts in described in the text work, even if their engagement with factual details is far more limited, enabling them to answer conceptual questions more accurately than was the case for factual questions.

The slightly higher performance for conceptual understanding for participants using paper in the within-subjects condition may be explained by existing evidence of the importance of visuo-spatial processing and spatial elements found in conceptual processing (cf. Chapter 2.3.5) – the advantage given by the more stable page layout and ontological connection between word and substrate allows for stronger visuo-spatial mental simulations, which are important for conceptual understanding. That participants were given 5 minutes to revise before completing their tests suggests that paper's more stable visuospatial layout may make a difference for reading- and revision-based learning.

It is possible that this tendency of the digital word to encourage a greater degree of skimming or shallow(er) reading is in part due to its virtual nature – it is by definition insubstantial (in that it is unstable, impermanent, fluid) and therefore can subconsciously be treated less seriously (as a study tool). An everyday example of this, as Mangen (2013a) notes, is that legal documents are still largely printed out and often only seen as being official or 'real' when converted to paper-based format. The multifunctional nature of tablets may also play a role – a tablet can be used to play games, recreationally watch videos, browse the web or social media platforms, in addition to reading through and studying from electronic textbooks. A textbook, on the other hand, is generally only used to study from and therefore may encourage a more studious attitude in its user. However, more careful and controlled research experiments are required to investigate this matter more fully, examining issues such as reading speed, scrolling behaviour.

6.2. Research question 2

Research Question 2: Are there differences in learning (measured by the ability to correctly answer questions from each of Butler's (2010) categories of question, with a delay of

approximately one week between reading task and test) when text is read and notes are taken on paper compared to when text is read and notes are taken using a tablet PC?

In a reverse of the reading-only conditions, participants in the reading and note-taking condition showed no differences in performance for factual questions, suggesting that adding the action of note-taking may mitigate against the digital word's tendency to encourage skimming and encourage learners to focus more carefully on facts and details presented in the text. This may be because making notes requires participants to extract information to write out as notes and factual details are generally easier to note than the action of summarising conceptual explanations, encouraging the learner to focus more carefully on factual details. The between-subjects condition displayed no difference in performance for conceptual questions, with an effectively zero effect size. The more statistically powerful within-subjects condition, however, displayed a statistically significant difference (higher score for paper), with a moderate effect size. Given the reasonably large sample size for the within-subjects group (N = 42), which is largely comparable to the N = 59 (paper) and N = 26 (tablet) sample sizes obtained for the between-subjects conditions, the within-subjects' result does appear to suggest real but relatively weak effects.

The act of studying a text by taking notes has some important differences in comparison to reading-only – for example, the former requires the learner to both mentally and physically (i.e. motorically) reconstruct portions of the text as part of the learning process. The stronger performance of participants in the paper (i.e. handwritten notes) condition on conceptual questions is consistent with Longcamp et al. (2003; 2005; 2006) and James and colleagues's (2006; 2009; 2010; 2012) findings on the neural importance of handwriting's motoric elements and its relation to reading and Mueller and Oppenheimer's (2014) general findings that handwritten text engages greater levels of processing than typing and leads to better recall of text and the notion that the

digital word can be less spatially addressable (i.e. containing fewer opportunities for visuospatial, perceptuomotor encoding) than the analogue word, thereby removing an important and useful aspect of the external memory field.

The text-centric nature of typed note-taking may be a disadvantage when studying concepts, where techniques more easily accomplished by the analogue word such as drawing diagrams are helpful. Given existing evidence of the importance of visuo-spatial processing and spatial elements found in conceptual processing (cf. Chapter 2.3.5), the more stable page layout of the printed text in the paper condition may also have contributed to participants in this condition performing better for conceptual questions (by allowing for greater degrees of perceptuomotor encoding).

This evidence, although interesting and helpful, does not clearly address to what extent the ontological disconnectedness of text and substrate played in this learning process – it is too heavily masked by potential confounding variables. Similarly to the previous research question, more research is needed to more carefully untangle potential confounding variables which in this case include note-taking proficiency and experience and general study (method) preferences.

6.3. Research question 3

Research Question 3: What differences exist, if any, between the results of research questions 1 and 2 and what is the nature of these differences?

As discussed in the previous two subsections (6.1. and 6.2.), the differences in results observed for research questions 1 and 2 are consistent with some existing empirical evidence and

do lend weight to some theorised claims around the digital word built upon this existing evidence and several theories. Research question 1 provides further support for the notion of the digital word subtly discouraging deep reading particularly for factual points and details, but provides less insight into the dynamics of differences for conceptual questions. Research question 2's results are effectively opposite to those of research question 1, but do provide very tentative support for ideas around the digital word and the impact of the ontological disconnectedness between marking and substrate in relation to the visuo-spatial nature of literacy. However, the potential existence of a range of confounding variables mean that this evidence only hints at theorised aspects of the digital word and that a number of carefully-designed and -controlled experiments are required to address these potential confounding variables and provide stronger evidence for these claims around the digital word.

6.4. Research question 4

Although enforced by logistical requirements rather than being a planned experiment, research question 4's deviation from the one-week delay procedure used in the rest of the data collection process has provided a useful insight to an important question for future research. In practical, logistical terms, the one-week delay (required to create a more ecologically valid measure of learning) lends itself to high rates of attrition, as participants must attend both sessions, a week apart, in order for any useable data to be obtained by the researcher. If shorter delay times were possible, this would improve researchers' ability to conduct further experiments which aim to measure learning rather than simply measuring comprehension. This finding, although admittedly limited by small sample sizes, provides introductory evidence to suggest that a shorter delay between reading task and testing may provide an approximately equally ecologically valid measure of learning as the original one week delay for participants for conceptual questions on

both paper and tablet and factual questions on paper. However, participants in the shorter delay period who used tablets did perform statistically significantly better on factual questions. The very large effect size and its implication that the mean difference exceeds one standard deviation and highly significant p-value (0.02) suggest that this result represents a real effect. However, given the very small sample size for students in this cell (N = 9), it is not possible to say with any degree of confidence whether this effect is in fact real – further research with larger sample sizes is required.

6.5. Supplementary analysis

The supplementary analysis was necessitated by (1) the highly multilingual nature of the participants involved and the fact that all experiments were conducted entirely in English and (2) the gender imbalances in some cells which were identified after completing these research experiments. Both variables have the potential to act as confounds and as such, these analyses provide an opportunity to account for two potentially confounding variables.

The obtained results for language exposure indicate no statistically significant correlations between self-report exposure to the English language and test scores for all within-subjects cells as well as for participants in the reading-only condition of the between-subject sample group. For reading and note-taking within the latter group, however, strongly significant correlations are observed for both factual and conceptual type questions. Both the between-subjects and within-subjects sample groups show a similar pattern – more highly insignificant correlations for reading-only and closer to significant for reading and note-taking. It must be noted that the measure used here – estimated English proficiency based on self-report percentage exposure to English, most dominant language and order of language acquisition – is not a bona fide measure of language

proficiency and is simply the best of the available items of the Language Experience and Proficiency Questionnaire (LEAP-Q) to provide a very rough estimate of the impact of language proficiency on test scores. The LEAP-Q itself is a widely-used and well-validated instrument (Marian et al., 2007) and even this individual item does provide some degree of insight – for example, all participants save for one across the entire study who listed English as their most dominant language reported being exposed to the English language more than 50% of the time. Future research will need to make use of a more robust instrument to assess proficiency in the language in which the experiments are being conducted.

The eight comparison of means tests conducted yield only one statistically significant result – males performed higher than females on conceptual questions in the reading-only condition from the statistically more powerful within-subjects group. This lack of statistically significant differences for gender suggests that the imbalance in these cells is potentially less problematic than might otherwise be the case. While this is not sufficient evidence to disregard the imbalance in its entirety, it does strengthen the data's results.

As mentioned in previous subsections and discussed in detail in Chapter 2.3.5., empirical evidence has demonstrated a visuospatial component of conceptual processing. However, it must be noted that conceptual processing being demonstrated to have a visuospatial component does not necessarily mean that conceptual understanding in textual engagement is a good proxy measure for visuospatial processing and that the obtained sample sizes are small and imbalanced – N = 16 (males) and N = 38 (females). Further research is necessary.

6.6. General discussion

The experimental data obtained is imperfect, but is strong enough to analyse and draw tentative conclusions from. The experimental results obtained are largely consistent with the

theoretical framework constructed and the existing empirical evidence discussed in Chapters 3 and 2 respectively. It is clear from these results and their indication of clear performance differences performing similar tasks by participants with a significant amount of experience using these devices (in addition to existing empirical evidence and a range of theoretical contributions) that the digital word is not equivalent to the analogue word. Furthermore, these results reiterate that reading is a complex, multi-faceted construct and that its theorised strong visuospatial and other grounded aspects are only part of the remarkably complex activity that is literacy.

The theoretical framework constructed in Chapter 3 effectively predicts not only meaningful differences between the analogue and digital word, but that a substantial degree of similarity between the two can be obtained by more effectively managing the mediation process enforced by devices such as laptop and tablet PCs. However, as suggested by the theoretical considerations discussed and as implied by results obtained and their analysis, a deeper and more detailed understanding of these mechanisms is required in order to better manage and more optimally utilise our interactions with and effective use of these digital devices.

A conclusion which can be drawn from all of this is that the introduction of these new digital technologies, rather than replacing paper, instead allows us to expand the usefulness of the written word, enabling new ways of using and interacting with the written word. It is in this that the strength of the digital word lies – in its ability to expand and complement, not replace print text or the analogue word.

6.7. Strengths of this study

This study has both theoretical and empirical value, with a number of relevant implications. Many existing studies in this field (e.g. Mangen et al., 2013; Wells, 2012, etc.) focus on testing comprehension (i.e. testing participants very soon after completing their reading task). While this is easier logistically to manage for researchers, it does not provide a very accurate or ecologically valid picture of real learning – very few studies have focused on this, with Mueller and Oppenheimer (2014) being one of very few examples. This study also examined both note-taking and reading-only from the perspective of learning, further strengthening its contribution. It also departs from Mueller and Oppenheimer's (2014) method, which involved learners watch recorded video lectures of the text passages being read to them, instead focusing purely on interaction with the written word.

A theoretical contribution made by this study centres on the synthesis and integration of are several key (existing) ideas which have served as the basis for advancing our understanding of educational technology, in particular modern mobile personal computing devices such as tablets for the purpose of improving our interactions with and relationship with the digital word: (1) recognising that the written word is not only a technology (or symbolic technology) in and of itself, but also one of the earliest forms of educational technology and responsible for fundamental changes to the human mind and human thought, enabling a vast array of things which were previously simply not possible; (2) recognising that human cognition is not abstract, but is instead embodied or grounded in perception, proprioception, bodily states, and simulations and the implications thereof for our interaction with technologies like the written word; and (3) recognising that digital text is fundamentally different from its predecessors because of its lack of fixity and

ontological disconnectedness from the substrate supporting it (as well as its ability to create the illusion of a virtual substrate).

Theorists such as Ong (1982) and Donald (2001) have highlighted the written word's seminal role as a technology or symbolic technology which has fundamentally transformed human thought and which has played a key role in the development of human civilisation and Donald (2001) does briefly visit the notion that human cognition is embodied. Currently active researchers in this field such as Anne Mangen (2008, 2013a, 2013b, 2016, among others) have highlighted the role of grounded cognition and Mangen in particular (2013a) has highlighted the digital word's lack of fixity and ontological disconnectedness from the substrate supporting it and has pondered the implications of this. Although these theoretical assertions are not new, this particular group of assertions are not commonly integrated and synthesised with one another. A strength of this study is that it simultaneously highlights these critical (existing) insights, discusses them in some detail and then integrates and synthesises them to strengthen the existing theoretical framework.

6.8. Limitations and future research

As mentioned several times during this chapter, the acts of reading and writing are extraordinarily complex. While the experiments conducted as part of this study provided useful insights, they also encountered a range of potential confounding variables. In addition to future research which builds on this theoretical and empirical work, future research will need to examine these various aspects again in a finer-grained manner, with more tightly-controlled research studies designed to test only one or so variables at a time, enabling for tighter control of potential confounding variables.

This research, in particular its experiments, were limited by the several factors. Firstly, the small and unbalanced samples in this study suggest future research needs to more carefully control for this by simplifying each experimental setup and testing for fewer things at a time with greater numbers of participants. Secondly, lack of standardisation across participant devices suggests that future research will need to better determine whether allowing participants to use their own devices adds sufficient ecological validity so as to warrant dealing with the other potential issues which it invites with it. Thirdly, no testing was done to determine participant proficiency at taking notes and whether this was in fact their preferred study strategy – future research needs to address this aspect more carefully. Given that multilingual populations are common in South Africa and many other countries, future research needs to more robustly measure English language proficiency to more effectively control for its impact, or else consider running these kinds of experiments in other languages.

Future research could also examine the impact of and effectiveness of other modern mobile PC device related functionalities and media such as the ability to record audio notes within parts of the text and how well this integrates with existing study methods. This would be particularly interesting to examine because it combines the written and spoken words in a way that traditional text-based study experiments simply does not.

6.9. Conclusion

In conclusion, this study has both theoretical and empirical value. First, existing empirical evidence was explored, evidence which points to important fundamental differences between the acts of reading and writing on various devices, ranging from traditional paper, print books and handwritten notes to modern touch screen tablet PCs. Following this, a range of theoretical considerations were examined and assembled, leveraging support provided by a large body of

empirical evidence to synthesise and integrate these considerations. These were used to construct a theoretical framework which asserted that the digital word possessed certain characteristics none of its analogue predecessors did, rendering it sufficiently distinct from the analogue word so as to constitute a distinct (although not necessarily ground-breaking) step in the history and development of literacy. Several research experiments were conducted to examine whether performance differences existed when tablet PCs and traditional pen and paper were used to complete reading and writing tasks with a time delay between task and test in order to better represent learning (rather than simply comprehension). Results obtained suggest real, but moderate-to-weak effects, with participants using paper performing better for questions which test factual recall in the reading-only condition and better for questions testing conceptual understanding in the reading and note-taking condition. These findings support the view that the digital word is not necessarily equivalent to its analogue predecessors and point towards further research in this area. It is concluded that further research is required in order to better understand the mechanisms which underpin the digital word and how to most optimally make use of it. Finally, it is suggested that the digital word's primary strength lies in its ability to expand the usefulness of the written word in conjunction with the more traditional analogue word.

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Appendices

Appendix A – Ethics clearance certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Wrigley

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H15/05/41**
PROJECT TITLE	Personal computing device interfaces and their psychological and neurophysiological impact on learning in South African secondary school students
INVESTIGATOR(S)	Mr T Wrigley
SCHOOL/DEPARTMENT	Human and Community Development/
DATE CONSIDERED	22 May 2015
DECISION OF THE COMMITTEE	Approved unconditionally
EXPIRY DATE	01 July 2018

DATE 02 July 2015 **CHAIRPERSON** _____ (Professor J Knight)

cc: Supervisor : Dr M Pitman

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

_____ _____/_____/_____
Signature **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix B – GDE permission to conduct research

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

For administrative use:
Reference no. D2016 / 178 GA
Enquiries: Diane Bunting

GDE AMENDED GROUP RESEARCH APPROVAL LETTER

Date:	15 July 2015
Validity of Research Approval:	15 July 2015 to 2 October 2015
Previous GDE Research Approval letter reference number	D2016 / 077 G dated 12 May 2016
Name of Supervisor/s:	Mellado B.
Name of Researchers:	Wrigley G.T.; Wigdorowitz M.; Masuku M.; Glover C.; Van Heerden F. and Wolpert J.
Address of 1st Researcher:	P.O. Box 9459; Cinda Park; Boksburg; 1463
Telephone / Fax Number/s:	082 042 8689; 083 305 1594; 073 146 2740; 072 610 5748; 082 059 2795; 084 583 7889
Email addresses:	thomas.wrigley@cern.ch; Mandy.wigdorowitz@gmail.com; Mthokozisi.masuku@wits.ac.za; chrisglover24747@yahoo.com; francolsvan heerden333@gmail.com; jayde_wolpert@hotmail.com
Research Topic:	Personal computing device interfaces and their psychological and neurophysiological impact on learning in South African Secondary school students.
Number and type of schools:	THIRTY-ONE Secondary Schools
District/s/HO	Ekurhuleni North; Ekurhuleni South; Johannesburg Central; Johannesburg East; Johannesburg North and Johannesburg West.

Re: Approval in Respect of Request to Conduct Research

2015/07/15

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests

Making education a societal priority

Office of the Director: Knowledge Management and Research
9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506
Email: Davic.Makhado@gauteng.gov.za
Website: www.education.gpg.gov.za

with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved. A separate copy of this letter must be presented to the Principal, SGB and the relevant District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted. However participation is VOLUNTARY.

The following conditions apply to GDE research. The researcher has agreed to and may proceed with the above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

CONDITIONS FOR CONDUCTING RESEARCH IN GDE

1. The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter;
2. A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB);
3. A letter / document that outlines the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned;
4. The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, SGBs, teachers and learners involved. Participation is voluntary and additional remuneration will not be paid;
5. Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal and/or Director must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage;
6. Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year. If incomplete, an amended Research Approval letter may be requested to conduct research in the following year;
7. Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.
8. It is the researcher's responsibility to obtain written parental consent and learner;
9. The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources;
10. The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations;
11. On completion of the study the researcher must supply the Director: Education Research and Knowledge Management with one Hard Cover, an electronic copy and a Research Summary of the completed Research Report;
12. The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned; and
13. Should the researcher have been involved with research at a school and/or a district/head office level, the Director and school concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

.....

Dr David Makhado
Director: Education Research and Knowledge Management

DATE: 2015/07/15

Making education a societal priority

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9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506
Email: David.Makhado@gauteng.gov.za
Website: www.education.gpg.gov.za

Appendix C – Demographic questionnaire

Demographic Questionnaire

Age		**Today's date**	201 / /
Birth year		**Grade**	
Gender	Male	Female	

Do you take any of the following subjects at grade 10–12 level?

(*please tick all applicable boxes*)

English Home Language (HL)		Physical Science	
English First Additional (FAL)		Life Sciences	
Mathematics		History	
Mathematical Literacy		Geography	
Information Technology		Computer Applications Technology (CAT)	

Please create a unique code to anonymise yourself:

This code will allow us to identify your responses without us knowing your name or any of your personal information. Please ask the researchers for help if you are unsure what to do.

Please write down the **last three letters** of your first name and the **last three letters** of your surname, followed the **day of the month** that your birthday is on and your **group number**

e.g. John Donne born on **31** March in Group 1A becomes: OHN-NNE-**31-**1A

Sipho Mabuse born on **6** February in Group 3C becomes: PHO-USE-**06—3C**

Please write your code here: | |

Please list all of the languages that you know. For each language, please tick whether you can speak, understand or read in that language.

	Language	I can …… this language (please tick) *You may tick all three options if applicable*		
1.		Speak	Understand	Read
2.		Speak	Understand	Read
3.		Speak	Understand	Read
4.		Speak	Understand	Read

Which language is your most dominant (i.e. language which you know the best)? Please write down the languages you know in order of dominance, with your most dominant language first.

1. (***Most dominant language)***	
2.	
3.	
4.	

In what order did you learn the languages that you know? Please list all the languages you know in order of acquisition, with your first language or mother tongue first.

1. (***Mother tongue/first language)***	
2.	
3.	
4.	

How often are you exposed to each language that you know? Please write down what percentage of the time you are, on average, exposed to each language (your percentages should add up to 100%).

	1	**2**	**3**	**4**
Language				
Percentage				

(*Together, your percentages should add up to 100%*)

What language (or languages) are spoken at home? Please list the language and the percentage of the time that you are exposed to each language while at home (your percentages should add up to 100%).

	1	**2**	**3**
Language			
Percentage			

(*Together, your percentages should add up to 100%*)

What language (or languages) are spoken with your friends? Please list the language and the percentage of the time that you are exposed to each language while with friends (your percentages should add up to 100%).

	1	**2**	**3**
Language			
Percentage			

(*Together, your percentages should add up to 100%*)

What was the language of instruction at your primary school? (i.e. what language were most of your subjects were taught in?).

What is the language of instruction at your high school? (i.e. what language were most of your subjects are taught in?).

For each item, please tick yes or no as applicable.

Do you own or have access to a laptop?	Yes	No
Do you own or have access to a desktop computer (PC)?	Yes	No
Do you own or have access to a tablet/iPad?	Yes	No
Do you own or have access to a smartphone? (e.g. Android, iPhone, Nokia, Blackberry)	Yes	No
Do you own or have access to an e-reader? (e.g. Kindle, Kobo etc.)	Yes	No

(*continued on next page*)

How often do you make use of the following devices? Please tick the appropriate options (or most appropriate option).

Laptop	Never	Once a month	Once a week	About 3 times a week	Every day
Desktop Computer (PC)	Never	Once a month	Once a week	About 3 times a week	Every day
Tablet / iPad	Never	Once a month	Once a week	About 3 times a week	Every day
Smartphone	Never	Once a month	Once a week	About 3 times a week	Every day
E-reader	Never	Once a month	Once a week	About 3 times a week	Every day

Appendix D – First text passage (Bats)

BATS

(*A word list with definitions is available on page 3 – last page*)

Please read this passage carefully. You will write a short multiple-choice test on this passage in your next session next week. You will be given 5 minutes to revise before writing.

Bats really stand out in the animal world. They are the only mammals that can fly, and they live much of their lives hanging upside down. Most species are active only from dusk until dawn, spending their days in dark caves. Many bats have developed adaptations or adaptive traits that let them find their way (and their prey) in complete darkness. Bats have survived as a group for more than 50 million years, longer than most other modern animals. All bat species are part of a phylogenetic order called Chiroptera, which comes from the Greek words cheir ("hand") and pteron ("wing"). There are more than 1,000 bat species in the world, making them one of the most widespread orders of mammals.

Traditionally, bat species are divided into two suborders or subcategories: Megachiroptera (megabats) and Microchiroptera (microbats). Most megabat species are frugivores (fruit eaters) or nectavores (nectar drinkers) and look a lot like other mammals, with large eyes, small ears, and extended snouts. In contrast, most microbat species are insectivores and have a unique facial appearance, with large ears and peculiarly shaped, stubby snouts. One microbat that is an exception to this is the vampire bat, which feeds not on insects, but on mammals' blood. It can consume half its body weight in blood in one feed.

While megabats have good eyesight, microbats use echo-location for navigation and finding prey. Also, the two suborders differ in terms of where they live: megabats are found only in Africa, Asia, and Australia, whereas microbats live all over the world. Although most scientists agree that the division of bat species into two suborders is a useful approach to studying bats, the phylogenetic relationship among the different groups of bats has been the subject of much debate.

Although bats and birds both fly, a bat wing actually has more in common with a human arm than a bird wing. A bird's wing has fairly rigid bone structure, and the main flying muscles move the bones at the point where the wing connects to the body. In contrast, a bat has a much more flexible wing structure. It is similar to a human arm and hand, except it has a thin membrane of skin (called

the patagium) extending between the “hand” and the body, and between each finger bone. Bats can use the wing like a hand, essentially moving through the air like a swimmer moves through water. The rigid bird wing is more efficient at providing lift, but the flexible bat wing allows for greater manoeuvrability.

To help them navigate and find their prey in the dark, microbat species have developed a remarkable system called echolocation. By emitting high-pitched sound waves and listening to the echoes, bats can determine with great precision the location of an object, how big it is, and the direction in which it is moving. Bats calculate the distance of the object by the amount of time it takes for the sound wave to return and the exact position of the object by comparing when the sound reaches its right ear to when the sound reaches its left ear. Similarly, a bat can tell how big an insect is based on the intensity of the echo: a smaller object will reflect less of the sound wave, and so will produce a less intense echo.

Although they hunt all night, bats will pass the daylight hours hanging upside down from a secluded spot, such as a cave or a hollowed-out tree. There are a couple of different reasons why bats roost this way. First of all, hanging upside down puts them in position for take-off, which is important because bats cannot launch themselves into the air from the ground. It is also a great way to hide from danger. During the hours when most predators are active, bats congregate (gather) where few animals look and most cannot reach. Although snakes, possums, and raccoons sometimes hunt bats, birds of prey are the main predator of bats. Most bat species roost in the same location every day, clustering with other bats for warmth and security.

Bats have a special physiological adaptation that enables them to hang upside down. A bat’s talons work like human fingers, except that humans must contract muscles to grasp an object, whereas bats must do the opposite – relax their muscles. When humans grasp an object, they contract several arm muscles, which in turn pull tendons connected to their fingers, which pull the fingers closed. To hang upside down, a bat opens its talons to grab hold of the surface, and then simply lets its body relax. The weight of the upper body pulls down on the tendons connected to the talons, causing them to clench. Since it is gravity that keeps the talons closed, instead of a contracted muscle, the bat doesn't have to exert any energy to hang upside down.

Like all mammals, bats maintain their body temperature internally. However, unlike most mammals, bats allow their body temperature to sink to the ambient temperature whenever they are not active. As their temperature drops, they enter a torpor state (state of physical inactivity), in

which their metabolism slows down considerably. By reducing their biological activity and not maintaining a warm body temperature, bats conserve energy. This ability is important because flying all night is hard work. When the temperature is cold for long periods during the winter months, some bats enter a deeper torpor state called hibernation. Other bat species follow a yearly migration pattern, traveling to cooler climates in the warm months and warmer climates in the cool months. This is why some regions experience “bat seasons” every year.

Many people have a negative reaction to bats, and it's easy to see why. Bats have also long been tied with vampires. While Bram Stoker was the first to have Dracula transform into a bat, a popular story titled Varney the Vampire published in 1845 is actually the earliest evidence we have of popular bat-vampire connection. Also, just by virtue of their appearance and behaviour, bats play into a number of human fears.

However, insectivorous bats are the best bug killers on the planet, For example, a famous colony of more than 20 million Mexican free-tail bats that lives in Bracken Cave, Texas will eat up to 200 tons of insects in a night. Nectavoric bats are also prolific plant pollinators. Many species feed on plant nectar, gathering pollen on their bodies as they feed and helping the plant to disperse its seed when they visit other plants.

Word list:

- Phylogenetic – study of the history, development and relationships among groups of genetically-related organisms
- Torpor – state of physical or mental inactivity; lethargy

Appendix E – Second text passage (Bread)

BREAD

(*A word list with definitions is available on page 3 – last page*)

Please read this passage carefully. You will write a short multiple-choice test on this passage in your next session next week. You will be given 5 minutes to revise before writing.

Bread is prepared by baking dough made from two main ingredients: flour and water. Bakers call the inner, soft part of bread the crumb, which is not to be confused with small bits of bread that often fall off, called crumbs. The outer hard portion of bread is called the crust. Bread can either be leavened or unleavened. Leavening is the process of adding gas to the dough before or during baking to produce lighter, more chewable bread. Most of the bread consumed in contemporary (existing in the present-day) cultures is leavened. However, unleavened bread has symbolic importance in many religions and, thus, nowadays it is primarily consumed in the context of religious rites, festivals and ceremonies. For example, Jews consume unleavened bread called *matza* during Passover.

Flour provides the primary structure to bread because it contains proteins – it is the quantity of these proteins that determines the quality of the finished bread. Wheat flour contains two non-water soluble (not able to be dissolved) protein groups (glutenin and gliadin), which form the structure of the dough. When worked by kneading (working flour into dough by hand), the glutenin forms long strands of chainlike molecules while the shorter gliadin forms bridges between the strands of glutenin, resulting in a network of strands called gluten. The network of strands, or gluten, is responsible for the softness of the bread because it traps tiny air bubbles as the dough is baked. If the network of strands is more cohesive or tightly linked, the bread will be softer. Gluten development improves if the dough is allowed to rest between mixing and kneading.

The amount of flour is the most significant measurement in a bread recipe. Professional bakers use a system known as Bakers' Percentage in their recipe formulations. They measure ingredients by weight rather than by volume because it is more accurate and consistent, especially for dry ingredients. Flour is always stated as 100%, and the rest of the ingredients are a percent of that amount by weight. For example, common table bread in the United States uses approximately 50% water, whereas most artisan bread (i.e. not produced in a factory) formulas contain anywhere from

60 to 75% water. The water (or sometimes another liquid like milk or juice) is used to form the flour into a paste or dough.

Yeast is used in baking as a leavening agent. A single-cell microorganism (most commonly *Saccharomyces cerevisiae*), yeast help bread to rise because they convert the fermentable sugars present in the dough into carbon dioxide gas and alcohol. The alcohol, which burns off during baking, contributes to the bread's flavour. The carbon dioxide gas created by yeast causes the dough to expand or rise as the carbon dioxide forms bubbles. The stretchy, balloon-like consistency of the gluten in the bread dough traps the bubbles and keeps the carbon dioxide from escaping. When the dough is baked it "sets" and the bubbles remain, giving the baked product a soft and spongy texture. Most bakers in the United States leaven their dough with commercially produced baker's yeast, which yields consistent, quick, and reliable results because it is obtained from a pure culture (pure set of yeast micro-organisms).

Gas-producing chemicals can also be used as a leavening agent. Whereas yeast takes two to three hours to produce its leavening action, a dry chemical leavening agent like baking powder is instantaneous. Many commercial bakeries use chemical additives to speed up mixing time and reduce necessary fermentation time, so that a batch of bread may be mixed and baked in less than 3 hours. "Quick bread" is the name that commercial bakers use for dough that does not require fermentation because of chemical additives. Often these chemicals are added to dough in the form of a pre-packaged base, which also contains most or all of the dough's non-flour ingredients. Commercial bakeries also commonly add calcium propionate to delay the growth of moulds.

The first commercial sliced bread was sold in 1928, and was marketed as Kleen Maid Sliced Bread. While today, we say "the greatest thing since sliced bread," the sales pitch for the first sliced loaf was "the greatest forward step since bread was wrapped."

While wrapping and slicing may seem like simple advances, the simplicity of bread is indicative of its history – it is one of the oldest prepared foods, dating back to the Neolithic era (approx. 7000 BC to 1700 BC). The first breads produced were probably cooked versions of a grain-paste, made from ground (crushed) cereal grains and water by hunter-gather tribes. The discovery of the first bread either occurred through accidental cooking or deliberate experimentation with water and grain flour. Descendants of these early breads are still commonly made from various grains worldwide, including the Middle Eastern *pita*, the Mexican *tortilla*, and the Indian *roti*. The basic

flatbreads of this type also formed a staple in the diet of many early civilizations, including the Sumerians who ate a type of barley flat cake and the Egyptians who ate flat bread called *ta* in 12th century BC.

The development of leavened bread can probably be traced to prehistoric times as well. Yeast spores occur everywhere, so any dough left to rest will become naturally leavened. For example, an uncooked dough exposed to air for some time before cooking would probably contain airborne yeasts as well as yeasts that grow on the surface of cereal grains. Thus, the most common source of leavening was early bakers retaining a piece of dough from the previous day to utilize as a form of dough starter. Although leavening is likely of prehistoric origin, the earliest archaeological evidence comes from ancient Egypt. Scientific analysis using electron microscopy has detected yeast cells in some ancient Egyptian loaves.

Bread has been of great historical and contemporary (present-day) importance in Western and Middle Eastern cultures, and it is commonly used in these cultures as a symbol of basic necessities, such as food and shelter. For example, the word bread is now commonly used in English speaking countries as a synonym for money (as is the case with the word "dough"). The political significance of bread is also considerable. In 19th century Britain, the inflated price of bread due to the Corn Laws caused major political and social divisions, prompting riots. The Assize of Bread and Ale, a 13th century law, showed the importance of bread in medieval times by setting heavy punishments for bakers who short-changed their customers. This led to a common practice of baking thirteen items when a dozen was ordered, so as to avoid being accused of short-changing; this is why, even now, thirteen items is known as a "baker's dozen." Today, bread remains a popular food in many societies, and the variety of breads enjoyed across these societies continues to expand.

Word list:

- Soluble – able to be dissolved, especially in water
- Kneading – work moistened flour or clay into dough or paste with the hands
- Ground cereal grains – edible cereal (a type of grass) grains which have been crushed into small particles or pieces

Appendix F – Third text passage (Respiration)

RESPIRATION

(*A word list with definitions is available on page 3 – last page*)

Please read this passage carefully. You will write a short multiple-choice test on this passage in your next session next week. You will be given 5 minutes to revise before writing.

Humans breathe in and out anywhere from 15 to 25 times per minute. The main function of the respiratory system is gas exchange between the external environment and the circulatory system. A gas that the body needs to get rid of, carbon dioxide, is exchanged for a gas that the body can use, oxygen. Located within the chest cavity and protected by the rib cage, the lungs are the most critical component of the respiratory system. The lungs are responsible for the oxygenation of the blood and the concomitant (naturally accompanying or associated with) removal of carbon dioxide from the circulatory system. The other major function of the lungs is to manage the concentration of hydrogen ions in the blood, an important factor in regulating the acidity of blood (pH), which must be kept in a narrow range. If too much carbon dioxide is retained, the blood's pH becomes too acidic; if too much is being released, the blood's pH becomes too alkaline.

When a person inhales (breathes in), the diaphragm and intercostal muscles (the muscles between the ribs) contract and expand the chest cavity. This expansion lowers the pressure in the lungs below the outside air pressure. Air then flows in through the airways (from high pressure to low pressure) and inflates the lungs. The lungs are made of spongy, elastic tissue that stretches and constricts during breathing. When a person exhales (breathes out), the diaphragm and intercostal muscles relax and the chest cavity gets smaller. The decrease in volume of the cavity increases the pressure in the lungs above the outside air pressure. Air from the lungs (high pressure) then flows out of the airways to the outside air (low pressure). The cycle then repeats with each breath.

The respiratory system has many components. Air enters the body through the nose or mouth and goes past the epiglottis into the trachea, a rigid tube that connects the mouth with the bronchi. The epiglottis is a flap of tissue that closes over the trachea when a person swallows so that food and liquid do not enter the airway. The air continues down the trachea until it reaches the bronchi. From the bronchi, air passes into each lung and spreads out by following narrower and narrower bronchioles. The bronchioles are the numerous small tubes that branch from each bronchus into

the lungs and get progressively smaller until they each end in an alveolus. Alveoli are tiny, thin-walled air sacs at the end of the bronchiole branches where gas exchange occurs. The total surface area of the alveoli in one set of lungs is approximately the size of a tennis court.

Within the alveoli, gas exchange occurs through diffusion. Diffusion is the movement of particles from a region of high concentration to a region of low concentration. The oxygen concentration is high in the alveoli, so oxygen diffuses across the alveolar membrane into the pulmonary capillaries, which are small blood vessels that surround each alveolus. The haemoglobin in the red blood cells passing through the pulmonary capillaries has carbon dioxide bound to it and very little oxygen. The oxygen binds to haemoglobin and the carbon dioxide is released. Since the concentration of carbon dioxide is high in the pulmonary capillaries relative to the alveolus, carbon dioxide diffuses across the alveolar membrane in the opposite direction. The exchange of gases across the alveolar membrane occurs rapidly – usually in fractions of a second.

Humans do not have to think about breathing because the body's autonomic nervous system controls it. The respiratory centres that control the rate of breathing are located in the pons and medulla oblongata, which are both part of the brainstem. The neurons that live within these centres automatically send signals to the diaphragm and intercostal muscles to contract and relax at regular intervals. Neurons in the cerebral cortex can also voluntarily influence the activity of the respiratory centres. A region within the cerebral cortex, called motor cortex, controls all voluntary motor functions, including telling the respiratory centre to speed up, slow down, or even stop. However, the influence of the nerve centres that control voluntary movements can be overridden by the autonomic nervous system.

Several factors can trigger such an override by the autonomic nervous system. One of these factors is the concentration of oxygen in the blood. Specialized nerve cells within the aorta and carotid arteries called peripheral chemoreceptors monitor the oxygen concentration of the blood. If the oxygen concentration decreases, the chemoreceptors signal to the respiratory centres in the brain to increase the rate and depth of breathing. These peripheral (relating to or situated on the edge of something) chemoreceptors also monitor the carbon dioxide concentration in the blood. Another factor is chemical irritants. Nerve cells in the airways can sense the presence of unwanted substances like pollen, dust, water, or cigarette smoke. If chemical irritants are detected, these cells

signal the respiratory centres to contract the respiratory muscles, and the coughing that results expels the irritant from the lungs.

Disorders of the respiratory system fall mainly into two classes. Some disorders make breathing harder, while other disorders damage the lungs' ability to exchange carbon dioxide for oxygen. Asthma is an example of a disease that influences the mechanics of breathing. During an asthma attack, the bronchioles constrict, narrowing the airways. This reduces the flow of air and makes the respiratory muscles work harder. In contrast, pulmonary oedema is an example of a disease that minimizes or prevents gas exchange. Pulmonary oedema occurs when fluid builds up in the area between the alveolus and pulmonary capillary, increasing the distance over which gases must exchange and slowing down the exchange. Various medical interventions are used treat disorders of the respiratory system, but coughing is the body’s main method of defence.

The respiratory systems of other animals differ from that of humans in varying degrees. Most other mammals have a similar respiratory system, but often have subtle differences. For example, horses do not have the option of breathing through their mouths and must take in air through their nose. The respiratory system of birds, which contains unique anatomical features such as air sacs, differs significantly from that found in mammals. Reptiles have a much simpler lung structure than mammals as they lack the extensive airway tree structure found in mammalian lungs. In amphibians, the skin is an important respiratory organ – it is highly vascularized and secretes mucus from specialized cells to facilitate rapid gas exchange. Overall, respiratory systems differ substantially across the animal kingdom.

Word list:

- Concomitant – naturally accompanying or associated with.
- Concentration – the relative amount of a particular substance contained within a solution or mixture or in a particular volume of space.
- Peripheral – relating to or situated on the edge of something

Appendix G – Fourth text passage (Vaccines)

VACCINES

(*A word list with definitions is available on page 3 – last page*)

Please read this passage carefully. You will write a short multiple-choice test on this passage in your next session next week. You will be given 5 minutes to revise before writing.

A vaccine is a biological preparation that establishes or improves immunity (resilience) to a particular disease. Most vaccines prevent or decrease the effects of a future infection by any natural pathogen (bacteria, virus, or other micro-organism that can cause disease). The flu vaccine is an example of such a vaccine that is given annually to protect against the influenza (flu) virus. However, vaccines have also been used for therapeutic purposes, such as for easing the suffering of people who are already afflicted with a disease. An example of such a therapeutic use is the vaccines currently being developed for the treatment of various types of cancer. Until recently, most vaccines have been aimed at children, but the development of therapeutic vaccines has increased the number of treatments targeted at adults.

The early vaccines were inspired by the concept of *variolation*, which originated in Asia. Variolation is a technique in which a person is deliberately infected with a weak form of a disease. Some historians claim that the earliest record of variolation can be found in an 8th century text from India called the Nidana. However, the first unequivocal reference to variolation comes from a Chinese text by Wan Quan called the *Douzhen Xinfa*, written in 1549. The *Douzhen Xinfa* describes how dried smallpox scabs were blown into the nose of an individual who then contracted a mild form of the disease. Upon recovery, the individual was immune to smallpox. A small proportion of the people who were variolated died, but nowhere near the proportion that died when they contracted the disease naturally.

By 18th century, the practice of variolation had spread to Africa, India and the Ottoman Empire. In 1717, the wife of the British ambassador to the Ottoman Empire, Lady Mary Montagu, learned about variolation in Constantinople (which is known as Istanbul today) and advocated for the practice when she returned to England. At her request, royal physicians (doctors) conducted an experiment in which a number of prisoners and abandoned children were variolated. When the children and prisoners were deliberately exposed to smallpox several months later and none

contracted the disease, the procedure was deemed safe. Nevertheless, variolation carried a large degree of risk. Not only could the patient die from the procedure, but also the mild form of the disease could spread, causing an epidemic (outbreak).

Over the following centuries, medical researchers like Edward Jenner and Louis Pasteur transformed the ancient technique of variolation into the modern day practice of inoculation with vaccines. Jenner immunized people against smallpox by inoculating them with cowpox, a related, but relatively mild, disease. The cowpox virus he used to prove the effectiveness of this technique came from a cow named Blossom, whose hide is now hanging in the St. George's Medical School Library.

Inoculation represented a major breakthrough because it reduced the risk of vaccination, while maintaining its effectiveness. Inoculation is the practice of deliberate infection through a skin wound. This new technique produces a smaller, more localized infection relative to earlier variolation in which inhaled viral particles in droplets spread the infection more widely. The smaller infection works better because it is adequate to stimulate immunity to the virus, but it also keeps the virus from replicating enough to reach levels of infection likely to kill a patient.

Vaccines work because they prepare the immune system to deal with pathogens that it may encounter in the future. When a vaccine is given, the immune system recognizes the vaccine agents as foreign, destroys them, and then "remembers" them. When the real virulent (harmful) version of an agent comes along, the body recognizes the protein coat on the virus and responds by destroying the infected cells before they can multiply. Of course, vaccines do not guarantee complete protection against developing the disease. Sometimes a person's immune system does not respond because of a lack of B-cells capable of generating antibodies to that antigen or a lowered immunity in general. Still, even when a vaccinated individual does develop the disease vaccinated against, the disease is likely to be milder than without vaccination.

Some vaccines are made from dead or inactivated virulent (harmful) organisms that have been killed with chemicals or heat. Examples are vaccines against influenza, cholera, and hepatitis. Other vaccines contain live, weakened virus organisms that are cultivated under conditions that disable their virulent properties. Examples include yellow fever, measles, rubella, and mumps. Aluminium-based adjuvants, such as squalene, are typically added to boost immune response to the vaccine. Vaccines can be monovalent or polyvalent. A monovalent vaccine is designed to

immunize against a single type of micro-organism. A polyvalent vaccine is designed to immunize against two or more strains of the same organism, or against two or more organisms.

One challenge in vaccine development is economic: many of the diseases that could be eradicated with a vaccine, such as malaria, exist principally in poor countries. Although many vaccines have been highly cost effective and beneficial for public health, pharmaceutical firms and biotechnology companies have little incentive to develop vaccines for these diseases because there is little revenue potential. Even in more affluent countries, financial returns are usually minimal while the costs are great. The number of vaccines administered has actually risen dramatically in recent decades, but this rise is due to government directives and support, rather than economic incentive. Thus, most vaccine development relies on "push" funding that is supplied by government, universities, and non-profit organizations.

Overall, the invention of vaccines has led to a marked decrease in the prevalence of certain diseases. For example, vaccines have contributed to the eradication of smallpox, one of the most contagious and deadly diseases known to man. Other diseases, such as polio, measles, and typhoid, are nowhere near as common as they were a hundred years ago. As long as the vast majority of people are vaccinated, it is much more difficult for an outbreak of disease to occur and spread, an effect called herd immunity. Yet, critics have campaigned in opposition to vaccination for centuries. Disputes have arisen over the morality, effectiveness, ethics, and safety of vaccination. Still, the mainstream medical opinion is that the benefits of preventing suffering and death from serious infectious diseases greatly outweigh the risks of rare adverse effects following immunization.

Word list:

- Pathogen – bacteria, virus, or other micro-organism that can cause disease
- Variolation - technique in which a person is deliberately infected with a weak form of a disease.
- Virulent – (of a disease or poison) extremely severe or harmful in its effects.
- Adjuvant – a substance which enhances the body's immune response to an antigen.
- Antigen – a toxin or other foreign substance which induces an immune response in the body.

Appendix H – Example of participant information sheet for learners

Psychology

School of Human & Community Development

University of the Witwatersrand

Private Bag 3, Wits, 2050

Tel: 011 717 4503 Fax: 011 717 4559

Participant information sheet

Hello,

I am Thomas Wrigley, a Psychology Research Master's student from the Department of Psychology at the University of the Witwatersrand, Johannesburg (Wits).

I would like to invite you as a secondary school student to participate in a research study! I am investigating the effectiveness of personal computing devices like tablets and laptops when we use them for educational purposes – how do they compare to traditional pen and paper? This research forms part of a Master's thesis.

If you would like to participate, I will ask you to attend four sessions over a period of four weeks. Each session will last approximately 40 minutes and will take place after school. In each session I will require you to perform a reading and writing task using either a tablet PC, a desktop or laptop PC, an E-ink electronic reader or printed paper and a pen. This task will take you approximately 30 minutes. I will also ask you to return after one week and complete a second task which is related to the first. This second task (when you return one week later) will also take you between 15 and 30 minutes.

Participation in this study in voluntary – you not be disadvantaged in any way if you choose not to participate. You have the right to withdraw from this study at any time without any penalty. Your responses are anonymous and no personally-identifying information of yours will be captured or stored by me. Please also note that your participation in this study will not disrupt ordinary teaching and learning.

If you would like to participate in our study, you need to sign a letter of informed consent. If you are under the age of 18, then you will need to sign a letter of informed assent and your parent/guardian will need to sign a letter of informed consent.

Thank you for considering this invitation. This research will contribute to our understanding of educational technology and the impact of personal computing devices on educational outcomes. Your responses will be invaluable in accomplishing this task. Should you have any queries, you are welcome to contact me via the email address provided below.

Kind regards

Thomas Wrigley thomaswrigley@icloud.com

Appendix I – Example of information sheet for parents of participants

Psychology

School of Human & Community Development

University of the Witwatersrand

Private Bag 3, Wits, 2050

Tel: 011 717 4503 Fax: 011 717 4559

Parent/Guardian Participant information sheet

Hello,

I am Thomas Wrigley, a Psychology Research Master's student from the Department of Psychology at the University of the Witwatersrand, Johannesburg (Wits).

I would like to invite your child as a secondary school student to participate in a research study! I am investigating the effectiveness of personal computing devices like tablets and laptops when we use them for educational purposes – how do they compare to traditional pen and paper? This research forms part of a Master's thesis.

If you would like your child to participate, I will require them to perform a reading and writing task using either a tablet PC, a desktop or laptop PC, an E-ink electronic reader or printed paper and a pen. This task will take your child between 15 and 30 minutes. I will also ask your child to return after one week and complete a second task which is related to the first. This second task (when your child returns one week later) will also take between 15 and 30 minutes.

Participation in this study in voluntary – your child will not be disadvantaged in any way if they choose not to participate. Your child has the right to withdraw from this study at any time without any penalty. Their responses are anonymous and no personally-identifying information of theirs will be captured or stored by me. Please also note that your child's participation in our study will not disrupt ordinary teaching and learning.

If your child is under the age of 18 and you would like your child to participate in this study, please sign the letter of informed consent in which you formally give permission for your child to participate in this research. If your child is under the age of 18, then they will need to sign a letter of informed assent in addition to you as the parent/guardian signing a letter of informed consent.

Thank you for considering this invitation. This research will contribute to our understanding of educational technology and the impact of personal computing devices on educational outcomes. Your responses will be invaluable in accomplishing this task. Should you have any queries, you are welcome to contact me via the email address provided below.

Kind regards

Thomas Wrigley thomaswrigley@icloud.com

Appendix J – Example of signed consent form

Signed Consent Form

(To be completed if you are above the age of 18 or if your child is below the age of 18 and you as parent/guardian are giving permission for his/her participation)

- I _____ (full name) have been informed about the study entitled 'Personal computing device interfaces and their psychological and neurophysiological impact on learning in South African secondary school students' by Thomas Wrigley.
- I understand the purpose and procedures of the study
- I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.
- I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without penalty.
- I hereby my permission to participate in this study/give permission for my child _____ (full name) to participate in this study and hereby state that I am his/her legal guardian.
- If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at:

  U211, Umthombo Building, University of the Witwatersrand, 1 Jan Smuts Ave, Braamfontein, Johannesburg, 2000

  E-mail: thomas.wrigley@icloud.com

Signed: _____

Date: _____

Appendix K – Example of signed assent form

Signed Assent Form

(To be completed if you are below the age of 18)

- I _____ (full name) have been informed about the study entitled 'Personal computing device interfaces and their psychological and neurophysiological impact on learning in South African secondary school students' by Thomas Wrigley.
- I understand the purpose and procedures of the study
- I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.
- I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without penalty.
- I understand that because I am below the age of 18, I require consent to participate from my parent/legal guardian as well as my own assent (permission) to participate.
- I hereby give my assent to participate in this study.
- If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at:

  U211, Umthombo Building, University of the Witwatersrand, 1 Jan Smuts Ave, Braamfontein, Johannesburg, 2000

  E-mail: thomas.wrigley@icloud.com

Signed: _____

Date: _____

Appendix L – Test on first text passage (Bats)

Bats – Multiple Choice Questions

Below is a list of questions on the text passage which you have just read. For each question, please select the **most correct** answer by ticking the applicable box or circling the applicable letter.

1. What phylogenetic order (group of genetically-related organisms) are bats part of?

☐	(A)	Reptiles
☐	(B)	Mammals
☐	(C)	Chiroptera
☐	(D)	Frugivores

2. What are two of the reasons given in the text why bats tend to roost upside down in a secluded place like a cave or hollow tree?

☐	(A)	Bats are sensitive to noise and heat and need to roost in cool, quiet places
☐	(B)	It provides a means of hiding from predators and puts bats in position for take-off, as they cannot launch themselves into the air from the ground
☐	(C)	Darkness allows bats to sleep more easily and provides a means of hiding from predators
☐	(D)	Bats' wings are not strong enough to hold their body weight and they prefer dark, damp places to roost in

3. A famous colony of Mexican free-tail bats lives in Bracken Cave., Texas. How many tons of insects per night does this colony of more than 20 million bats eat?

☐	(A)	200 tons
☐	(B)	2000 tons
☐	(C)	20 tons
☐	(D)	2 tons

4. The U.S. military is looking at bat wings for inspiration in developing a new type of aircraft. How would this new type of aircraft differ from traditional aircraft like fighter jets?

- [ ] (A) It would be more manoeuvrable than traditional aircraft
- [ ] (B) It would provide more lift than a rigid wing
- [ ] (C) Both A & B
- [ ] (D) None of the above

5. Sometimes bats die while they are sleeping. What will happen if a bat dies while it is hanging upside down?

- [ ] (A) They will fall to the ground
- [ ] (B) Their wings will automatically open
- [ ] (C) They will remain hanging
- [ ] (D) None of the above

6. Which of the following statements are correct?

I. Most megabat species are fruit eaters and nectar drinkers

II. Most microbat species have large eyes and small ears

III. Most megabat species eat insects

IV. Most microbat species have large ears and stubby snouts

V. Vampire bats are a type of megabat

- [ ] (A) I, III & V
- [ ] (B) II, IV & V
- [ ] (C) None of the statements are correct
- [ ] (D) I & IV

7. How do bats positively contribute to our ecosystem?

- [ ] (A) Nectavoric bats help plants by pollinating and insectivorous bats are very good at killing insects
- [ ] (B) Insectivorous bats help plants by pollinating and nectavoric bats are very good at killing insects.

- [ ] (C) Frugivorous bats help keep fruit trees healthy
- [ ] (D) All of the above

8. Many zoologists believe that bats' ability to enter a temporary torpor state (state of physical inactivity) evolved in response to natural selection pressures related to food consumption. Why might the supply of food have led bats to develop the ability to enter a temporary torpor state?

	(A)	Bats needed to hibernate during the winter
	(B)	If the supply of food is often interrupted, bats would need to be able to rest and conserve energy until they could find food again.
	(C)	If the supply of food is often interrupted, bats could not afford to rest until they had found more food
	(D)	Bats eat very large meals and would need to incorporate time for recovery after each feeding

9. Submarines use SONAR to navigate underwater much like bats use echolocation to navigate at night. Using SONAR, how does a submarine determine that an object is moving towards it (rather than away from it)?

	(A)	When an object is moving towards the submarine, the sound wave takes more time to return from the object than it took to reach the object
	(B)	An object moving towards the submarine will produce a more intense echo
	(C)	An object moving away from the submarine
	(D)	When an object is moving towards the submarine, the sound wave takes less time to return from the object than it took to reach the object

10. What is the earliest evidence we have of the popular connection between bats and vampires?

	(A)	Varney the Vampire
	(B)	Bram Stoker’s Dracula
	(C)	Ivan the Terrible
	(D)	Frankenstein

Appendix M – Test on second text passage (Bread)

Multiple Choice Questions

Below is a list of questions on the text passage which you have just read. For each question, please select the **most correct** answer by ticking the applicable box or circling the applicable letter.

1. What are the two protein groups that make up the protein gluten, and help form the structure of bread dough?

☐ (A) Water soluble and non-water soluble
☐ (B) Glutenin and soya
☐ (C) Glutenin and gliadin
☐ (D) Flour and yeast

2. If bread is kneaded too much, the network of strands formed by the non-water-soluble proteins will break down. How will over-kneading affect the consistency or texture of the bread?

☐ (A) It will become softer
☐ (B) It will become harder
☐ (C) It will become brittle
☐ (D) It will remain unchanged

3. Why is a "baker's dozen" thirteen items?

☐ (A) You can typically fit thirteen items on a baking tray
☐ (B) A dozen has thirteen items
☐ (C) It was based on tax laws in the 13th Century
☐ (D) To avoid being accused of short-changing people

4. In addition to helping bread to rise, yeast are often used for fermentation in brewing both alcoholic beers and non-alcoholic beers, such as root beer. What are the two main

ways in which the fermentation process can be adjusted to vary the alcohol content of beer?

- [ ] (A) Increasing both the fermentable sugar and yeast
- [ ] (B) Decreasing both the fermentable sugar and yeast
- [ ] (C) Increasing the fermentable sugar and decreasing the yeast
- [ ] (D) Increasing the yeast and decreasing the fermentable sugar

5. Yeast is often used as a leavening agent in baking bread. How does yeast help the bread to rise?

- [ ] (A) Yeast is a single-celled organism and this allows bread to rise
- [ ] (B) Yeast converts the alcohol present in the dough into carbon dioxide gas and non-fermentable sugars. The non-fermentable sugars causes the dough to expand and rise
- [ ] (C) Yeast reacts with carbon dioxide and produces *Saccharomyces cerevisiae* which causes the bread to rise
- [ ] (D) Yeast converts the fermentable sugars present in the dough into carbon dioxide gas and alcohol. The carbon dioxide gas causes the dough to expand and rise

6. What is the purpose of adding calcium propionate to bread?

- [ ] (A) To reduce the growth of mould
- [ ] (B) To add to the leavening process of the bread
- [ ] (C) To give the bread its flavour
- [ ] (D) To give the bread its golden colour

7. What was the slogan of Kleen Maid, the first commercial sliced bread?

- [ ] (A) The greatest forward leap since bread was made
- [ ] (B) The greatest thing since sliced bread
- [ ] (C) The greatest forward step since bread was wrapped
- [ ] (D) The best thing ever

8. The polymer coating that is applied to nylon hot air balloons functions in a similar way to the gluten formed from proteins in bread making. How does the polymer coating affect hot air balloons?

	(A)	It regulates temperature similarly
	(B)	It creates pockets where the carbon dioxide can escape
	(C)	It traps and keeps the carbon dioxide from escaping
	(D)	Both (A) and (C)

9. On a camping trip, a group of people want to produce leavened bread. If they have flour and water, but forgot to bring yeast or any other leavening agent, how could they produce leavened bread?

	(A)	They could cover the dough up with a wet cloth
	(B)	They can leave the dough exposed to air for about a day
	(C)	They can cook it at a higher temperature
	(D)	None of the above

10. Professional bread makers use a system called Bakers' Percentage for recipes. How does this system work?

	(A)	The bakers get to decide the amount of ingredients used
	(B)	The ingredients are measured by weight rather than by volume because it is more accurate and consistent
	(C)	The ingredients are measured by volume rather than by weight because it is more accurate and consistent
	(D)	The overall percentage of the ingredients is 100% and all the other ingredients are worked back from there

Appendix N – Test on third text passage (Respiration)

Respiration – Multiple Choice Questions

Below is a list of questions on the text passage which you have just read. For each question, please select the **most correct** answer by ticking the applicable box or circling the applicable letter.

1. The lungs are the component of the human respiratory system responsible for oxygenation of the blood and the removal of carbon dioxide. What other major function do they serve?

☐ (A) Managing blood pressure

☐ (B) Managing the concentration of hydrogen ions and helping to regulate the acidity or pH of the blood

☐ (C) Controlling breathing rate

☐ (D) Oxygenation of the blood and the removal of carbon dioxide

2. What areas in the brain automatically control the rate of breathing?

☐ (A) Cerebral cortex

☐ (B) Basal ganglia

☐ (C) Motor cortex

☐ (D) Pons and medulla oblongata

3. What can a horse not do, in terms of respiration?

☐ (A) Control their breathing rate

☐ (B) Breathe through their nose

☐ (C) Breathe through their mouth

☐ (D) Breathe very slowly

4. About how large is the surface area of the lungs' alveoli?

☐ (A) The size of a tennis court

☐ (B) The size of a swimming pool

( ) (C) The size of a classroom

( ) (D) The size of a football field

5. Gas exchange occurs in a part of the human respiratory system called the alveoli. How does the process of gas exchange work?

( ) (A) Through the process of diffusion, where high concentrations of oxygen in the alveoli move into the small blood vessels that surround each alveolus

( ) (B) Through the process of diffusion, where low concentrations of oxygen in the alveoli move into the small blood vessels that surround each alveolus

( ) (C) Through the process of effusion, where high concentrations of oxygen in the alveoli move into the small blood vessels that surround each alveolus

( ) (D) Through the process of diffusion, where high concentrations of nitrogen in the alveoli move into the small blood vessels that surround each alveolus

6. Describe the flow of air from the nose or mouth through the lungs. What structures must the air pass through to reach the alveoli?

( ) (A) Air enters the body through the nose or mouth and goes past the bronchioles into the trachea, continuing until it reaches the epiglottis, after which it spreads out and travels along the epiglottis until it reaches the alveoli

( ) (B) Air enters the body through the nose or mouth and goes past the trachea into the epiglottis, continuing until it reaches the alveoli, after which it spreads out and travels along the alveoli until it reaches the bronchioles.

( ) (C) Air enters the body through the nose or mouth and goes past the epiglottis into the trachea, continuing until it reaches the bronchi, after which it spreads out and travels along the bronchioles until it reaches the alveoli

( ) (D) Air enters the body through the nose or mouth and goes past the alveolus into the trachea, continuing until it reaches the bronchi, after which it spreads out and travels along the bronchioles until it reaches the epiglottis

7. The pressurization system of a submarine that is 10,000 feet below the surface of the ocean suddenly begins to malfunction, increasing the air pressure in the cabin. Assuming there is still plenty of oxygen in the cabin, how would the respiration of the crew be affected?

- [ ] (A) The crew would become asthmatic
- [ ] (B) The crew would struggle to exhale (breathe out)
- [ ] (C) The crew would breathe more slowly
- [ ] (D) The crew would struggle to inhale (breathe in)

8. If a person's epiglottis were not working properly, what would be likely to happen?

- [ ] (A) There will be no noticeable difference
- [ ] (B) The person will not be able to breathe deeply
- [ ] (C) The person will snore when sleeping
- [ ] (D) Food and liquid may enter a person’s airway when they swallow

9. Most cars that burn gasoline have an emissions control system that includes a component called an oxygen sensor, which functions in a similar way to the system in the human body that can trigger involuntary breathing. How does this emissions control system work?

- [ ] (A) The sensor measures oxygen levels
- [ ] (B) Rate of air intake is increased or decreased if oxygen levels are too high or low
- [ ] (C) The emissions control system keeps the oxygen levels stable
- [ ] (D) All of the above

10. Photosynthesis in plants involves the intake of carbon dioxide and the conversion of carbon dioxide into sugars using energy from sunlight. There are two main classes of disorders that can affect photosynthesis in plants that are very similar to the two main classes of disorders that can affect human respiration. How would each of these two classes of disorder affect photosynthesis?

	(A)	Some disorders will make the intake of carbon dioxide more difficult, while others will improve the ability of plants to convert carbon dioxide into sugars
	(B)	Some disorders will make the intake of carbon dioxide easier, while others will improve the ability of plants to convert carbon dioxide into sugars
	(C)	Some disorders will make the intake of carbon dioxide more difficult, while others will decrease the ability of plants to convert carbon dioxide into sugars
	(D)	Some disorders will make the intake of carbon dioxide more difficult, while others will decrease the ability of plants to convert sugars into carbon dioxide

Appendix O – Test on fourth text Passage (Vaccines)

Vaccines – Multiple Choice Questions

Below is a list of questions on the text passage which you have just read. For each question, please select the **most correct** answer by ticking the applicable box or circling the applicable letter.

1. What is "herd immunity"?

☐	(A)	This occurs when a disease cannot be passed onto humans from animals
☐	(B)	Vaccines which are developed from large groups of animals
☐	(C)	Occurs when the majority of a population is vaccinated against a particular disease, making it difficult for the disease to spread
☐	(D)	When an entire group of people or animals develops immunity to a disease

2. Vaccines vary in terms of their valence. What does the valence of a vaccine refer to?

☐	(A)	The number of electrons present in the outermost shell of the vaccine's atoms
☐	(B)	The number of strains or types of micro-organisms targeted by a vaccine
☐	(C)	The effectiveness of a vaccine at protecting against disease
☐	(D)	The speed at which a vaccine works

3. Before the invention of modern vaccines, royal physicians conducted an initial experiment with variolation. Which two groups of people served as subjects in this experiment?

☐	(A)	Soldiers and sailors
☐	(B)	Prisoners and beggars
☐	(C)	Beggars and abandoned children
☐	(D)	Prisoners and abandoned children

4. What was the name of the cow whose cowpox was used to demonstrate the effectiveness of Edward Jenner's technique of inoculation against smallpox?

- [ ] (A) Barbara
- [ ] (B) Blossom
- [ ] (C) Bubbles
- [ ] (D) Buttercup

5. A vaccine can be beneficial even if people develop the disease against which they have been vaccinated. What is the benefit of a vaccine if the illness it was supposed to prevent is developed?

- [ ] (A) The vaccine will reduce the number of people who contract the disease from you sneezing
- [ ] (B) The vaccine will help you to rest more deeply and aid in your recovery
- [ ] (C) You won’t feel as bad because you have had the symptoms before and will know what to expect
- [ ] (D) The disease is likely to be less severe than it would be without vaccination

6. Which of these injected vaccines would be most likely to cause a mild form of the disease it was attempting to prevent, and why? Cholera, Hepatitis, Influenza, Yellow Fever.

- [ ] (A) Yellow Fever, because its vaccine contains live, weakened virus organisms
- [ ] (B) Hepatitis, because the disease itself is more virulent (harmful)
- [ ] (C) Cholera, because its vaccine contains live, weakened virus organisms
- [ ] (D) Influenza, because its vaccine contains inactivated organisms killed by heat

7. The recently developed nasal spray flu vaccine, which is inhaled through the nose, contains weakened versions of the viruses that only cause infection at the cooler temperatures found within the nose. In what sense does this new method of vaccination combine the techniques of inoculation and variolation?

- [ ] (A) This method involves deliberate infection via breathing which mimics variolation, but is also more localised as the virus only works within the temperatures of the nose, mimicking vaccination

	(B)	This method combines infection by breathing and direct injection into the body
	(C)	This method involves deliberate infection via breathing which mimics variolation, but is also more localised as the virus only works within the temperatures of the nose, mimicking inoculation
	(D)	This method involves deliberate infection via breathing which mimics inoculation, but is also more localised as the virus only works within the temperatures of the nose, mimicking variolation

8. Generally speaking, people given a monovalent vaccine develop immunity faster than people given a polyvalent vaccine. Why does immunity develop faster with a monovalent vaccine?

	(A)	The monovalent vaccine uses more expensive compounds and is therefore more effective
	(B)	The polyvalent vaccine is less easily absorbed into the bloodstream.
	(C)	The monovalent vaccine is focused on a single type of organism and can target this organism more effectively
	(D)	The polyvalent vaccine is focused on a single type of organism and can target this organism more effectively

9. Controlled burning is a forest management technique used to prevent wildfires that relies on a similar principle to that of the practice of inoculation in vaccinating people. How does controlled burning work?

	(A)	Controlled burning involves injection fire-resistant organisms into trees which make them less likely to catch fire
	(B)	Controlled burning involves burning excess organic material (wood, grass etc.) in a planned way to avoid an unexpected fire burning out of control
	(C)	Controlled burning involves burning excess organic material to kill disease
	(D)	Controlled burning involves burning large trees to stop them from ‘strangling’ or taking nutrients and water from smaller trees and shrubs

10. Psychologists have investigated a phenomenon known as "attitude inoculation," which works on the same principle as vaccination, and involves exposing people to weak arguments against a viewpoint they hold. What would this theory predict would happen if the person was later exposed to a strong argument against their viewpoint?

	(A)	This person would be more likely to change their viewpoint
	(B)	This person would become ill
	(C)	This person would not become ill because of the inoculation
	(D)	This person would be far less likely to consider an opposing viewpoint or to change their mind

Appendix P – Supplementary Analysis (ANCOVA)

Table 18. Between-subjects (one-week) reading only condition

Question Group	Device	N	Mean	SD	Mean Square	F	df	Sig.	Partial eta squared
Factual	Paper	24	.22	.55	.405	1.136	1	.296	.039
	Tablet	7	-.07	.85					
Conceptual	Paper	24	-.04	.74	.005	.010	1	.921	.000
	Tablet	7	-.09	.55					

Table 19. Within-subjects reading only condition

Question Group	Means (Paper/ Tablet)	Mean Diff.*	Stand. Dev.	Mean Square	F	df	Sig.	Partial eta squared	Levene's Homogeneity of Variance
Factual	.46	.44	.707	1.82	2.941	1	.095	0.078	.773
	.02		.848						
Conceptual	.18	.26	.778	.644	1.223	1	.276	0.34	.352
	–.08		.67						

* Positive mean indicates that paper-device scores are higher than those for tablets; N = 19

Table 20. Between-subjects (one-week) note-taking condition

Question Group	Device	N	Mean	SD	Mean Square	F	df	Sig.	Partial eta squared	Levene's Homogeneity of Variance
Factual	Paper	47	.048	.76	.135	.258	1	.613	.004	.986
	Tablet	19	.009	.72						
Conceptual	Paper	47	.031	.70	.185	.443	1	.508	.007	.347
	Tablet	19	.025	.58						

Table 21. Within-subjects note-taking condition (ANCOVA)*

Question Group	Means (Paper/ Tablet)	Mean Diff.*	Stand. Dev.	Mean Square	F	df	Sig.	Partial eta squared	Levene's Homogeneity of Variance
Factual	-.05	-.12	.756	0.286	.539	1	.465	.007	.998
	.07		.733						
Conceptual	.19	.30	.682	1.887	4.511	1	.037	.476	.453
	-.11		.636						

* Positive mean indicates that paper-device scores are higher than those for tablets; N = 41