A Critical Review of Digital Technology in Education that should give Policy Makers and Educators Pause for Thought

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A TRADITION OF INDEPENDENT THINKING

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Coláiste na hOllscoile Corcaigh

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"Digital Technology is hardly the benign, neutral presence in education that we are often assured it to be"

Selwyn (2015, p. 247)

Abstract

There is a dearth of scientific evidence and evidence-based practice to justify current levels of digital technology use for educational purposes in the classroom and in the home. In contrast, there is a growing body of scientific studies across several disciplines that highlight the direct and indirect negative effects of Digital Technology use on human cognition, learning, and behaviour. This paper considers objective evidence from peer-reviewed scientific studies in cognitive psychology, neuroscience, and related disciplines, as well as the field of education itself, to review the fundamental problems that beset Digital Technology use in education. The paper highlights, for example, that: (1) Screens lead to sleep disruption and deprivation, which impacts on learning, and is associated with obesity, and other physical disorders, such as computer vision syndrome; (2) Computer use in class disrupts the learning process and impairs learning outcomes for users and non-users alike; (3) Learning with books and paper is superior in comparison to learning with e-books; (4) Taking notes with pen and paper, as opposed to touch typing lecture notes in class, leads to better learning outcomes; (5) Smart phone, iPAD and laptop use result in student distraction and multitasking, which, impair learning and lead to neural addiction problems, such as Internet addiction disorder and other psychological maladies; (6) There are islands of success in an ocean of failure when it comes to Digital Technology and educational technologies, with researchers arguing that there is little evidence to support the proposition that Digital Technology and/or EdTech improve pedagogy or learning outcomes; (7) Finally, basic education about Digital Technology is one topic that needs to find a place in the curriculum. However, as with all Digital Technology initiatives, the introduction of programmes at primary and secondary schools level need to be considered mindfully, with the strengths and limitations of the proposed enabling technologies clearly in focus. All this should give educators, administrators and politicians pause for thought. The paper concludes by discussing its findings, offering practical recommendations, and by suggesting a change in emphasis in pedagogy in and through Digital Technology.

Introduction

Ever since the emergence of information and communication technologies, of which Digital Technology is the most recent, educators have sought to apply them in order to improve both the process and product of education. One might be forgiven for thinking that this is a recent phenomenon, with emergence of personal computers in the 1980s, or the Internet in the 1990s. However, as Larry Cuban, Professor Emeritus of Education at Stanford University, illustrates in his *Teachers and Machines: The Classroom,* the origins of this preoccupation with technology, and the utopian hopes that attach to it, can be traced back to moving pictures and radio. In this seminal review, which ends just as the personal computing revolution was beginning, Professor Cuban (1986) explores why the hopes invested in such technologies had not been realized. Much has happened since then. However, in *Oversold and Underused,* which was initially published in 2002, Cuban (2009) subjected the use of Digital Technology in education to critical analysis. Once more he illustrates that the Digital Technology fails to deliver on its promises to improve both the pedagogical process and related learning outcomes, as the title of his book indicates. In his latest study, he addresses confusions generated by those "well-intentioned and well-heeled crusaders seeking to improve teaching and schooling" (Cuban, 2018, p. 102). Despite the widespread use of Digital Technology in classrooms across the US, Cuban concludes yet again that overall little has changed. John Willinsky, Khosla Family Professor of Education and Director of the Program in Science, Technology, and Society at Stanford University, concludes that "When it comes to answering the question of whether technology is the difference than makes a difference, even in the hands of the exemplary teacher and students, Cuban says yes and no in the face of change and stability…For the tornado of tablets and other devices in American classrooms may have only caused the needle on student learning to flutter, without moving the schools in the substantial ways that many of us might have hoped." (Willinsky, 2018).

Digital Technology fails to deliver in the classroom

"Since 2010, laptops, tablets, interactive whiteboards, smart phones, and a cornucopia of software have become ubiquitous. Yet has academic achievement improved as a consequence? Has teaching and learning changed? Has use of devices in schools led to better jobs? These are the basic questions that school boards, policymakers, and administrators ask. The answers to these questions are "no," "no," and "probably not.""

Larry Cuban, Professor Emeritus of Education, Stanford University.

In 2011, in *The Third Source: A Message of Hope for Education*, Dustin Hueston (2011) claims that "children's capabilities will be buttressed by a new wave of 'enhanced instructional software' that will offer individualized interactive instruction with precision and artistic beauty for all children, not just children with access to excellent schools." However, Ornellas and Sancho (2015) argue that this is just the latest in a long line of myths which claim that the application of technology will solve enduring problems in education. Ornellas and Sancho provide proof that debunk such myths and offer convincing evidence that Digital Technology, in all its guises, has failed to make significant changes to pedagogy or to enhance learning outcomes. I revisit this evidence below.

This critical review paper makes several important contributions to the debate on

Digital Technology use in education by drawing on recent research across several disciplines to highlight fundamental problems with Digital Technology that have a negative impact on students' academic performance, health, and well-being. Such problems indicate why, in many circumstances, Digital Technology-enabled education may fail to live up to the expectations of stakeholders. It also indicates that traditional approaches, such as taking notes using pen and paper and reading from printed media, are superior to Digital Technology in promoting learning. The arguments I present are, for the most part, based on the findings of peer-reviewed studies conducted using the scientific method. These are augmented by expert opinion from senior scholars across several disciplines.

It the OECD's (2015) *Students, Computers and Learning: Making the Connection* is unequivocal in raising significant doubts on the use of Digital Technology for and in education. The findings of that study, which focused on 15-year-old students who participated in the Programme for International Student Assessment (PISA), illustrates that student use of Digital Technology in the classroom and the home has no effect on learning outcomes. However, the higher the level of Digital Technology use in classroom and the home, the greater the negative effect on learning outcomes.

A meta-analysis of the PISA data by McKinsey & Company called *How to improve student educational outcomes: New insights from data analytics* "found that deploying ICT to teachers, rather than to students, works best." (Mourshed et al. 2018, p. 9). One of the report's central conclusions was that: "Overall, our analysis suggests that systems should aim to balance inquiry-based methods with sufficient teacher directed instruction to ensure that teachers are able to explain scientific concepts clearly, and that students have sufficient content mastery to fully benefit from inquiry-based teaching." The report also validates the OECD's conclusions viz. "Across all the regions that undertook the PISA student ICT survey, providing students with e-book readers, tablet computers and laptops had a negative impact on test scores."

There is a small overlap between the studies cited in the OECD report and those included in this study. However, this paper covers a broader range of topics, provides deeper insights, and presents additional evidence in key areas to illustrate the downside risks for children. The next section addresses the core construct—Digital Technology.

What is Digital Technology?

In any rigorous study the central concepts (or constructs) require unambiguous definition. Formally referred to as Information and Communication Technology (ICT), Digital Technology is a high-level concept under which we may categorize the various types of information, communication and computer-based technologies. There are a plethora of textbook definitions of ICT and Digital Technology. However, a richer conceptualisation, which is generally absent from the literature, is that of an information system (IS). An information system is typically conceptualised as an arrangement or combination of people, processes and Digital Technology. Thus, an Educational IS, may simply be defined in terms of people (students, teachers, and parents, for examples), processes (pedagogical procedures and techniques) and Digital Technology. But what then is Digital Technology?

I define Digital Technology in terms of the various members of the hardware and software technology families. The hardware branches in the taxonomy includes all types of computers (smart phones, tablets, notebooks, laptops, servers, mainframes, data stores, etc.) and telecommunications and internetworking devices (landline and mobile devices, switches and routers of all shapes and sizes (including broadband switches and routers), telephony exchanges, fibre optic and microwave links, and so on). The software family branches include operating systems (Windows, Android, Linux, iOS), system software (including TCP/IP, HTTP (i.e. web browsers), and so on), and the entire family of applications, both generic and process/task-specific (stand-alone (Word, Excel, etc.), client-server, web-based, hosted, Web 1.0, Web 2.0 and 3.0 applications and so on).

In helping answer the above question for educators, *Bloom's Digital Taxonomy*[1] (BDT) has been proposed as a novel mechanism to enable teachers understand the practical uses of Digital Technology in education. It is being put to practical use and also is being applied in research in an educational context (cf. Rahimi et al., 2014; Schwartz, 2014). *Blooms Digital Taxonomy* captures the categories I describe above pretty well. However, extensions such as that proposed by Alan Carrington [2] suffer from the aforementioned problem of empirical validation in their ability of the applications posited to support the activities of Remembering, Understanding, Applying, Analysing, Evaluating, and Creating (i.e. Bloom's Taxonomy). Indeed, validating educational technology applications is becoming an impossible task, as there are in excess of 200,000 educational applications in Apple's App Store. Whether the BDT, or its extensions, have empirical fidelity has yet to be ascertained. It is significant that BDT's claims made for Digital Technology categories (software applications of various types, including Facebook and Twitter) linked with the original Bloom's Taxonomy have not been proven empirically. Neither has the SAMR Model (Puentedura, 2009), which is being used to extend Bloom's Digital Taxonomy. That issue aside, nebulous terms like computers in education, educational technology (EdTech), technology-enhanced learning, computer-aided learning, abound in the literature, without delineating specifically the Digital Technology-based mechanism(s) producing enhanced learning outcomes. This is an issue that requires attention.

Having defined the various categories of Digital Technology, it is clear that some act

Blooms Digital Taxonomy Example

as primary mechanisms for producing enhanced learning outcomes, while others act as secondary or enabling mechanisms. In applying an information systems lens, we can bracket out secondary mechanisms like data links, internetworking technologies, operating systems, and so on. Thus the primary mechanisms include (1) a screen, and related data input/output technologies (keyboard, sound and video, whiteboard, etc.) and (2) a software application, which may be generic (e.g. Internet Explorer, Mozilla, Google, YouTube, Facebook etc.) or process/task specific (educational applications). At its most basic conceptualisation, an educational information system includes a student(s), a teacher(s), a teaching and learning process (self-regulated or variants thereof—cf. Azevedo et al. 2008; Mega et al. 2014) and an application served up on a screen by personal computer (e.g. tablet, iPad, notebook).

Over the past number of years, research in cognitive psychology, neuroscience, and related areas in medical science has revealed the unintended physiological and psychological consequences of life in the Digital Age. It is now apparent that Digital Technology has a 'dark side' (Tarafdar et al., 2015) with negative consequences for society that often outweigh the benefits that

[1]http://edorigami.wikispaces.com/Bloom%27s+and+DIGITAL TECHNOLOGY+tools#DIGITAL TECHNOLOGY Tools Key and examples

[2]http://www.unity.net.au/padwheel/padwheelposter.pdf

it brings. Before turning to research on the success or not of Digital Technology in education, I will address fundamental issues of great importance, which generally have not been included in the discourse or research on the topic. This lacuna in research and practice has significant consequences, as the next section illustrates.

Why are Screens the Achilles Heel of Digital Technology-based Education?

It may surprise many of you that the very mechanism posited to open up a world of possibilities for learning, may, in fact, undo all of the assumed benefits of Digital Technology-enhanced education. I am referring to the physical properties of 'screen' itself, whether it be on an iPad, tablet, notebook, or smart phone. The problem here is the light being radiated by the light-emitting diodes (LEDs), which are used in all screens to project text and images, whether it is a tablet or television. The natural light that streams in your bedroom window each morning serves to regulate the circadian rhythm or biological clock. It does this by influencing the production of melatonin in the brain's pineal gland. Computer screens are equipped with LEDs which produce short-wavelength 'white light' in the blue range at between 440-500 nm. This type of light interferes significantly in this process, particularly in the evening and nighttime resulting in sleep disruption for screen users, particularly children.

On the Relationship between Sleep Disruption and Learning

A meta-analysis of extant studies by Kopasz et al. (2010) illustrate that sleep is important for working memory and long-term memory consolidation in children and adolescents. Indeed Walker and Stickgold (2014, p. 160-161) state unambiguously that "It is now clear that sleep mediates learning and memory processing" and is vital for memory "encoding, consolidation, and reconsolidation, into the constellation of additional processes that are critical for efficient memory development." Chua et al. (2014) find that short term sleep deprivation also affects cognition, vigilance, mood, behavior, ability to learn, immune function, and general performance. More seriously, epidemiological studies associate poor sleep with long-term outcomes such as diabetes, obesity, depression, hypertension, and general mortality from all causes (Mukherjee, 2015).

Sleep and Learning

"It is now clear that sleep mediates learning and memory processing" and is vital for memory "encoding, consolidation, and reconsolidation, into the constellation of additional processes that are critical for efficient memory development."

Walker and Stickgold (2014, p. 160-161)

The research literature is unequivocal in finding that sleep is crucial for children and adolescents' memory, learning, and academic performance. Rigorous research finds that going to bed late, poor sleep patterns, fragmentation of sleep, and waking early in the morning have a serious negative effect on a student's capacity to learn, academic performance in school, and general neurobehavioral function. Research also indicates that the average level of sleep for both children and adolescents is approximately 9 hours per night (Dewald et al., 2010). That is, 9 hours on average, with some requiring more, and some less—8-10 hours appears to be the required range. Significantly, Dewald et al. (2010, p. 187) state that "research showed a stronger association between sleep quality and neurobehavioral functioning in younger children than in older children… the influence of low sleep quality, insufficient sleep, and sleepiness on prefrontal cortex functions and therefore also on cognitive functioning and school performance is larger during early rather than later adolescence.” Thus, young children and adolescents, whose brains are undergoing relatively greater formative development, are at significant risk (see Crowley et al., 2018). Hence, parents and teachers should ensure that they obtain the required levels of sleep commensurate with their age. Screen use poses a significant obstacle to this (Lissak, 2018).

On the Serious Negative Impact of Screens on Sleep

There is a significant body of research that highlights the negative impact of screen use on sleep (Hysing et al., 2015). Studies show that the light from all LED-based screens resets circadian rhythm, suppresses melatonin production, and improves nocturnal alertness and performance by elevating brain activation (Cajochen et al., 2011). The downside, however, of screen-induced nocturnal alertness and elevation of brain activity is disturbed sleep patterns, increased stress, and several other debilitating conditions. Recent research by Chang et al. (2015) compared the biological effects in subjects who read a book from a LED screen on an e-reader with those from subjects who read a printed book before bedtime. The group who read the eBook took longer to fall asleep, were more alert but less sleepy, had reduced melatonin levels, and were less alert the next morning. The scientists concluded that such technologies have a negative impact on “sleep, performance, health, and safety.” This is an extremely important consideration when introducing iPads, tablets, smart phones, and other devices to replace printed books.

Magee et al. (2014) illustrate the negative effects of screen time on children’s sleep. Likewise, Fossum et al. (2014) illustrate that screen time for game playing, net surfing and reading by adolescents and young adults was directly related to insomnia and had a negative effect on morning alertness—so too has mobile/smart phone use. Hasler et al. (2014) also find that insomnia raises the risk of substance abuse disorders in adolescence. A recent meta-analysis by Hale and Guan (2015, p. 50) confirms previous findings and they recommend that that adolescents be “advised to limit or reduce screen time exposure, especially before or during bedtime hours to minimize any harmful effects of screen time on sleep and well-being.” The impact of such advice is indicated by Wolfson et al. (2015) who studied the implementation of a Sleep Smart Program aimed at improving sleep health behaviours, academic performance and general well-being. The seventh graders who took part in the programme experienced “significantly greater sleep health efficacy, improved physiological and emotional sleep hygiene, more time in bed, and earlier bedtimes vs the comparison group.” There was also evidence of those who participated in the programme maintaining academic performance, which was not the case for the non-treatment group.

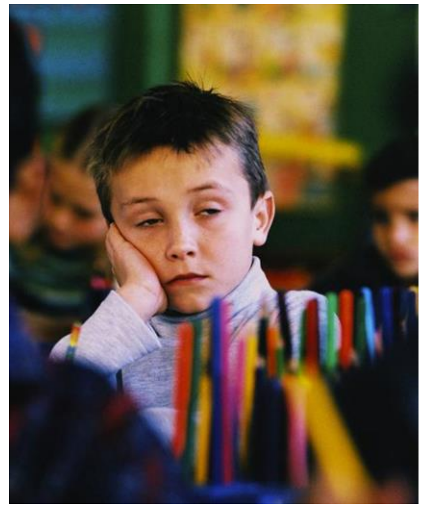
Sleep disruption

“Children and adolescents spend their leisure time in front of gaming consoles, televisions, and cell phones, and in fact, many adolescents do “multi-screening,” which means that they use more than one screen at a time.”

Figueiro et al. (2011, p. 1437)

The research literature on the effect that LED screens have in suppressing melatonin levels is also unequivocal. The experimental study by Cajochen et al. (2011, p. 1432) is most approachable in this regard. It provides convincing evidence of the effect that "A 5-h evening exposure to a white LED backlit screen… elicited a significant suppression of the evening rise in endogenous melatonin and subjective as well as objective sleepiness, as indexed by a reduced incidence of slow eye movements and EEG low-frequency activity (1–7 Hz) in frontal brain regions." The findings of this study are limited to the 19-35 year-old males, however. Given evidence from the general literature on sleep cited above, it would be expected that the negative effects on endogenous melatonin production in young adolescents and children would be greater, leading to more sleep disruption and related physio-psychological effects. We know from Figueiro et al. (2011) that just a 2 hour exposure to LED screen tablets can result in a measurable, statistically reliable suppression of melatonin in young adults. They (ibid., p. 1437) point out that "Children and adolescents spend their leisure time in front of gaming consoles, televisions, and cell phones, and in fact, many adolescents do "multi-screening," which means that they use more than one screen at a time. If one assumes that they spend part of this time in front of a computer screen, particularly during the evening, this behavior and our results here could contribute to answering the question of why an increasing number of sleep problems, particularly delayed sleep phase, are reported for this age group." Further insights into the extent of this problem comes from a national survey in the United States which found that 8-to-18-year-olds spend an average of 7 hours and 38 minutes each day using electronic entrainment media, much of which is increasingly screen based. In contrast, the OECD (2015) reports that 15 year olds spend on average 2 hours a day online, up to a maximum of 4 hours. However, as the UK's communications regulator reports, 16-24 year olds spend over 27 hours per week online [3]. However, this has increased significantly, with media use estimated at 6 hours per day, not including school (see

A cause of sleep disruption?



Researchers recommend that screen time for young children and adolescents be limited to 1 hour after 5 pm.

Twenge Martin, and Spitzberg, 2018). Add to this 6 hours in class with an iPAD and that is up to 12 hours for some adolescents.

Wood et al. (2012) replicate Figueiro et al.'s findings using Apple iPads and suggest that exposure of less than 1 hour may not trigger melatonin decrease. However, as children and young adolescents differ physiologically and are more sensitive to such light sources, as indicated above, melatonin suppression may occur at lower levels of exposure. Thus, researchers recommend that screen time for young children and adolescents be limited to 1 hour after 5 pm. However, it must be remembered that the impact of screen use is cumulative across multiple screen sources. Hence, in light of the widespread use of screens, and the likelihood of a reduction in use to less than 1 hour remote, Wood et al.'s (2013, p. 240) advice "it is recommended that these devices be dimmed at night as much as possible in order to minimize

[3] http://stakeholders.ofcom.org.uk/binaries/research/media-literacy/media-lit-10years/2015_Adults_media_use_and_attitudes_report.pdf

melatonin suppression, and that the duration of use be limited prior to bedtimes."

Computer Vision Syndrome

In offering explanations for why screen media in an educational context are problematic, Mangan et al. (2013) point to the visual ergonomics of screens. I have already highlighted the problems that LED screen home use during the evening has for students' sleep disturbance and learning. However, LCD (Liquid Crystal Display) screens cause visual fatigue due to the fact that they project light. So do LED screens, which have generally replaced LCD screens. There is evidence that LED screens cause even more eye fatigue.[4] (I would at this point direct educators to the link below as it indicates how visual fatigue and sleep disturbing blue light can be addressed.) LED and LCD screen design features such as refresh rate, luminance contrast levels, fluctuating light, backlighting, and contrast contribute to eye strain and visual fatigue—this has become known as *computer vision syndrome* (Yan et al., 2008). *Computer vision syndrome* can have an indirect but significant effect on learning outcomes, as the factors that contribute to it affect the visual legibility of the text, and may have negative implications for higher-level processes such as comprehension. My article on this topic for the Sunday Times[5] advocated Digital Technology-based screens or e-readers, that used electronic ink, as they are light reflecting, as opposed to light emitting, technologies. Thus, budget Kindle and Kobo electronic ink-based eReaders do not cause the same type of eye strain and are the ideal platform for schools to provide e-books, PDF or otherwise, to students. However, even here there are problems where human cognition and learning is concerned.

That said, recent research revealed even more disturbing findings. In 2019, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) warned that "exposure to an intense and powerful [LED] light is 'photo-toxic' and can lead to irreversible loss of retinal cells and diminished sharpness of vision."[6] ANSES also found that. there is an increased risk of age-related macular degeneration after chronic exposure to lower-intensity sources, such as screens

Why is Digital Technology-enabled Learning Inferior to Traditional Methods?

It is interesting to note that the smart phone, tablet or iPad in your child's bedroom incorporates all of the major innovations in human communication and information transfer in the 19th and 20th century—mail (email), telegraph (instant messaging, Twitter, Instagram etc.), telephone (e.g. Skype, FaceTime), radio (e.g. Internet radio, iTunes, Spotify), personal photography, television (YouTube, Netflix), and the World Wide Web (WWW). Add to this social media applications (e.g. Facebook), and online gaming, all of which continue to evolve, integrate, and attract an ever-younger audience. Such innovations are powered by the Internet, with data typically stored in the Cloud. It is clear that since the survey by Rideout et al. in 2010 the way in which digital media is being accessed by children and young adolescents has changed and become more screen centric (cf. Figueiro et al. 2011; OECD, 2015). This has enormous implications for the current trend in using iPads and tablets in class and at home.

According to Spitzer (2014) there are risks and unforeseen consequences in using Digital Technology for education. He draws on extant research to illustrate these effects. Nevertheless, further analysis is required, as Professor Spitzer's evidence is based on mixed sources, many of which are secondary. His arguments are sound, however, and reflect his experience as a

[4] http://www.eizo.com/library/basics/eyestrain/

[5] Tom Butler "Learn by the book, not apps" Sunday Times, Think Tank article, September 9th 2012.

[6] https://medicalxpress.com/news/2019-05-eyes-health-authority.html

The pen is mightier than the keyboard

Students who take written notes in class are better able to answer questions on the lecture content than those who used laptops and touch-typed their notes verbatim…*"when laptops are used solely to take notes, they may still be impairing learning because their use results in shallower processing."*

Mueller and Oppenheimer (2014, p. 1)

researcher in the OECD's Centre for Research and Education and founder and Head of Department at the Psychiatric Hospital, University of Ulm (Universitätsklinik für Psychiatrie), Germany. In setting out his thesis, his first proposition is that typing on a keyboard impairs reading and writing in students and which, in turn, impairs learning and memory. There is scientific evidence for this, which I will now elaborate.

The Pen is Mightier than the Keypad

The embodied, as opposed to embrained, nature of human cognition is not generally recognised. Our five senses act to capture data about the world. But how we act and express what we know, or are in the process of knowing, also affects how we learn. Spitzer (2013, p. 95) states that "the hand is not just an implement for grabbing but also a sense organ. Whenever we hold something, the hand sends sensations of touch and pressure as well as information about the position of the joints to the brain, where these sensations are combined with what we see, and sometimes hear (as in music performances)…most tasks involving movements are guided by the sensorimotor centers in our brain. In short, the arms of modern robots are tactile-mechanical idiots when compared to the hands of preschool children." The act of writing plays a pivotal role in learning. Typing keys on a keyboard does not have the same effect. Writing and typing involve different cognitive-neurological processes and outcome in terms of neural circuitry. Edouard Gentaz, Professor of Developmental Psychology, University of Geneva states that "Handwriting is a complex task which requires various skills – feeling the pen and paper, moving the writing implement, and directing movement by thought….Children take several years to master this precise motor exercise: you need to hold the scripting tool firmly while moving it in such a way as to leave a different mark for each letter."[7] Pressing a key on a keyboard is not the same as writing the same letter on paper (on an iPad with a stylus). Pressing keys are tasks that children learn very quickly, but there is little involved in terms of the amount of brain circuitry created as a result in comparison to that created when writing letters or numbers.

A study by Longcamp et al. (2008, p. 802) confirmed earlier experiments (Longcamp et al., 2005) in that "results provide strong arguments in favor of the view that the specific movements memorized when learning how to write participate in the visual recognition of graphic shapes and letters." Their experiments illustrate that if a child learns to write by hand, they will recognise letters better than if they learned how to type (Longcamp et al., 2005). The latter experiment was carried out on adults and it was found that "the stability of the characters' representation in memory depends on the nature of the motor activity

[7]http://www.theguardian.com/science/2014/dec/16/cognitive-benefits-handwriting-decline-typing. This section draws on this article which was published in the Guardian Tuesday 16 December 2014. Accessed 29-08-2015.

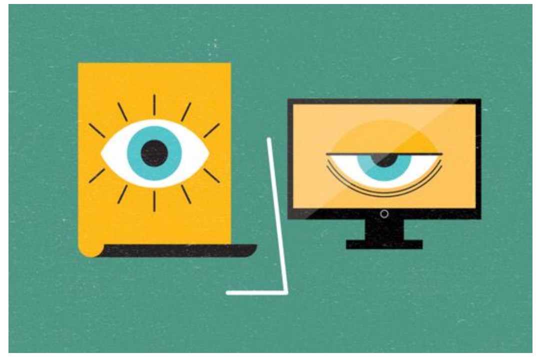
produced during learning"—this confirms the results of studies that illustrate the significant advantages of writing over typing for learning (Longcamp et al., 2006, p. 646). The results of these studies are supported by other experiments. James and Engelhardt (2013) studied how preliterate five-year old children printed, typed, or traced letters and shapes. They were then shown images of the letters and shapes while undergoing a functional MRI scan. This (ibid, p. 32) illustrated that a "previously documented "reading circuit" was recruited during letter perception only after handwriting—not after typing or tracing experience. These findings demonstrate that handwriting is important for the early recruitment in letter processing of brain regions known to underlie successful reading. Handwriting may therefore facilitate reading acquisition in young children."

It is clear from this study that learning to write letters helps them to be perceived better in comparison to just typing them. Thus, Professor Gentaz[6] holds that writing letters by hand helps improve a child's (or adult's) grasp of an alphabet as humans have a "body memory". Gentaz adds that "Some people have difficulty reading again after a stroke. To help them remember the alphabet again, we ask them to trace the letters with their finger. Often it works, the gesture restoring the memory." The decline in handwriting is therefore disturbing and may have long-term implications for students learning outcomes (Carter and Harper, 2013). These studies provide important insights into the limitations of laptops and tablets in education. A recent study provides unequivocal evidence in terms of laptop use by students for note-taking and achieving learning outcomes.

Using Laptops in Class is Detrimental to Learning Outcomes

In a large controlled study, whose objective it was to find out if laptop use by students in lectures negatively impacted learning outcomes of students taking notes on paper in the same class, Aguilar-Roca et al. (2012) made a surprising discovery. There was a correlation between learning outcomes and how students took notes in class. Students who wrote notes on paper "scored significantly higher and laptop users scored significantly lower than predicted by pre-class academic indicators ($p < 0.01$, paired t-test)" (ibid. p. 1300). It was left to a later study to determine if laptop use was correlated with, or causative of, negative learning outcomes. In *The Pen Is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note*, Mueller and Oppenheimer (2014) report on three studies they conducted on college students from Princeton University and at the University of California, Los Angeles: Study 1 included 67 students; Study 2 involved 151 students; and Study 3 involved over 300 students. This research found that that students who took written notes in class were better able to answer questions on the lecture content than those who used laptops and touch-typed their notes in verbatim. Mueller and Oppenheimer (2014, p. 1) state that: "The present research suggests that even when laptops are used solely to take notes, they may still be impairing learning because their use results in shallower processing. In three studies, we found that students who took notes on laptops performed worse on conceptual questions than students who took notes longhand. We show that whereas taking more notes can be beneficial, laptop note takers' tendency to transcribe lectures verbatim rather than processing information

Paper vs. Screen-based Learning



"Subjects who read the texts on paper performed significantly better than subjects who read the texts on the computer screen"

Mangen et al. (201, p. 65)

Which approach produces better learning outcomes?

There is a significant advantage of writing notes over typing for learning outcomes.

and reframing it in their own words is detrimental to learning." Hence, students who take written notes summarize, synthesize, rephrase or paraphrase what the lecturer is saying in their own words. To do this they must first pre-process the information in order to summarise it—this also appears to have the effect of enhancing comprehension.

In contrast, students who typed in notes often making literal transcriptions of what the lecturer was saying and generally did not pre-process information to the same degree. Mueller and Oppenheimer (ibid., p. 8) illustrate that "laptop use can negatively affect performance on educational assessments, even—or perhaps especially—when the computer is used for its intended function of easier note taking." This study has been confirmed by several others, notably one by Frangou et al. (2018) which found that handwriting led to better recollection of dictated stories 30 minutes and then 7 days later. Another study by Morehead, Dunlosky, and Rawson (2019) found only a marginal increase for handwriting when both groups of students studied their notes. A study by Kennedy (2019) demonstrated unequivocally, however, that "student performance on exams and in the course increased within the electronics free classroom, especially for students at the lower end of the grading scale."

In a direct comparison between hand writing and tablet use Arreola et al. (2019) "indicated that although all tablet features were available (e.g., swiping, voice recording), participants engaged in less cognitive offloading when using tablets compared to paper, and this resulted in lower recall performance for the tablet condition." Note takers engage in cognitive offloading to reduce short-term memory demands (Arreola et al. 2019).

One important point bears mention. All the forgoing studies were on university students, who, in all probability had learned to write in the traditional way. The importance of hand writing proficiency is underpinned in a recent study by Feng et al.(2019) which emphasized the importance of handwriting development to the overall development of writing on any media. Thus, ceteris paribus, children and adolescents need to have their handwriting and note-taking skills honed and perfected, if they are to take full advantage of the digital world.

The findings of Fisher and Frey (2018) bear consideration here: "the brain preferred paper for some complex tasks. To be sure, adolescent and adult learners need instruction and experience with navigating and comprehending digital texts and in using digital note-taking in optimal ways. These technologies offer many benefits, including efficient search and sort functions and annotation and mark-up tools, to say nothing of the portability and convenience. After all, a digital reader can hold 100 books, a veritable library that can travel nearly anywhere. A productivity app allows a learner to organize notes in ways that are nearly impossible when written on paper. An informed user is able to optimize tools, choosing those that best fit the purpose. However, it is impossible to provide information to our students about the relative benefits and drawbacks of paper and digital formats if we are ourselves unaware."

My conclusions here are that digital media are vital for processing large volumes of data. However, for that data to become information, children and adolescents need to exercise the relationship between hand

and brain, to engage in the haptics of writing (Mangen et al., 2015).

We Learn Better through Paper than Screens

If capturing information using screen-based applications produces inferior learning outcomes for students, what about reading from screens? There are several ways in which information may be presented on screens—as plain text, such as in PDF format, or in hypertext, whether in HTML or other presentation formats. In looking at the typical way information is displayed on screens from the web—hypertext versus traditional text formats, DeStefano and LeFevre (2007, p. 1616) found that "the increased demands of decision-making and visual processing in hypertext impaired reading performance. Individual differences in readers, such as working memory capacity and prior knowledge, mediated the impact of hypertext features. For example, readers with low working memory and low prior knowledge were usually disadvantaged in hypertext." They (ibid., p. 1636) stated that "there was considerable evidence that at least some features of hypertext can lead to poorer performance compared to traditional linear presentation and that the reduced performance was linked to cognitive load." In sum, reading hypertext increases cognitive demands on student's decision making and visual processing, which impairs reading as it increases the cognitive load on the reader.

A study by Ackerman and Goldsmith (2011) is particularly interesting in this regard. Comparing reading performance from On-Screen Learning (OSL) and On-Paper Learning (OPL), the authors found that under fixed study time (Experiment 1), test performance did not differ significantly. However, when study time was self-regulated (Experiment 2), poorer performance was observed in screen reading than in paper reading. The lower test performance of OSL was accompanied by significant overconfidence with regard to predicted performance (shorter study time + lower level of actual learning), whereas subjects in the OPL group monitored their performance more accurately. Ackerman and Goldsmith (2011, p. 29) conclude that people appear to perceive the medium of print as more suitable for effortful learning, whereas the electronic medium (in this case, a computer) is better suited for ''fast and shallow reading of short texts such as news, e-mails, and forum notes [. . .]. The common perception of screen presentation as an information source intended for shallow messages may reduce the mobilization of cognitive resources that is needed for effective self-regulation''.

As Mangen et al. (2013) point out, hypertext is not the only way to represent digital text on a screen for educational purposes—other formats, such as PDF are also in use. The question they pose is, 'Whether this too has a negative effect on ease of reading and comprehension?' In order to answer this, Mangen et al. conducted a field experiment with 72 tenth graders (15-16 year olds) in two primary schools in Norway. The participating students were randomly selected and placed into two groups. One group read two 1400–2000 word texts in print, while the other read the same texts as PDF on a screen. Subjects were pretested in reading comprehension, word reading and vocabulary. Mangan et al. (ibid., p. 65) found that "Subjects who read the texts on paper performed significantly better than subjects who read the texts on the computer screen" in PDF.

Recent research by Haddock et al. (2019) corroborates these findings and is summarized thus: "In Study 1, participants read a traditional- or modern-themed short story from either a book or an e-reader…Story comprehension was greater when participants read from the printed medium compared to the e-reader. In Study 2, participants read a persuasive message that emphasized either a traditional versus modern solution to improving health in either a magazine format or on an iPad. Message comprehension was marginally greater among participants who read their message in a printed format." Here again is evidence of the superiority of paper over digital print where learning is concerned (see the review paper by Kong, 2018, which provides additional support).

In my field research I regularly engage with international law and professional services firms. The common refrain among partners in these companies is that law graduates and post-graduates no longer can read deeply. They also do not appear to be able to problem-solve beyond Google searches. Males appear to be most affected here, as one senior lawyer informed me that he employs more female than male junior lawyers, as female junior lawyers are more attentive to detail in reading legal texts.

Professor Maryanne Wolf, Director of the Center for Dyslexia, Diverse Learners, and Social Justice at UCLA, explains why we are witnessing these trends in her book *Reader Come Home*. She states that "As work in neurosciences indicates, the acquisition of literacy necessitated a new circuit in our species' brain more than 6,000 years ago. That circuit evolved from a very simple mechanism for decoding basic information, like the number of goats in one's herd, to the present, highly elaborated reading brain. My research depicts how the present reading brain enables the development of some of our most important intellectual and affective processes: internalized knowledge, analogical reasoning, and inference; perspective-taking and empathy; critical analysis and the generation of insight. Research surfacing in many parts of the world now cautions that each of these essential "deep reading" processes may be under threat as we move into digital-based modes of reading."[8]

She continues, providing an answer to the question that plagues educators in universities no less than partners in law and professional services firms:

> "Increasing reports from educators and from researchers in psychology and the humanities bear this out. English literature scholar and teacher Mark Edmundson describes how many college students actively avoid the classic literature of the 19th and 20th centuries because they no longer have the patience to read longer, denser, more difficult texts. We should be less concerned with students' "cognitive impatience," however, than by what may underlie it: the potential inability of large numbers of students to read with a level of critical analysis sufficient to comprehend the complexity of thought and argument found in more demanding texts, whether in literature and science in college, or in wills, contracts and the deliberately confusing public referendum questions citizens encounter in the voting booth."

It is clear that the use of digital devices in primary and secondary education presents a real risk to the development of children. This conclusion is supported in a recent study based on data from 31 participants in the Programme for the International Assessment of Adult Competencies (PIAAC) 2011 to 2015. Here, Sikora, Evans, and Kelley (2019) provide evidence to support the central conjecture of scholarly culture theory "that immersing children in book-oriented environments benefits their later educational achievement, attainment and occupational standing" and this "equips youth with life-long tastes, skills and knowledge."

Digital Technology Use in Class and Student Distraction

There is a significant body of evidence that smart phones, iPads, laptops etc. cause a range of cognitive and psychological disorders in users, including students. Spitzer (2013), for example, argues that students use of computers (smart phones, iPads, laptops etc.) in WiFi-enabled in lecture rooms increases student distraction and shortens their attention spans. Thus, the use of laptops and other screen-based media in classrooms is increasingly controversial (Yamamoto, 2007).

A mixed method study of 3000 students by Ragan et al. (2014) applied a combination of

[8]https://www.theguardian.com/commentisfree/2018/aug/25/skim-reading-new-normal-maryanne-wolf

student surveys and in-class observations to investigate how students use their laptop in classes where laptop use is unmonitored and unrestricted. The findings indicate that note taking and browsing social media websites was the most common use for the computers by students. Significantly the findings illustrated that students engaged in off-task computer activities and using social media 66% of the time in class (cf. Junco, 2012; Tallvid et al., 2015). A wealth of studies provide evidence that students using laptops etc. are typically not on-task during lectures (Kay and Lauricella, 2011; Sovern, 2013). It is no surprise then that educators believe that the internet and all forms of screen media in class, not only laptop computers, serve as distractions in educational settings, as students fail to engage in class discussion and learning (cf. Yamamoto, 2007; Junco, 2012; Ravizza et al. 2014).

Other studies show decreased academic performance as a result of off-task computer activities (Kraushaar and Novak, 2010; Wood et al., 2012). Consequently, Wurst et al. (2008) find laptop-using students are less satisfied with their education than their pen and paper note-taking peers. Thus, studies consistently report that "participants who did not use any technologies in the lectures outperformed students who used some form of technology" (Wood et al., 2012, p. 365).

Research also indicates that those using computers in class affects other students' performance viz. "participants who multitasked on a laptop during a lecture scored lower on a test compared to those who did not multitask, and participants who were in direct view of a multitasking peer scored lower on a test compared to those who were not. The results demonstrate that multitasking on a laptop poses a significant distraction to both users and fellow students and can be detrimental to comprehension of lecture content" (Sana et al., 2013, p. 34).

The Growing Problem of Multitasking

Distraction is not the only issue, also of import are the related negative effects of multi-tasking (Crenshaw, 2008; Rosen, 2008). Both are among the growing disorders to afflict students at all levels. I produce this quote from Beaulieu and Sharpe (2015, p. 4) on a keynote speech by Taylor (2014) liberally to illustrate the problems of distraction and multitasking

> "One of the greatest obstacles preventing young people (and adults) from effectively focusing today is multitasking. Taylor offered this analogy: whereas intentional focusing is more like scuba diving, where one goes deep and is in the moment, multitasking is like jet skiing, or going fast at the surface. But Taylor stressed that multitasking is a myth; the human brain is really a single-core processor. Although many of us think we are good "multitaskers" and it is a sought after skill in our society, multitasking is really just spreading our ability to single-task across a variety of tasks, which makes the completion of any one task more difficult. According to Dr. Taylor (2014), we need to teach young people how to single-task. When we single-task, we are focused on one specific activity at a time, giving our entire attention and energy to the task at hand. This allows us to be more efficient in our work, decreases our stress levels, and actually improves our time management."

Multi-tasking is epidemic in a digital age. Levintin (2015) provides evidence from

We can't multitask and neither can children

"Even though we think we're getting a lot done, ironically, multitasking makes us demonstrably less efficient."

Levintin (2015, p. 96)

research in neuroscience and cognitive psychology to illustrate not only the extent, but the physiological and psychological effects, on users, particularly those related to technology use and abuse the digital age. He (ibid., p. 96) states that "Although we think we're doing several things at once, multitasking, this is a powerful and diabolical illusion. Earl Miller, a neuroscientist at MIT and one of the world experts on divided attention, says that our brains are "not wired to multitask well… When people think they're multitasking, they're actually just switching from one task to another very rapidly. And every time they do, there's a cognitive cost in doing so."… Even though we think we're getting a lot done, ironically, multitasking makes us demonstrably less efficient." Sundem (2012) echoes these findings and points out that just 2% of people can multitask efficiently—meaning, of course, that 98% of people cannot. However, this research is silent on physiological effects of multitasking, which are significant.

Why Humans can only Single-task: A Computer Analogy

The single-core processors found in previous generations of computers, and referred to by Taylor above, multitask very well. Or they give that illusion, as they too switch between tasks. The difference between computers and humans is that the former were engineered by the latter, so they are efficient are what they do, as peripheral sub-systems around primary and secondary memory and input-output operations can store and transfer data independently. However, the core of such computer systems, the central processing unit (CPU) can only execute one instruction at a particular instant in computer time called a clock cycle. Computer scientists have, however, designed subsequent multi-core CPUs to execute 2, 4, 6, 8, 12, 16 and more instructions in parallel for every clock cycle serving multiple users. This is true computational multitasking, thus making computers more powerful in performing certain complex data manipulations than human beings. Make no mistake, the human brain is still a more powerful computer; however, it does have limitations, which are not generally recognised.

The Single-tasking Brain

The problems being experienced by students in, and the limitations of, multitasking is down to the basic design of the human brain. Unlike a CPU, the human brain evolved over hundreds of thousands of years to its present form, which is little different than that of our Stone Age ancestors. Carr (2010) points out, for example, that the architecture of the human brain has not changed in 40,000 years. It may seem astonishing that this Stone Age Brain has achieved so much in a relatively short period in the earth's existence. As Levitin (2015) illustrates, the brain is complex in structure and resembles a building that has been modified and extended randomly during its pre-historic evolution to fit inside the average human skull. Think of a stone-age hut, onto which other structures have been layered, attached, extended, and folded in on top themselves.

I often read, or hear advocates of technology opine, that the human brain will evolve to overcome problems like distraction and multitasking. In the future, the digital mythmakers proclaim, students will master and overcome our present day limitations as their brains will evolve with the advances in technology. It has taken nature eons of random genetic mutations and the process of natural selection—the survival of the fittest mutations—to get where we are today. It is pure fantasy and downright delusional to think that the short-lived digital age will produce the type of system-level change required to add the brain's equivalent of the processing capabilities of even one CPU, let alone the 4 CPUS required by students to listen to teachers, update their Facebook page, answer emails, and read Tweets on Twitter, all at the one time, successfully. In addition, it must be noted, the brain's equivalent of primary, secondary, tertiary and on-line storage would need to evolve to support information processing. The social, cultural, and scientific advances made by humans is down to the brain's plasticity, not elasticity, as Carr (2010) points out.

Digital Technology and the Brain

Recent research has highlighted that Digital Technology use is having profound negative effects on the functioning of the human brain, particularly in terms of cognition, memory, brain chemistry, and so on (Levitin, 2015). This is not a trivial matter, as we have seen above with respect to the phenomena of distraction and multitasking. Thus, while Hinkley et al. (2014) found that the overuse of Digital Technology by children is a good predictor of poor general well-being, the source of related health and psychological problems are to be found in Digital Technology's negative effects on brain development and function. Take, for examples, Maass et al. (2015) indicate that Digital Technology use impairs cognitive performance, while Ziegler et al. (2015) illustrate the acute and chronic impact of Digital Technology on the brain. These topics receive extensive treatment in Levitin (2015). However, my point of departure here comes from Carr's (2010) thoughts on brain plasticity.

Learning and Brain Plasticity

Our understanding of brain plasticity is relatively new (Kolb and Whishaw, 1998). We now know that the brain can adapt and the mind can learn throughout a person's life—learn new languages, new ways of doing things, change careers, change our 'minds', and re-wire and repair our brains, when damaged through stroke or physical injury (Kolb, 2013; Ramachandran, 2012). If you think of the range of human, linguistic, artistic and cultural diversity, we get some idea of the adaptive and plastic nature of the human brain.

Two important points need to be made at this juncture. First, the possibilities for human learning and advancement provided for by brain plasticity and adaptability referred to above takes place within the overall architecture of the human brain as it has presently evolved. Thus, the physical limitations of the brain's architecture place limits on what is possible. Second, as Kolb (2013) points out, while many view plasticity and the remodelling of neural circuitry as positive, in that the adaptations are functionally beneficial, such changes may also be negative, and where the remodelling of neural circuitry leads to dysfunctional and pathological behaviours. As Carr (2010, p. 34-35) concludes "Bad habits can be ingrained into our neurons as easily as good ones" as "neuroplasticity has been linked to mental afflictions ranging from depression to obsessive-compulsive disorder to tinnitus."

Neural addiction in action

"Make no mistake: Email, Twitter, and Facebook checking constitute a neural addiction."

Levitin (2015, p. 101)

Furthermore, Doidge (2007) indicates that pathological behaviours wired into the brain's circuitry can overwrite those that produce good behaviours. Hence, the concerns regarding the problems of distraction and multi-tasking wrought by new types of Digital Technology, which involve physical rewiring of brain circuitry. However, that is not the only effect, as indicated by Levitin (2015).

Digital Technology, Brain Chemistry, and Neural Addiction

Technology-based multitasking increases the production of cortisol and adrenaline—the former is the stress hormone and the latter the fight-or-flight hormone. This is a potent chemical cocktail that can overstimulate a student's brain, reduce clarity of thought, and produce muddled thinking. Levitin (2015, p. 96) also illustrates how multitasking results in a "dopamine-addiction feedback loop, effectively rewarding the brain for losing focus and for constantly searching for external stimulation."

Distraction plays a key role here as the brain's prefrontal cortex is biased to search for novel stimuli—consequently, a student's attention can be easily drawn to something new. Thus, reading a hypertext document a student may come across a link to a novel topic and thereby follow it increasing cognitive load (DeStefano and LeFevre, 2007). This explains why some students end up being distracted by the promise of novel links and switch from the difficult task of learning. Not every form of multitasking involves the production of potent chemicals. Normally when students study, information is processed in the brain's hippocampus region; here the information is organised and categorised to make it easy to retrieve. However, if the student is watching TV while studying, the information being studied ends up the striatum which specialises in storing new skills and techniques and skills, as opposed to the specific concepts being studied.

The ultimate consequences of all this is described by Levitin (2015, pp. 96-97), who points out "the very brain region we need to rely on for staying on task is easily distracted. We answer the phone, look up something on the internet, check our email, send an SMS, and each of these things tweaks the novelty- seeking, reward-seeking centres of the brain, causing a burst of endogenous opioids (no wonder it feels so good!), all to the detriment of our staying on task." This not just habit forming, Levitin (2015, p. 101) puts it thus "Make no mistake: Email, Twitter, and Facebook checking constitute a neural addiction." However, the addictive nature of technology does not end here.

The rise of Internet Addiction Disorder

"Children are more susceptible to developing a long-term problematic dependency on technology."

Sigman (2014, p. 610)

Internet Addiction Disorder and other Problems

Building on research on screens and sleep problems, Wood et al. (2013, p. 240) offer the following additional insights viz. "it is important to acknowledge that usage of selfluminous electronic devices before sleep may disrupt sleep even if melatonin is not suppressed. Clearly, the tasks themselves may be alerting or stressful stimuli that can lead to sleep disruption." The question that begs to be answered here is that LED induced melatonin suppression aside, how could using screens lead to sleep disruption? The answer lies not in the screen per se, but the applications presented on-screen. A recent study by Rosen et al. (2013) illustrates the potential links between clinical symptoms of psychiatric disorders and Digital Technology use where Facebook is concerned. However, Rosen et al. (2014, p. 364) argue that Digital Technology use is a predictor of "ill-being among children, preteens and teenagers independent of the negative health impacts of exercise and eating habits.” This gives rise to the existence of iDisorders.

Spitzer (2013) indicates the existence of IT-addiction in up to almost 20% of students—this has been confirmed across several studies. In their review paper, Weinstein et al. (2014) illustrate that Problematic Internet Use (PIU) or Internet Addiction Disorder (IAD) have emerged over the over the past 16 years. They identify four basic forms of IAD: The first related to on-line gaming, the second online gambling, the third related to cybersex and pornography, and the fourth includes social networking, e-mailing and messaging. According to Sigman (2014) discretionary Screen Time (ST) is now the norm for children in the developed world. In his review article for general practitioners in the UK, he argues, based on the significant body of evidence adduced on its ill-effects, that ST is a lifestyle factor on the level of nutrition and physical activity. As with the findings of research presented herein, high levels of ST is now considered an independent risk factor in heart disease, poor development outcomes among children, adult disease, and untimely death.

Sigman (2014) cites several studies which illustrate that high ST is in the range of 2–20%, depending on activity. In a large study of computer gaming among 8–14-year-olds it was found that up to 9.9% of children fall into the category of pathological gamers. Another British study revealed that over 50% of the students’ produced scores high on the Internet Addiction Test (IAT) which indicated problematic non-pathological behaviour patterns. Sigman (ibid., p. 610) states that “There is significant comorbidity between, for example, pathological internet use and depression or attention deficit hyperactivity disorder (ADHD) symptoms. Patients presenting with dependent screen use as a primary problem should be screened for associated comorbidities.” Worryingly, he concludes that “Children are more susceptible to developing a long-term problematic dependency on technology” (cf. Kuss et al., 2014).

Is online learning effective?

“Despite what appears to be strong support for blended learning applications, the studies in this meta-analysis do not demonstrate that online learning is superior as a medium.”

Means, et al. (2010, p.xviii)

Islands of Success in an Ocean of Failure?

In his recent commentary on the use of information and communication technologies (Digital Technology) in education, Larry Cuban [9] states that “[s]ince 2010, laptops, tablets, interactive whiteboards, smart phones, and a cornucopia of software have become ubiquitous. Yet has academic achievement *improved* as a consequence? Has teaching and learning changed? Has use of devices in schools led to better jobs? These are the basic questions that school boards, policymakers, and administrators ask. The answers to these questions are “no,” “no,” and “probably not.”” Professor Cuban has conducted research in the use of technology in education for over 30 years and concludes that there is no scientific evidence that Digital Technology-enabled education has enhanced teaching or is producing superior learning outcomes (cf. LeBaron and McDonough, 2009; Livingstone, 2012; OECD, 2015). Nevertheless, Don

[9] https://larrycuban.wordpress.com/2015/02/05/the-lack-of-evidence-based-practice-the-case-of-classroom-technology-part-1/

Passey Professor of Technology Enhanced Learning at Lancaster University in the UK illustrates in his study "*Inclusive technology enhanced learning"* (Passey, 2013) that some measure of success is evident in particular areas. Mainly positive in information search, and negative in other key areas, resulting in a null effect (Falck, Mang, and Woessmann, 2018). However, studies consistently find that "that computer use in college classrooms has a negative impact on course grades. [Furthermore]… students who are induced to use computers in class perform significantly worse… We find that the negative effects of computer use are concentrated among males and low-performing students and more prominent in quantitative courses (Patterson and Patterson, 2017, p. 66).

Consequently, and generally speaking, results in applying Digital Technology to improve learning outcomes remain mixed, with successful outcomes rare and heavily contingent on a web of institutional and social conditions and factors, which are more often than not ignored by policymakers, school administrators, principals, teachers, parents and pupils (cf. OECD, 2015; Mourshed, Krawitz, and Dorn, 2017). These points are underpinned by Burch et al. (2014) who report that Digital Technology has no effect on student learning in some studies, while others report positive effects, contingent on certain factors which include consistent contact between students and teachers, with regular feedback for teachers, and high levels of access to computers by students. We now examine a number of such studies to illustrate the type of conflicting results reported in the literature.

One much cited study found that students who *occasionally* use computers and/or the internet at school have better learning outcomes than those who do not (Fuchs and Woessmann, 2004). Furthermore, while these researchers report that there is a positive correlation between learning outcomes and the overall computer use, "once we control extensively for family background and school characteristics, the relationship gets negative for home computers and insignificant for school computers. Thus, the mere availability of computers at home seems to distract students from effective learning" (Fuchs and Woessmann, 2004, p. 1).

Research reported above explains the effects of distraction on students. Taking a different tack, researchers in the US formed the hypothesis that *if the majority of children come from low-income and minority families, and as such have limited access to computers, then their educational achievement should be impeded*. In one of the largest field experiments of its type, 1,123 children from ages 6-10, from 15 schools in California, were provided with free computers for home use (Fairlie and Robinson, 2013). The study found that despite the increase in computer use, there were no improvements observed in "educational outcomes, including grades, standardized test scores, credits earned, attendance and disciplinary actions" of students. We can conclude from this that computer use in the home is problematic. Thus, a further question mark is raised over the use of iPads, e-books, etc.

A meta-analysis of over a thousand studies on online learning between 1998-2008 by Means, et al. (2010, p. ix) for the US Department of Education found that "When used by itself, online learning appears to be as effective as conventional classroom instruction, but not more so." This effect was found to be larger in situations where blended learning included both online and face-to-face instruction. However, Means et al. (2010, p. ix) state that "these blended conditions often included additional learning time and instructional elements not received by students in control conditions. This finding suggests that the positive effects associated with blended learning should not be attributed to the media, per se." Thus, additional interactions between tutors and students appear to account for the enhanced learning outcomes. Means, et al. (2010, p.xviii) conclude that "Despite what appears to be strong support for blended learning applications, the studies in this meta-analysis do not demonstrate that online learning is superior as a medium."

This is a significant finding that puts into question the evidence for a moderately better positive learning benefit for online learning. An explanation for this comes from Professor Sonia Livingstone (2012, p. 9) who states that the meta-analysis "did not control for curriculum content, aspects of pedagogy or learning time." Livingstone also points out that the study illustrates learning outcomes were not improved when online learning solutions included additional media such as videos and/or online quizzes. However, learning outcomes appear to be improved when educational technologies that "trigger learning activity or learner reflection and self-monitoring of understanding" are present (Means et al. 2010, p. xvi). Furthermore, in studies that showed a modest advantage for online learning there were significant differences between the online- and lecture-based courses in terms of course length, curriculum and pedagogy. Means et al. also fail to specify the combination of features that would have contributed to the enhanced learning outcomes reported in online studies. They (ibid., p xviii) also pointed to the fact that "many of the studies suffered from weaknesses such as small sample sizes; failure to report retention rates for students in the conditions being contrasted; and, in many cases, potential bias stemming from the authors' dual roles as experimenters and instructors." However, another problem is that the generalizability of the findings to primary and secondary students is questionable, as the vast majority of the studies focused on career technology training, medical and university education, in addition to corporate and military training.

Advocates of online education, Massive Open Online Courses (MOOCs) and educational technology would argue that things have moved on since 2008, which was the year that the studies reviewed by Means et al. (2010) ended. Evidence presented above, would suggest, however, that the use of computers for online learning outside the classroom may be leading to inferior learning outcomes for students. Certainly there are higher drop-out rates for online courses than traditional programmes and little in the way

Too much of a good thing?

"Yes, I did the book report myself. I found it on eBay myself, I bid on it myself, I paid for it myself, I printed it myself..."

On an OECD PISA study, Students, Computers and Learning: Making the Connection, Andreas Schleicher, OECD Education Director reports that "The results also show no appreciable improvements in student achievement in reading, mathematics or science in the countries that had invested heavily in information and communication technology (ICT) for education."

of learning at all if the low completion rates for MOOCs are anything to go by (Kizilcec and Halawa, 2015). Sinclair et al. (2015) report dropout rates from MOOCs are over 90%. Stein and Allione (2014) found a higher dropout rate for college students and adolescents. Stein and Allione stated that their findings are consistent with the existing literature to the effect that students can be classified into two groups—committed learners and browsers, with browsers in the majority.

The cornerstone of many online learning courses is the video lecture. But there are fundamental problems here too. Szpunar et al. (2014, p. 161) examine "how well students think they will perform on a later assessment associated with learning from a video-recorded lecture". They cite previous research which indicates that students overestimate their understanding of lecture topics when presented via video. This overconfidence has a negative impact on long-term retention of subject matter and learning outcomes, as students tend not to re-study, or refresh their understanding, which leads to poor academic performance. As with all other forms of Digital Technology, Yousef et al. (2014) report that there are conflicting results from video-based learning. However, it does appear to have a place in a blended approach when integrated with traditional methods.

The Mythical New Age of Digital Technology in Education

Advances in educational technology are championed by many as heralding a 'mythical new age' in computer-based instruction. However, advocates and acolytes alike appear to be losing patience in the progress towards a Digital Technology-based educational nirvana. Take, for example, that Colin Latchem, Asia-Pacific Corresponding Editor of the British Journal of Educational Technology, complained recently that "the revolution is always about to happen" (Latchem, 2014, p. 5).

Hence, Selwyn (2015, p. 250) points out, "the academic study of technology and education continues to be blighted by a prevalence of what Duncan-Andrade (2009, p. 184) terms 'hokey hope' (i.e. a naïve view that somehow things will get better, despite the lack of evidence to warrant this view) accompanied by a fair amount of 'mythical hope' (i.e. a "profoundly ahistorical and depoliticized denial of suffering that is rooted in celebrating individual exceptions")" (cf. Ornellas and Sancho, 2015). Thus, the overall subtext of the highly informative collection of papers in *Critical Perspectives on Technology and Education* is one of critical hope—a well-intentioned anticipation that somehow EdTech might deliver on its promise (Bulfin et al., 2015). The OECD (2105) report, discussed below, is a fine example of 'hokey hope' in action. Hope, however, springs eternal, and an indication of where the problem lies comes from King et al. (2014). Their thesis (ibid., pp. 9-10) is that the problems lie at a fundamental level which should prompt EdTech "developers and policy-makers to ask 'what type of software works, in which conditions and for whom?'"

The final word on this comes from Andreas Schleicher, OECD Education Director, who on the 15th September 2015 participated in an article for the BBC titled, *School technology struggles to make an impact*[10]*.* The article is based on the most recent study from the OECD Programme for International Student Assessment (PISA), *Students, Computers and Learning: Making the Connection* (OECD, 2015). Limited as it is to 15 year old adolescents, PISA provides a comprehensive international analysis on the use of Digital Technology in and for education. I reproduce the following in its entirety as the implications are disturbing, but reflect the many points made above:

> "Even where computers are used in the classroom, their impact on student performance is mixed at best. Countries with the best results are more moderate users of technology in school, says the OECD education expert. Students who use computers moderately at school tend to have somewhat better learning outcomes than students who use computers rarely. But students who use computers very frequently at school do a lot worse in most learning outcomes, even after accounting for social background and student demographics. The results also show no appreciable improvements in student achievement in reading, mathematics or science in the countries that had invested heavily in information and communication technology (Digital Technology) for education. And perhaps the most disappointing finding is that technology seems of little help in bridging the skills divide between advantaged and disadvantaged students. Put simply, ensuring that every child attains a baseline level of proficiency in reading and mathematics seems to do more to create equal opportunities in a digital world than expanding or subsidising access to hi-tech devices and services. Last but not least,

[10] http://www.bbc.com/news/business-34174795
Accessed 15-09-2015.

> most parents and teachers will not be surprised by the finding that students who spend more than six hours on line per weekday outside of school are particularly at risk of reporting that they feel lonely at school, and that they arrived late for school or skipped days of school in the two weeks prior to the Pisa test."

These findings are startling and should have policy makers, school administrators and parents reconsider the unthinking use of Digital Technology in the classroom and the home.

But the same OCED report holds out hope, of the 'hokey' variety. It argues that "*Despite the many challenges involved in integrating technology into teaching and learning, digital tools offer a great opportunity for education. Indeed, in many classrooms around the world, technology is used to support quality teaching and student engagement, through collaborative workspaces, remote and virtual labs, or through the many Digital Technology tools that help connect learning to authentic, real-life challenges"* (OECD, 2015, p. 191). Chapter 8 in the report ends by implying that the failure of Digital Technology to make good on its promise to enhance learning outcomes is in fact failed people—"teachers, school leaders and other decision makers" who obviously lack "the vision, and the ability, to make the connection between students, computers and learning" (cf. Mourshed, Krawitz, and Dorn, 2017).

All this indicates a root and branch rethink in extant thinking and approaches as indicated by Martin Weller's (2018) review and conclusions. "When we look back twenty years, the picture is mixed. Clearly, a rapid and fundamental shift in higher education practice has taken place, driven by technology adoption. Yet at the same time, nothing much has changed, and many edtech developments have failed to have significant impact. Perhaps the overall conclusion, then, is that edtech is not a game for the impatient." Similarly Roderic Crooks (2018) concludes that: "Just as the promise that computers will radically change education for the better has persisted for decades, so too have constant, bitter reports of the failure of computers to make good on this promise."

Education about Technology

My first experience on the other side of the classroom began as a Field Training Officer in the Irish Department of Posts and Telegraphs in 1980. Here I devised a new curriculum for Trainee Technicians in Digital Technology-based telecommunications systems. The objective was to provide trainees with applied competencies. My experiences here shaped my approach as a university lecturer when I began teaching operating systems and data communications at undergraduate and masters level in 1995. It was in this context that I was the first to use Computer-Based Training (CBT) to provide students with practical tuition in the Windows NT Server Operating System. Of course, the computer labs at that time did not have access to the Internet, and email was novel and limited to staff, so students had no screen-based distractions and could remain on-task. This approach proved quite successful. Since then, I have used various media, when available, to help students understand the inner workings of computers and software systems. I do not believe that these topics are being adequately supported by the EdTech sector, and hence is something that could provide useful in education about technology at all levels.

Courses on Digital Technology are generally found at third level institutions or in industry. The former are typically delivered as part of computer science or engineering diploma and degree programmes. Professor Don Passey's (2015) review of the state of practice in this area is revealing. He illustrates that bridging primary, secondary and tertiary education is this regard is problematic and is hotly debated. I certainly would prefer my undergraduates to come to me with an understanding of the basics of Digital Technology; however, with the exception of a tiny minority, there is an astounding level of ignorance among 'digital natives' on the very technologies that they use each day.

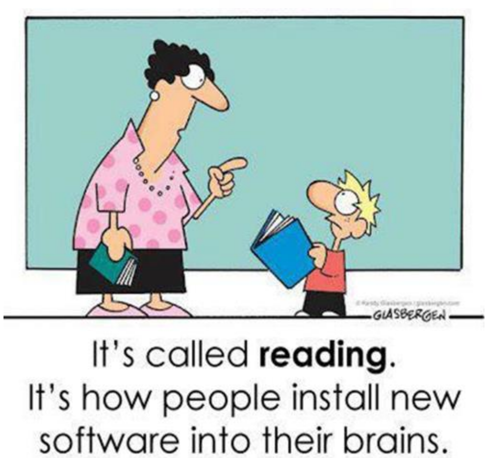
Passey (2015) points out that the school curricula typically focus on Microsoft Office/OpenOffice applications and niche technologies such as robots. He reports that in England and Australia schools have begun to shift their focus onto computer science topics such as programming and problem-solving—all of which are vital for developing Digital Technology systems. He argues that a global level "policy makers at national, regional and local levels are concerned about this shift: whether the shift should be made; how it can be made; and how it can be made effective for teachers and learners." He cites the Australian Curriculum, Assessment and Reporting Authority's (2013) ambitions to bring computer science into the classroom by integrating foundational computer science into the curriculum up to age 13-14 years (Year 8), with pupils specializing from age 14-16 years (Years 9 or 10). The Foundation to Year 8 will cover two topics: Design and Technologies and Digital Technologies—specialization builds on both of these. In the UK, its primary and secondary curricula are structured into Stages 1 and 2, which includes 5- to 11-year-old children. As with the Australian model, the UK primary-to-secondary level education seeks to equip students with 'computational thinking and creativity'. Thus, computer science will be taught alongside the traditional science subjects with students being taught computer science, principles of information and computation, digital systems, and programming. This will, I expect, be problematic, as Passey (2015, p. 12) reports that *"In the England curriculum the programmes of study indicate what pupils should be taught, but they do not indicate how, or how to address what are known to be issues for learners. The success of this development, therefore, would appear to be likely to be based at least to some extent upon the abilities of teachers to address learner and learning concerns, not just teaching needs."* It is clearly early days yet, with many problems to be ironed out in the UK and Australia.

It will be interesting to see how initiatives like this pan out. Certainly, both first- and second-level education is woefully under resourced when it comes to the traditional curriculum. Perhaps policy makers should shift resources from third-level in a root-and-branch review of first- and second-level and get the fundamentals right, ever before they consider teaching computer science. On that note, my recent engagement with industry indicates that problem-solving skills are more valued than programming skills, as advances in technology, particularly AI, means that human coding of applications will be rendered obsolete, as machines learn, and can meet human design specifications more effectively, than programmers can currently achieve. My MSc and PhD research back in the 1990s indicated this the emergence of this trend. Thus, training children how to code in primary and secondary school may be more a history lesson in how technology was developed, as opposed to providing them with future digital skills. Such is the relentless pace of change in the digital era.

Discussion and Practical Recommendations

Schools in Ireland are emulating those in the US, Australia, the UK, and elsewhere, in introducing iPads, tablets, and, more recently, smartphones, into the classroom and the home as primary or secondary tools for learning. As I indicate above, the scientific findings and practice-based evidence is that such technologies have little benefit for student learning and do not produce enhanced learning outcomes. While adopting schools have published studies of Digital Technology use in the classroom, and reported positive outcomes generally, I would argue that many of these are subjective and biased. Such studies were not conducted using the scientific method, nor indeed any rigorous research method, nor were they peer-reviewed. Their findings are questionable, at best. Significantly, Larry Cuban, says of iPads, for example; "There is very little evidence that kids learn more, faster or better by using these machines."[11] The many rigorous studies on Digital Technology use in education corroborate his conclusions. Studies that illustrate a benefit of Digital Technology and EdTech for student learning outcomes indicate that Digital Technology applications may develop very narrow, non-transferable, cognitive and/or motor skills in children at the expense of more important reading, mathematical skills, interpersonal and problem solving skills. Digital Technology executives from organizations such as Microsoft, Google, Amazon, Intel and so on, are aware of such findings—so much so, that many now send their children to computer-free Waldorf Schools in order to ensure they develop creativity and problem solving skills.

Back to Basics: Paper and Effortful Learning



Students appear to perceive the medium of print as more suitable for effortful learning, whereas screens better suited for "fast and shallow reading of short texts such as news, e-mails, and forum notes"

Ackerman and Goldsmith (2011, p. 29)

The philosophy of Waldorf schools is that students do not benefit from using Digital Technology before the 12 years of age. Thus, pupils attending Waldorf Elementary schools are discouraged from using all forms of Digital Technology, including device use at home, while middle school pupils are introduced to Digital Technology in a controlled environment, and high school students use Digital Technology as tools for learning[12]. Indeed, I believe that policy makers and educators should examine this model, which is balanced and addresses the development and educational needs of children and adolescents.[13] (I urge readers to follow the link below, to find out more on these wonderful schools). The reasons for my enthusiasm for such schools is to be found in the findings of this paper and related published research.

The evidence adduced in this paper indicates that unfulfilled promises and unsubstantiated benefits aside, the use of Digital Technology by children for education, social and entertainment purposes holds several generally unrecognized dangers. First, research has shown that the use of smart phone, tablet, and computer screens after 5 pm can cause to sleep disruption, sleep deprivation, and is associated with obesity, and a range of health problems in children and adults. Second, research finds that the general use of computer screens results in a condition called *computer vision syndrome*, and ocular damage. These direct effects negatively influence student learning as described above. Third, students who use computers in class disrupt the learning process and impair learning outcomes both for themselves and other students not using Digital Technology. Fourth, there is an increasing body of scientific evidence which finds that learning with books and paper-based sources produces superior outcomes than by learning with e-books. Fifth, when students take notes with pen and paper they learn more, understand better, and have

[11] http://www.nytimes.com/2011/01/05/education/05tablets.html?_r=0 Accessed 15/09/2015.

[12] http://www.whywaldorfworks.org/11_EffPractices/pdfs/AWSNA%20SURVEY%20ON%20TECHNOLOGY%20IN%20WALDORF% 20%SCHOOLS%20%20JUNE%202013-2.pdf

[13] http://richmondwaldorf.com/our-school/waldorf-in-the-news

superior learning outcomes than those who touch-type lecture notes. And sixth, students who use smart phones, iPads/tablets and laptops suffer from distraction and other neurological dysfunctions, particularly those associated with screen and application multitasking. All this significantly impairs student learning and leads to neural addiction problems, such as Internet addiction disorder (IAD) and other psychological problems.

As for unfulfilled promises and unproven benefits, Stanford University's Professor Larry Cuban (1986, 2009, 2018) illustrates that the mistaken beliefs and misplaced confidence of politicians, policy makers, school principals and teachers in the role of technology for education is not new. It has been a common theme since the 1920s. Digital Technology is just the latest to be oversold and to under deliver. There are, as I indicate, islands of success in an ocean of failure, when it comes to the application of Digital Technology and educational technologies in the classroom and the home. Overall, research has shown that there is little evidence to support the proposition that Digital Technology and/or EdTech improve pedagogy or learning outcomes. There is also evidence that politicians and policy makers need to introduce computer science formally into the curriculum, but that is a rapidly changing scenario. Following the Waldorf experience, computer education should ideally happen at second level, not at primary level. However, to be a success, this would need careful planning and adequate resources.

The findings of the OECD Programme for International Student Assessment (PISA) study cited above were summarised in an article written by Andreas Schleicher, OECD Education Director, for BBC News on the 15th of September 2015. Both it and the findings of the OECD study were widely reported in the international media. To recap, the OECD (2015) found that the use of Digital Technology for education did not generally improve learning outcomes, despite the heavy investment in it by school administrators and policy makers. The media reaction in Ireland, my home, was immediate with the findings being widely commented on and educators and politicians interviewed for their opinions. It was clear from the media response that politicians and educators were ill-informed and exhibited 'hokey hope' optimism in the face of the overwhelming evidence from scientific studies on human and childhood behaviour, including those conducted on students.

The brains of children and adolescents are immature and not fully developed until their early 20s (Ramachandran, 2012; Levitin, 2015). Consequently, adolescents are over-confident in their own abilities, and operate from the assumption that they know more than their parents, and just about any adult. Parents of teenagers will recognize these general tendencies. But why, in general, do adults and children appear to act irresponsibly and fail to engage fully in Digital Technology-enabled learning?

We know from Daniel Kahneman (2012) of the primacy of System 1 (the impressionable, automatic, emotional, fast thinking, easily distracted, brain) over System 2 (the concentrating, rational, analytic, calculating, effortful, energy-intensive, and lazy brain). These two conceptualizations of the human brain's functioning are akin to Daniel Levitin's (2015) *mind-wandering* and *executive* brain systems.

The research cited on Digital Technology in this paper indicates that, on average, Digital Technology provides the perfect medium for the mind-wandering and easily distracted System 1, as opposed to the executive System 2, which is lazy and is, in turn, typically distracted by System 1. Thus, students in class and at home will fall prey to novel stimuli provided by their smartphones and tablets. All this is evidenced by the growing trend for university professors to limit the use of computers in class.[14] I took this step several years ago. My students are now more engaged, take better written notes, and, generally speaking, have much improved learning outcomes.

Evidence-based Recommendations

The findings of this study illustrate that the physical and psychological impact of Digital Technology have to be factored in when considering its role in and for education. This is generally neither recognized nor appreciated by policy makers and educators alike. Thus, my recommendations have been drafted accordingly.

The first set of recommendations relate to issues identified with physical screen use:

(1) To avoid sleep disruption, pupils should not spend more than 1 hour per evening before an iPAD/ tablet/computer/smart phone screen. The younger the student the less time should be spent. Light-filtering glasses or goggles should be worn for periods longer than this, or appropriate applications employed to electronically alter the light emitted by the device to an eye-friendly spectrum.

(2) Given (1), e-books that use reflected light, as opposed to emitted light from Light Emitting Diodes (LEDs), should be used for learning in class and in the home.

(3) The practice of using e-books should be discouraged, as research has shown that students learn better from paper-based media. Also, the rise of *computer vision syndrome* is causing here-to-fore unrecognized physical effects and adding to cognitive loads on students, all of which impairs learning.

(4) In order to enhance learning, students should write notes in class using pen and paper and not type them in on a keyboard. Likewise, project work should be written by hand.

(5) Except where students are receiving instruction on their use, or for data gathering purposes, as part of project work, tablets and laptops should be avoided in the class or the home.

(6) Students need to be educated early on the many problems caused by using smart phones, tablets and laptops, particularly with respect to diminution in learning and general dysfunctions caused by distraction, multitasking and Internet addiction disorder.

My second set of recommendations relate to the application of Digital Technology and EdTech. Based on the scientific evidence, and given that fact that the human brain is effectively a single-tasking computer, an effective screen-based learning technology should:

(1) Provide content, subject matter and learning materials in a focused, linear fashion.

(2) Provide no opportunity for users to 'browse' or be distracted by other applications, particularly in online learning where students self-regulate. As blended learning may produce superior outcomes for students, the screen-based learning component should be based on and/or be a complement to classroom learning.

(3) Content should be text and symbol-based, with related multimedia content, while minimizing the use of hypertext and hypermedia, which may cause increased cognitive load through distraction, switching, and multitasking.

(4) Applications should present students with well-defined learning outcomes and interactive feedback.

[14] https://www.washingtonpost.com/blogs/answer-sheet/wp/2014/09/25/why-a-leading-professor-of-new-media-just-banned-technology-use-in-class/

(5) EdTech applications employed in schools should be scientifically tested, with results published in peer-reviewed journals, and subsequently evaluated to ensure that the positive improvements and learning outcomes are actually achievable, and without side-effects.

These recommendations are founded on the findings of rigorous scientific studies and common sense.

Conclusions

As challenging as these recommendations may appear to unquestioning supporters of the Digital Technology in education agenda, their implementation will ensure that there is a return on the significant investment in Digital Technology at second- and third-level education. They will also help protect children from the physical, neurological and psychological side-effects of excessive screen use. However, as with the proponents of Waldorf approach, I do not believe that children under 12 should be exposed to 1-1 notebook or screen-based education in the curriculum. There are arguments to the effect that all use of Digital Technology in primary and secondary education should be heavily limited to supervised information search.

On a personal note, in drafting this paper, I used Google Scholar and the Google search engine extensively, in concert with my university's online library resource. Most articles I read and researched were in PDF, HTML or Word format. I could not have researched nor written this article in such a short period without using Digital Technology. It was drafted mainly at home, but also on planes, a trains, on an inter-city bus journey, and in a hospital A&E—all on my trusty notebook. And yet I am critical of the way the same Digital Technology is being used in education. Why is this? Among other things, and given the fundamental problems described above, the productive use of Digital Technology requires single-mindedness, motivation, commitment, and the ability to defer gratification—all of which are, generally, a product of experience, and rarely found to the required degree in the average child or adolescent.

In writing this paper I came across an article which reported that one principal of a Waldorf school in the US had the following opinion: "To see a 3, 4 or 5 year old using an IPad is like giving them a steak knife…It is potentially just as harmful and dangerous. Technology is powerful, and should be used when it is appropriate." [15] The research papers I have reviewed effectively support this perspective. I will go one further, however.

Given what neuroscientists have discovered about the dysfunctional and addictive effects of screen-based applications on the human brain, providing an adolescent with a smart phone or a tablet is akin to giving them a cannabis plant with lots of fertilizer. As strange as this analogy sounds, consider the findings of recent research, which established that the cognitive losses from multitasking are greater than those caused by smoking cannabis (see Levitin, 2015). Thus, multitasking users of Digital Technology, like cannabis smokers, have impaired memories and an inability to focus on several things at once. This presents a challenge for parents, educators and society to recognize this unpalatable truth and take steps to remedy it.

What do I conclude from my research? I believe that there is a fundamental mismatch between the affordances provided by Digital Technology and the pre-wired and/or nascent cognitive behaviors and neurological functioning of the human brain. Hence, screen-based applications on multicore, multitasking computers trigger dysfunctional and addictive behaviors in the single core, single tasking brains of children and adolescents, in particular. We can see today

[15] http://www.komonews.com/seattlerefined/lifestyle/A-No-Technology-School-The-Waldorf-Approach-275165931.html

how students using Digital Technology are unable to stay on task, as their Stone Age brains are wired to detect novel stimuli. In prehistoric times, this was a survival mechanism. Thus, text messages, instant messaging, emails, and other such Digital Technology-generated stimuli are all forms of distraction and trigger multitasking behaviours. One solution to this problem which I have suggested is to ensure that Digital Technology/EdTech applications are designed to guarantee that pupils stay on-task by avoiding occasions for distraction and multitasking. Certainly, the technology exists to help achieve this goal.

In a general context, 'evidence of absence is not absence of evidence', or so the OCED (2015) report implies when it comes to conclude on the utility of Digital Technology for education. Given the dearth of supporting evidence and corroborating findings, and "Despite the many challenges involved in integrating technology into teaching and learning, digital tools offer a great opportunity for education" the OECD (ibid., p. 191) concludes. I believe this to be true, given certain conditions and factors (see Mourshed, Krawitz, and Dorn, 2017).

One key area for attention by educators and policymakers is reading from digital screens in preference to printed medium. Following the results of a four-year study by 200 scientists across Europe, the Stavanger Declaration a key passage of which states:

> "Research shows that paper remains the preferred reading medium for longer single texts, especially when reading for deeper comprehension and retention, and that paper best supports long-form reading of informational texts. Reading long-form texts is invaluable for a number of cognitive achievements, such as concentration, vocabulary building and memory. Thus, it is important that we preserve and foster long-form reading as one of a number of reading modes."[16]

The conclusions of research by Delgado et al. (2018) are that "ignoring the [scientific] evidence of a robust screen inferiority effect may lead to inefficient political and educational decisions." School boards and principals who introduce electronic textbooks are going against the grain of scientific opinion. They would do well to read Dr Klaus Zierer, Professor of Education at the University of Augsburg, who paints a compelling picture of the problems and potential of educational technology in his book *Putting Learning Before Technology!*, published in 2019. Dr Zierer describes in detail the possibilities and limitations of digital technology in the classroom. Hence. not to take a balanced approach risks damaging the futures of so many of our young people.

In conclusion, I agree with Daniel Levitin (2015, p. 336) who argues that given the complexity of the digital age, "the primary mission of teachers must be to shift from the dissemination of raw information to training a cluster of mental skills that cluster around critical thinking." In addition, I would add that children need to be trained to be single-minded, motivated, and committed in their use of Digital Technology for education. Given that children live in a world in which Digital Technology is playing an increasing role in their lives, in society, and in the workplace, this would not be a bad place to start.

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[16] http://ereadcost.eu/wp-content/uploads/2019/01/StavangerDeclaration.pdf

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