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From E-Waste to Eco-Wonder: Resurrecting Computers for a Sustainable Future

Jorge Reyna [1,*], Jose Hanham [2] and Joanne Orlando [2]

[1] Education and Training, The Royal Australian and New Zealand College of Ophthalmologists (RANZCO), Sydney, NSW 2010, Australia
[2] School of Education, Western Sydney University, Penrith, NSW 2751, Australia; j.hanham@westernsydney.edu.au (J.H.); j.orlando@westernsydney.edu.au (J.O.)
* Correspondence: jreyna@ranzco.edu

Abstract: Educational institutions are massive consumers of computing technologies, often replacing their computing infrastructure in a 3-to-5-year timeframe. Once decommissioned, many components of computing technologies are no longer useable and become electronic waste. Replacing computer infrastructure within these short timeframes is a significant e-waste sustainability issue that educational institutions need to address. This article aims to introduce and provoke new thinking regarding e-waste management and its implications for education. The authors introduce the term sustainable device literacy to conceptualise how educators and educational institutions can take an educative approach to refreshing computing technologies beyond their presumed obsolescence. Two example case studies that demonstrate the upgrade of a laptop from 2012 and a desktop computer from 2015 are included to provoke new discussions regarding e-waste and education. Using benchmarking tools, the findings from the case studies show that computing technologies that may be considered obsolete can be upgraded to include much of the functionality of current computers. The broader implications for sustainability are discussed.

Keywords: education for sustainability; e-waste; innovative ideas; recycling computers; sustainability

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1. Introduction

Electronic waste (e-waste) is one of the fastest growing solid waste streams in the world [1]. E-waste refers to discarded components from electronic devices or electrical appliances. Approximately 50 million metric tons of e-waste are generated globally every year, and it is predicted that e-waste production will reach 75 million metric tons per year by 2030, representing a 60% increase in just under a decade [2]. The social costs of e-waste are significant; for example, residents of many low-income countries are negatively impacted by the illegal and unsafe disposal of e-waste for income. Given the toxic and harmful nature of this waste and its slow breakdown, such figures indicate an urgent need for strategies to reduce our e-waste footprint [1]. This paper aims to translate and adapt common knowledge from the computing field to provide new directions for how educational institutions can take an educative approach to reducing e-waste. The authors term this *sustainable device literacy*, an approach that combines the physical refreshing of computing technologies that are presumed obsolete with the education of teachers and students on the value of this approach for sustainability and reducing e-waste.

In countries like Australia, many schools and universities refresh their computing infrastructure every 3–5 years by mass leasing of new computing models. During the refresh process, many used computers are decommissioned by the leasing vendors. Although there are recycling programs by vendors like Dell and Apple to recycle the components of decommissioned computers, a significant amount of e-waste is still generated when computers reach their so-called use-by date. This is due to several factors. For example, modern computers are becoming more challenging to recycle or upgrade because of "planned obsolescence" [1], in which products are deliberately designed to have a limited shelf-life. Common strategies include nonremovable or nonreplaceable batteries. Another method manufacturers use to shorten the useable lifespan of computers is to solder components like Random Access Memory (RAM) directly onto the motherboard. RAM is a crucial piece of hardware that temporarily stores the operating system (OS), software programs, and any currently used data, allowing for swift access by the device's processor. This enhances the efficiency and responsiveness of the device. However, when RAM is soldered on, it restricts the ability to upgrade or replace this component. This limitation can reduce the computer's overall lifespan by preventing hardware updates that could improve performance or extend usability. Additionally, computer storage solutions such as eMMCs (embedded multimedia cards) and solid-state drives (SSDs) are modern alternatives to traditional hard drives (HDs). They store the operating system, software, and data within the device. While these storage types offer faster access and more reliable performance than older hard drives, their integration and form factor in some devices may also be less accessible for upgrades or replacements, further limiting the device's lifespan with design choices [3].

It is also important to emphasise that many of the chemical components in e-waste from computing technologies cannot be recycled. Recycling is expensive and complicated, with processes like disassembling computers requiring manual labour and exposing workers to many toxic elements [4]. Recent estimates of e-waste recycling indicate that only 17.4% of reported e-waste is recycled. Approximately 50 million metric tons of e-waste are generated globally every year, and it is predicted that e-waste production will reach 75 million metric tons per year by 2030, representing a 60% increase in just under a decade [4].

Although it is arguably up to the vendors to decide how computers are handled after they have been decommissioned [5], the fact that schools and universities mass lease computers on a cyclical basis represents a significant sustainability dilemma for educational institutions. On one hand, teachers and researchers in many schools and faculties require access to the latest computing technologies. Indeed, academic disciplines such as engineering, architecture, IT, data science, and creative industries rely heavily on advances in computing technologies to enhance research, teaching, and innovation. However, on the other hand, efforts also need to be made to reduce the e-waste produced by the refresh cycle.

The authors propose that resurrecting decommissioned computers, or those due to be decommissioned, could be a valuable strategy to reduce the e-waste footprint of students and educational institutions. This approach aligns with the vision of a circular economy which extends the productive life of resources through long-life design, reuse, repair, remanufacturing, and recycling [6]. The notion of sustainable device literacy takes a three-stage approach that contributes to students' capacity to become informed citizens, particularly regarding their technology purchasing choices. These stages are (1) resurrecting decommissioned computers; (2) a curriculum that teaches the skills and knowledge for this process; and (3) an environment that promotes a sustainable approach to maintaining and upgrading digital devices effectively. With sustainable device literacy, teachers and students are not only aware of the alternatives to purchasing new technologies, but they also now possess knowledge about hardware and software upgrades they can make to their existing computing resources which negate the need to purchase new computing technologies. In the case of laptop and desktop computers, this includes knowledge of the functionality of devices that enables the user to operate them effectively, including hardware (e.g., RAM, eMMC, SSD), software (operational systems upgrades), and the knowledge and skills needed to upgrade computers for optimal performance.

1.1. Resurrecting Decommissioned Computers

The resurrection of computing technologies refers to upgrading decommissioned but still useable computers (e.g., laptops and desktop systems). When old computer hardware still has acceptable resolution (1280 × 800 pixels or higher), processors (i3, i5, or i7), and

RAM (random access memory) (4 GB or more), it can be considered suitable for an upgrade. In contrast, when old computers become suboptimal in their functioning for reasons like low-resolution screens (e.g., 640 × 480 pixels), slow processors (Intel Pentium), or small RAM (less than 2 GB), they cannot be upgraded. Although old computers are generally modular, there are limitations concerning whether they can be upgraded. For example, some RAM memory chips (e.g., DDR2) are not compatible with the latest generation of RAM DDR3 and DDR4. Also, resolution is not upgradable, so old computers that have low resolution will be incompatible with the requirements to run modern software applications, for example, those found in Adobe Creative Cloud (e.g., 1280 × 800). Most new software programs and applications require a minimum resolution of 1280 × 800 pixels, at least an i3 processor, and 4 GB of RAM. It is important to emphasise that in practice, to run many of the advanced features of modern software applications, computers need to be capable of operating well above the minimum specifications outlined in software program documentation. When evaluating the suitability of a computer for an upgrade to obtain the functionality needed for tasks in everyday teaching and learning environments, these minimum standards need to be met; otherwise, upgrading is not feasible.

Although updating modern computer components is increasingly challenging [7], any computers released prior to 2017 can be resurrected because their design followed a modular approach (e.g., easy to remove and replace hard drives, RAM, and batteries). These modular design computers can be upgraded to the functionality needed for modern classroom learning and teaching. In this article, the authors provide two case studies showing that a laptop from 2012 and a desktop from 2015 can be upgraded inexpensively to obtain much of the functionality of the latest computing technologies.

The functioning of ecosystems provides a helpful analogy for thinking about resurrecting and recycling old computers. In an ecosystem, nutrients are recycled through organisms (e.g., bacteria, fungi, insects) and the elements (e.g., soil, water, wind), creating an autonomous system. Plants and organisms absorb nutrients, releasing them when they die via organic matter decomposition [8]. Similarly, materials for computers, such as metals and plastics, are extracted through mining and manufacturing. Refurbishing computers by upgrading them (e.g., replacing a hard drive with a solid-state drive (SSD) [9], increasing RAM, and upgrading operational systems) extends their lifespan. Resurrecting dated but still functional computers minimises the environmental impact of the highly toxic materials contained in e-waste. The hardware components removed can be reused to build new systems, reducing the need for further resource extraction. However, it is essential to emphasise that not all components are currently recyclable, so there will be some unavoidable e-waste [10]. Nonetheless, upgrading and recycling computers is important to reduce, if not eliminate, e-waste volumes.

This paper uses two example case studies demonstrations to provoke new discussions regarding e-waste and education. The upgrade of a laptop from 2012 and a desktop computer from 2015 are presented to provoke new thinking regarding the resurrection of computing technologies and their potential role in contributing to digital literacy, particularly the previously overlooked subdimension of this construct, which the authors call sustainable device literacy. The authors explore the concept of sustainable device literacy and then provide two case studies that illustrate the steps for resurrecting two old computing technologies. Following the presentation of the case studies, the authors elaborate on how resurrecting old computing technologies can positively contribute to issues like affordable access, sustainability, and the environmental impact of computer consumption.

1.2. Digital Literacy and Sustainable Device Literacy: Empowering Users through Understanding

Digital literacy emerged in the 1990s following the introduction of the Internet and the World Wide Web into the public sphere [11]. Over the last several decades, digital literacy has grown in importance as digital technologies have become an indispensable feature of teaching and learning in education [12]. Being digitally literate means accessing, evaluating, creating, and communicating with digital tools [13].

Digital literacy encompasses technical skills, critical thinking, and ethical considerations which enable individuals to navigate the digital world, solve problems, and make informed decisions in education, work, and everyday life [12]. In a previous article [13], the authors coined the term *device functionality* to refer to a subcomponent of digital literacy which is concerned with the knowledge and skills digital citizens should have to understand how hardware and software work together to "bring alive" a device (e.g., a laptop or desktop computer). The concept of bringing a device alive is discussed in the next paragraph using an analogy.

The authors consider that this term should be revised and renamed sustainable device literacy, because device functionality can be seen as the features offered by a device. Looking at the literature, current models of digital literacy have neglected sustainable device literacy [12–15]. The authors consider these terms essential to empowering digital citizens to upgrade their existing computing technologies and contribute to a sustainable future.

Using an analogy, sustainable device literacy applied to a laptop or desktop computer can be related to the anatomy and physiology of a living organism. In both cases, a complex interplay exists between components that work together to enable functionality. Just as anatomy encompasses an organism's physical structures and organs, hardware represents a computer's physical components. At the same time, physiology corresponds to the processes and functions occurring within the organism. Hardware provides the structure, like organs do, and software brings life and functionality, like physiological processes do, enabling devices to perform tasks. Understanding this analogy emphasises the importance of comprehending the interplay between hardware and software for computer upgrades. By grasping these relationships, teachers and students can become empowered users, optimising performance and effectively upgrading their technology as required.

Knowledge about computer functionality is becoming a necessity in many spheres of society. What makes a laptop fast? Is it the processor, the eMMC/SSD, the RAM, or a combination of them? Typically, consumers rely on sales representatives when making decisions about purchasing new devices [16–18]. However, these representatives may have their own agendas, ranging from clearing out old stock to pushing expensive models. Sometimes consumers may end up with a device with poor battery life or an ill-designed keyboard (e.g., an Apple laptop with a butterfly keyboard that gets stuck and becomes unresponsive). Educating consumers about sustainable device literacy and device specifications empowers them to become critical consumers of technology, avoiding the risk of purchasing an underused and expensive device.

Integrating sustainable device literacy into the broader construct of digital literacy and curriculum can enhance students' empowerment, independence, and proficiency as technology users. Possessing a sufficient level of sustainable device literacy should enable students and those who are responsible for mass purchases of computing technologies (e.g., procurement officers) to make informed decisions when purchasing devices, considering long-term viability, upgrade options, and environmental impacts, as well as an informed commitment to IT sustainability practices and the value of reusing equipment rather than purchasing new resources.

1.3. Factors That Shape Technology Purchase Decisions: Empowering Informed Choices

When students and procurement services in educational institutions seek technology that suits their needs, understanding sustainable device literacy becomes crucial. Developing critical buying skills and awareness of factors influencing poor purchase decisions is also essential, because ill-advised purchasing decisions can have serious consequences [18]. These factors can include insufficient or inadequate research, budget constraints, impulse buying, lack of understanding of specifications, brand perceptions, and limits to future upgrades. Students and those responsible for procuring computing technologies in educational institutions should hone their ability to search and retrieve information from reputable sources [19], such as CNet or PCMag, which is known as information literacy. For instance, biased gadget reviews on YouTube can mislead consumers into purchasing unnecessary technology [18]. Also, influencers on platforms like Instagram who advertise or recommend products have the potential to mislead consumers [19]. When reviewers have undisclosed relationships with manufacturers, their opinions may be swayed, leading to exaggerated praise and unrealistic perceptions [20]. Regrettably, there is limited research on this topic, and relying solely on such biased reviews can result in teachers and students overlooking their real needs and making impulsive purchases based on persuasive marketing or trendy features. Before investing in technology, students and educators must consider multiple sources, evaluate information critically, and assess their needs.

Technology companies are, of course, focused on making profit, so they design and produce products with inherently short lifespans which would need more capacity to enable upgrades to the latest functionality [21]. This has been evident with smartphones, tablets, and laptops. For example, it is typical for software updates and support to cease after a certain period has elapsed, often when the devices are otherwise functional (e.g., ultrabooks). Notably, developments in the gaming and virtual reality worlds are governed by advances in innovative technologies (e.g., faster processors and high-resolution displays). For instance, the XReal Air Augment Reality Glasses require the latest operating systems and Nebula software to function. Only a limited number of devices support XReal. Technology companies such as XReal are promoting consumption of new laptops, mobiles, and tablets. Asking them to make their new devices compatible with old gadgets is unrealistic. If the gadget vendor discontinues their support, it could be the end of the device being used with innovative technologies such as XReal. Therefore, it can be concluded that modern technologies contribute to e-waste production.

Before purchasing a new device, defining specific needs and considering factors such as suitability, cost, and future upgradability is wise. Making purchases with a clear understanding of requirements can lead to better-informed technology decisions. Teachers, particularly those with knowledge of educational psychology, should raise awareness among students about the influence of neuromarketing, brain-based strategies, perceptions, and emotions to prevent the impulse buying of technology [16]. Fostering sustainable device literacy and understanding the factors influencing technology purchase decisions are crucial skills for digital citizens to cultivate towards a sustainable future.

1.4. Resurrecting Old Laptop Computers

Some technical aspects must be considered before upgrading hardware and software to resurrect old computers. Screen resolution can be a limitation. For instance, a screen resolution of 640×480 pixels is too low; on-screen text will look blurry, and colours will not display accurately. Additionally, most current software and versions of operational systems for Windows and Macintosh will not run on such a low resolution. This resolution was popular with computers in the early 1990s and is not worth upgrading. Modern entry-level laptops (e.g., Lenovo) offer resolution (1366×768 pixels) comparable to that of laptops produced a decade ago. Although this resolution suffices for web browsing, video watching, and word processing, it falls short for professional-level video or graphics production. Old computers with similar resolution to modern entry-level laptops can still be used in educational settings for text, image, and video-based learning activities like creating stop-motion animations and short videos. For instance, the Apple MacBook Pro Core 2 Duo 2.8 17″ (Mid-2009), which was high-end at that time, has a better resolution than contemporary entry-level Lenovo laptops (e.g., 1920×1200 pixels). Another example is the Toshiba Satellite 15.5″ P55t 4K Ultra HD with a resolution of 3840×2160 pixels, released in 2014. These laptops are good candidates for upgrades as they can run software smoothly afterwards.

Another drawback to consider before upgrading laptops is their shorter battery life compared to newer machines (e.g., MacBook Air M2 with 14 h of battery life). Additionally, the latest operating systems of manufacturers like Microsoft and Apple may not support these upgraded devices. However, this obstacle could be overcome by refurbished computers running modern operational systems via installation of patches (e.g., OpenCore Patches) or running Linux operating systems (e.g., Ubuntu, Fedora, Debian). The Linux ecosystem offers a critical value-add, with a large community of developers creating open-access software programs as free alternatives to popular subscription services like Adobe Creative Cloud or Microsoft Office. While Linux may not improve battery life, replacing a laptop battery is a simple and inexpensive procedure (AUD 50–80; USD 30–50; GBP 20–40). Battery packages are available on platforms like eBay or Amazon, complete with instructions and necessary technical equipment like screwdrivers. Students with sustainable device literacy skills could safely do this at home within minutes for external batteries or 20–30 min for devices with internal batteries. There are plenty of tutorials on YouTube for various laptop models.

1.4.1. Case Study 1: Laptop Upgrade

This section describes how the authors upgraded a MacBook Pro 15″ i7 (Mid-2012) (Table 1). This laptop's original configuration was not capable of running recent versions of productivity applications, including Office365 (e.g., Teams, Word, OneDrive), Adobe Creative Cloud, and current versions of browsers such as Chrome. It could only run outdated versions (e.g., versions on CD-ROMs) which have limited functionality and pose online safety risks (e.g., unauthorised access to passwords). In this section, comparisons are made between original and enhanced specifications after upgrading. Educators can find a complete step-by-step tutorial online (https://www.youtube.com/watch?v=ivnidLIE_TI, accessed on 29 July 2023). Changing the hard drive (HD) to a solid-state drive (SSD) tripled the speed and doubled storage capacity. The upgrade quadrupled RAM from 4 to 16 GB, which enhanced the ability of the computer to open and run applications quickly. With these hardware upgrades, the computer can now run OSX Catalina. This is not the most recent version but, importantly, it allows the installation of required software, including Adobe Creative Cloud applications, Microsoft Office365 productivity applications, and recent versions of Chrome applications suitable for everyday activities in educational settings. Moreover, the computer can now run smooth video editing of 4 K of footage (15 min) without slowing down the processor.

Table 1. MacBook Pro 15″ i7 middle 2012 laptop original vs. upgraded specs. Upgraded speeds were gathered using BlackMagic Disk Speed (https://apps.apple.com/us/app/blackmagic-disk-speed-test/id425264550?mt=12, accessed on 8 February 2024), Cinebench (https://www.maxon.net/en/cinebench, accessed on 8 February 2024), and Geekbench (https://www.geekbench.com/, accessed on 8 February 2024).

Hardware	Original Specs	Upgraded
Processor	2.3 GHz Intel Core i7 3615QM	
OSX	Mountain Lion (OSX 10.8, 2012)	Catalina (O 10.15, 2019)
Video support	Two displays (2560 × 1600 pixels)	
Hard drive storage capacity	500 GB	1000 GB
Hard drive (read speed)	5400 RPM (80 Mbps)	--
Hard drive (write speed)	160 Mbps	--
SATA SSD (read speed)	--	477.6 Mbps
SATA SSD (write speed)	--	454.6 Mbps
RAM	4 GB (two 2 GB) 1600 MHz DDR3	16 GB (two 8 GB) 1600 MHz DDR3
Capable of running Adobe Creative Cloud?	No	Yes

As of November 2022, Catalina no longer receives security updates, which means security risks for users. To overcome this problem, the authors decided to use a third-party open-source patcher (OpenCore Legacy Patcher 1.3.0 https://dortania.github.io/OpenCore-Legacy-Patcher/, accessed on 12 January 2024) that addresses the issue of being unable to run the installation of the latest OSX Sonoma and supports the latest software and applications.

In future, if the OpenCore Legacy Patcher 1.3.0 is no longer available, there is an excellent alternative, the Ubuntu operating system. Educators can find a complete Ubuntu 22 step-by-step installation tutorial online which would be simple for students with sustainable device literacy skills. After installing the latest Ubuntu-built and open-source alternatives to the mainstream software [13], the computer ran smoothly, and the authors did not need to spend money on monthly software subscriptions.

In summary, the authors rescued an old computer (11 years old) and invested around $AUD320 (SSD and RAM). As a result, this machine runs graphics and video editing programs smoothly with open-access software. This procedure can be performed with iMac (Intel-based only), MacBook, MacBook Pro, MacBook Air, and Mac Mini models up to 2014. Apple laptops with M1, M2, and M3 processors are not upgradable because all the components are soldered onto the logic board.

1.4.2. Case Study 2: HP ProDesk 400 G3 SFF

This case study (Table 2) presents details of the upgrade of a small-factor PC HP ProDesk 400 G3 SFF released in 2015. This entry-level business desktop computer originally ran Windows 8, released in 2012. The problems with this computer include Windows 8 now being unsupported, meaning that it is highly vulnerable to security breaches. Furthermore, the desktop computer does not have the necessary hardware components to run modern software applications, such as those presented in Case Study 1. However, despite its age (9 years) and dated hardware, it is still a viable solution for home, office, and even light gaming. The motherboard uses the H110 chipset and supports a 6th Gen Intel Core processor, 32 GB of DIMM DDR4-2133 memory, and a dedicated graphics card. The upgrades the authors employed for this computer included replacing the hard drive (HD) with a solid-state drive (SSD), increasing the speed of the hard drive more than forty-fold, and increasing the RAM from 4 to 32 GB, increasing the processing speed to run applications eightfold. These steps allowed the authors to install the current versions of Office 365 and Adobe Creative Cloud applications. Previously, the machine could not be used for editing or viewing 4 K videos. However, with these upgrades, this machine can now be used to view and edit 30–45 min 4 K video segments. As this computer is a desktop form factor, it was possible to upgrade the HD to the latest NVMe M.2 SSD (https://www.amazon.com.au/Gigabyte-Internal-10000MB-9500MB-AG510K2TB/dp/B0BVRS52T5, accessed on 24 September 2023) that supports read-speeds up to 10,000 MB/s and write-speeds up to 9500 MB/s. It required an adapter from NVMe M.2 to PCIe (https://www.jw.com.au/product/silverstone-ecm22-dual-m-2-to-pcie-nvme-sata-adapter-card?msclkid=9aae30360e6414a63890548303ece9c3&utm_source=bing&utm_medium=cpc&utm_campaign=2020%20Low%20Priority%20Products&utm_term=4576236136794643&utm_content=Low%20Priority%20Products, accessed on 25 September 2023). As in Case Study 1, the latest operating system or software versions could only be installed with computer reconfigurations. Even so, the upgraded desktop's capabilities now align with everyday activities in educational settings.

The authors picked up the computer at a recycling store for AUD 25, the RAM cost was AUD 90, the SSD was AUD 250, and the adapter was AUD 45. The total cost of this machine was, thus, AUD 410. Although the device was unsupported for upgrade to Windows 11, the authors found a tutorial online about installing it. There are some limitations to acknowledge, namely that the computer had an incompatible version of Bluetooth, so it was necessary to purchase a USB Bluetooth adapter for AUD 10. The computer still runs smoothly and receives upgrades frequently.

Table 2. HP ProDesk 400 G3 SFF 2015 micro tower original vs. upgraded specs. Upgraded speeds were gathered using CrystalDiskMark (https://sourceforge.net/projects/crystaldiskinfo/files/9.2.3/CrystalDiskInfo9_2_3.exe/download, accessed on 22 March 2024), Cinebench (https://www.maxon.net/en/cinebench, accessed on 22 March 2024), and Geekbench (https://www.geekbench.com/, accessed on 23 March 2024).

Hardware	Original Specs	Upgraded
Processor	Intel Core i5-6600 processor	
OSX	Windows 8	Windows 11 Pro
Video support	Three displays (3840 × 2160 pixels, 60 Hz refresh rate)	
Hard drive storage capacity	500 GB	1000 GB
Hard drive (read speed)	150 Mbps	--
Hard drive (write speed)	120 Mbps	--
SATA SSD (read speed)	--	7000 Mbps
SATA SSD (write speed)	--	5500 Mbps
RAM	4 GB (1 slot) PC4-2400 U, DDR4	32 GB (two 16 GB) PC4-2400 U, DDR4
Capable of running Adobe Creative Cloud?	No	Yes

These case studies were presented with a problem, solution, outcome, and limitations to illustrate how sustainable device literacy could make it possible to resurrect old computers and upgrade them. Incorporating these ideas into secondary and tertiary education would raise awareness, empower students with sustainable practices, and foster a responsible culture of computer disposal and recycling.

2. Discussion

E-waste is one of the most rapidly growing categories of waste globally. Taking a sustainable device literacy approach, educational institutions could play a potentially important and ongoing role by reducing their e-waste footprint. The educative element of this form of literacy could have a broad-ranging impact beyond institutional boundaries. Graduates with sustainable device literacy could apply their knowledge and skills in the workplace, home, and local community. The two case studies highlighted how old computers can be resurrected with a small or medium investment and they provided two examples of sustainable practices that schools and teachers can adopt to reduce e-waste. The cases describe limitations of the process of upgrading computers, including resolution, maximum RAM, and computer processor and battery life. The authors proposed alternatives when the upgraded computer could not run the latest operational system, e.g., the use of patches or installation of the Ubuntu operating system, which is an excellent operating system that will run smoothly on resurrected computers and is currently free. Although reducing e-waste is a crucial goal, there are numerous benefits beyond this. The resurrection of these computers is made possible through sustainable device literacy, which encompasses the hardware's "anatomy" and the software's "physiology".

Upgrading and recycling computers, dedicating curriculum to the skills, knowledge, and value of it, and modelling it in a meaningful way, promote sustainability and e-waste reduction. Various initiatives, such as educational programs, industry collaborations, and community engagement, could be undertaken. Educational institutions could take an active role in promoting sustainability and responsible e-waste management. Integrating sustainable device literacy into the curriculum would emphasise the importance of recycling and upgrading computers. Studies show that high school students have a positive attitude towards addressing the problem of e-waste, but that this is not reflected in their actions [20]. These ideas could be incorporated into science and social science subjects in school settings.

Industry collaborations play a pivotal role in driving sustainable practices and reducing e-waste. By partnering with technology companies, it would be possible to develop innovative programs that promote computer upgrading and recycling while incentivising consumers to dispose of their devices responsibly. Establishing community recycling centres would provide convenient locations for people to donate old computers for proper recycling and refurbishment. Officeworks Australia has an electronics recycling program where consumers can drop off their old electronics at Officeworks retail stores. These community-driven efforts raise awareness, empower individuals, and contribute to a stronger, more sustainable society.

In addition to the explicit knowledge and skills that students would learn in sustainable device literacy, they would also be immersed in an environment in their schools or universities which values, promotes, and models sustainable device practices. This goes beyond subject-based lessons to a holistic approach to understanding and valuing the need for e-waste to be managed in a more sustainable way. Immersive modelling of e-waste, along with a dedicated curriculum and skill development for students and schools, can assist in the development of much needed meaningful e-waste policies and establish e-waste value chains that sustain the e-waste ecosystem within the school and beyond [21].

Educating consumers, including students and parents, about the environmental impact of their choices empowers them to make informed decisions. Emphasising the benefits of modular computers, with their upgradability and reduced e-waste compared to non-modular counterparts, becomes crucial. Encouraging consumers to explore alternatives like upgrading existing devices or purchasing refurbished ones could help minimise the demand for new products. As a potential caveat, promoting refurbishment of electronics could exacerbate crime in developing countries (e.g., in Peru, 200 mobile phones are stolen per hour) [22], so governments should implement measures to ensure refurbished electronics come from legal sources. In Australia, several companies sell refurbished electronics, including Reebelo, CeX, Green Gadgets, and Cash Converters. They offer competitive prices and guarantees for their goods. By raising awareness, advocating for sustainable options, and empowering consumers, it would be possible to collectively drive positive change and adopt a more environmentally conscious approach to technology consumption.

A recycling computers initiative can be integrated into sustainable urban development similar to a mobile roaming WiFi4EU initiative, which integrates digital connectivity with environmental responsibilities [23]. As cities strive to become smarter and more connected, there arises a parallel need to address the environmental impact of technological advancements, including the proliferation of e-waste. Recognising this, efforts to promote sustainable connectivity can be complemented by initiatives aimed at responsibly managing e-waste, such as computer recycling programs. By harnessing the power of technology to facilitate both digital connectivity and environmental stewardship, stakeholders can work towards a more sustainable future where technological innovation is harmonised with ecological preservation. Thus, the convergence of sustainable connectivity initiatives with endeavours like computer recycling exemplifies the multifaceted approach required to navigate the modern era's complex interplay between technology, urban development, and environmental sustainability.

Research and innovation are pivotal in shaping a sustainable future. Supporting research efforts would drive the development of environmentally friendly and energy-efficient technologies and create a greener computing landscape. Prioritising designs that focus on recyclability would ensure easier disassembly and, thus, responsible recycling of future devices. Fostering innovation in sustainable computer recycling involves exploring novel methods for extracting valuable materials from e-waste, reducing waste generation, and minimising the environmental footprint of the recycling process. Research and innovation could unlock ground breaking solutions for a more sustainable and circular economy.

Policy advocacy is also essential in driving sustainable practices within the technology industry. It is possible to push for policy measures like extended producer responsibility periods and holding manufacturers accountable for their product lifecycle by advocating for change. Stricter regulations on e-waste management would ensure proper disposal and recycling of electronic devices. Incentives for eco-friendly design and manufacturing would encourage the development of more sustainable technologies. Collaborating with policymakers helps to develop comprehensive recycling frameworks and guidelines and establish effective systems for responsible disposal and recycling. Policy advocacy will make it possible to shape a brighter future by integrating sustainability into the core of technological advances.

Lastly, providing professional development opportunities for educators is crucial to enhance their knowledge and understanding of e-waste management, computer upgrading, and recycling. Offering workshops, training sessions, and online courses will equip educators with the necessary skills and information to integrate sustainability. Developing certification programs in collaboration with educational associations and organisations, or badges for educators (e.g., microlearning approaches), is possible, further promoting their professional growth and recognition. Through such initiatives, it would be possible to foster a culture of computer upgrading and recycling that addresses the environmental impact of e-waste and the need for sustainable technology consumption.

However, it is important to acknowledge the potential barriers to success. The process of developing sustainable device literacy can be time-consuming, requiring the acquisition of a brand-new body of knowledge. Indeed, teachers already grapple with the challenges of a crowded curriculum and the burdens of heavy workloads, so this aspect must be considered.

Arguably, a key function of schools and higher education institutions is to serve the needs of society by nurturing highly skilled, ethical, and critically informed citizens. There is an expectation that teacher knowledge and skills will evolve as society evolves. Technology will undoubtedly continue to evolve in the next decade, albeit with natural limits imposed by human factors. The rise of ChatGPT and other AI (Artificial Intelligence) engines poses a sustainability threat to society with their carbon footprints [24]. The exact energy cost of a single AI model is challenging to estimate. Researchers have estimated that creating the much larger GPT-3, which has 175 billion parameters, consumed 1287 megawatt hours just in preparing the model for launch before any consumers started using it [25]. As responsible educators, e-waste reduction is a high priority worldwide because the future will bring new technologies like these which will tax the environment.

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