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Internet of Things (IoT): Education

Implications for Students with Disabilities

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Glossary

AT	Assistive technology
IoT	Internet of Things
LMS	Learning management system
NFC	Near field communication
RFID	Radio frequency identification tags
W3C	World Wide Web Consortium
WCAG	Web Content Accessibility Guidelines
WoT	Web of Things

Author Biographies

Scott Hollier is a senior research officer in the Department of Internet Studies and the Department of Electrical & Computer Engineering at Curtin University. He specialises in the field of digital accessibility and is the author of the book *Outrunning the night: a life journey of disability, determination and joy.* Scott is also an internationally-recognised researcher and speaker; consultancy areas include consumer-based support for service organisations, developer-based support for ICT professionals for web and app-related work, and support across different organisational roles to achieve compliance with digital accessibility standards such as WCAG 2.0. Scott also lectures at Edith Cowan University, Western Australia and the University of South Australia in the areas of information management and web accessibility. Scott is also an active participant in the W3C Web Accessibility Initiative Research Questions Task Force. In addition, Scott is legally blind and as such has both a professional and personal understanding of the importance of accessibility.

Dr Leanne McRae is a research officer at Curtin University. Her current research interests revolve around disability, digitisation, and education, with special interest in the Internet of Things. Recent publications have focused on MOOCs, physical cultural studies, and social media in education.

Katie Ellis is Associate Professor and senior research fellow in the Department of Internet Studies at Curtin University, Western Australia and the convener of the Curtin University Critical Disability Research Network. She has worked with people with disabilities in government, academia and the community and has convened disability research advisory panels. She has authored and edited nine books and numerous articles on the topic. She began a Discovery Early Career Researcher Award (DECRA) in 2013 to investigate the impacts of the changing television environment on the social inclusion and exclusion of people with disabilities.

Mike Kent is Associate Professor and Head of Department at the Department of Internet Studies at Curtin University, Western Australia. Mike's research focus is on people with disabilities and their use of, and access to, information technology and the internet. His other area of research interest is in higher education and particularly online education.

Executive summary

A 6-month research project was undertaken at Curtin University to determine the significance of the Internet of Things (IoT) in a tertiary education context. The research consisted of both an analysis of the current literature – focussing on consumer-based IoT, the IoT and disability, and the IoT and education – and interviews conducted to determine the perspectives of IoT of five students with disabilities.

While the deployment of this technology in higher education, particularly in relation to students with disabilities, is still in its infancy, recent developments – such as the ubiquitous availability of smartphones, improvements in consumer-based IoT engagement such as standalone digital assistants, greater affordability, as well as the ease of collecting real-time data – provide significant opportunity for IoT innovations and solutions. The potential to seamlessly link students to their learning environment – in traditional classrooms or remotely – has great promise. In addition, students access the IoT via their own devices, thereby enabling their preferred assistive technologies (AT) and their individualised settings. Nevertheless, it is also critical that issues relating to privacy, security and interoperability are also addressed within the IoT context.

Recommendations

While IoT in higher education is still an emerging technology, particularly in relation to access for people with disabilities, universities need to seize the opportunities presented and develop plans to both engage with, and develop, these technologies in a learning and teaching environment. They also need to ensure that these technologies are interoperable with student’s own technology, particularly AT and to address the challenges to the privacy and security for both students and staff presented by IoT technologies.

In addition, this report recommends:

1. The implementation of IoT solutions should focus on the use of personal smartphones as the primary IoT interface device for students with disabilities.

2. The IoT equipment associated with learning such as a digital whiteboard should have the ability to provide its output to students via an LMS or app. This would ensure that students with disabilities can process the data with their preferred AT.
3. The use of IoT to observe students and the lecturer to enhance the effectiveness of learning materials and facilitate the implementation of improvements.
4. All IoT-related implementations will need to consider privacy, security and interoperability as highlighted by the ongoing World Wide Web Consortium (W3C) Web of Things (WoT) research.
5. Any IoT solution must be accompanied by training to ensure that all staff and students are able to use it effectively.
6. Trials of standalone digital assistants such as Google Home and related devices such as Google Chromecast should be provided to students with disabilities to assess their long-term effectiveness in improving educational outcomes.
7. The applicability of using a digital assistant as a real-time captioning device warrants further research.
8. IoT solutions for classroom environmental controls should be explored for automatic optimisation for student learning – this could be available to students via an aggregated voting system, possibly via a smartphone app.

1. Introduction

1.1. Introducing the Internet of Things

In technical terms, the Internet of Things (IoT) – also referred to in broad terms as the Internet of everything or the Web of Things (WoT) – is defined as the enabling of advanced services by interconnecting both physical and virtual things based on existing and evolving interoperable information and communication technologies (International Telecommunications Union, 2012). However, the more specific relevance of IoT to this research project can be best described by Kevin Ashton who is generally credited for creating the term in 1999. Ashton stated that, "Today, computers, and therefore the Internet, are nearly wholly dependent on humans for information. The problem is, people have limited time and accuracy, all of which means they are not very good at capturing data about things in the real world. And that's a big deal" (Ashton, 2009). As a result, humans need help in collecting data and assessing its usefulness – and this is where the role of IoT becomes so important.

With an estimated 8.4 billion devices connected online by the end of 2017 – up 31 per cent on last year and growing to an estimated 20.4 billion devices by 2020 (Gartner, 2017) – few would argue against the idea that the evolution of IoT and its data implications are indeed a big deal. As Ashton explained, the benefit for IoT is that it allows us to monitor and interact with devices in a way that humans find difficult. For example, a fitness tracker can simultaneously monitor distance travelled and heart rate while also providing real-time information about the location of the individual via GPS and even share information on social media, something which would be virtually impossible for a human to do without interrupting the primary activity of exercise.

While IoT is generally considered to be a new concept due to the recent explosion in product availability, its conceptual roots can be traced back 75 years. The 1940 comic strip Dick Tracy (Figure 1, © Chicago Tribune New York News Syndicate) introduced a two-way wristwatch which could be easily used for communication and interaction between humans and devices, thereby embedding the concept into popular culture (Press, 2014). Indeed, with the arrival of the Apple Watch in 2015 (Hopewell, 2015) touted as a revolutionary way for people to interact with devices and each other, it is unsurprising that our fictional stories and dreams about interconnectivity have been acknowledged as largely realised in the form of everyday online consumer-based products. In short, our hopes for always-on and always-engaged are now a practical reality, with smartphones, wearables and digital assistants being a part of daily life.

Figure 1.1 Dick Tracy and his two-way watch

However, while the ability to collect data with IoT is now a fairly common occurrence, its benefits and applicability still need to be grounded back into real-world applications. Furthermore, it is important to consider if there are sections of our society that may further benefit from these developments, and if those benefits are being fully realised in the rush by large companies to achieve IoT dominance for their particular product or digital ecosystem.

In this context, it is important to consider a group which to date has had little specific mainstream focus in the IoT area –the approximately 15 per cent of people with disabilities worldwide (World Health Organization, 2017). For people with disabilities, the ability for every device to interact with us and with each other has the potential to yield significant benefits. In terms of engagement, the arrival of smart appliances is already offering benefits – examples include the ability for a person in a wheelchair to give verbal commands to an IoT-enabled washing machine if the buttons are out of reach, or for a blind person to receive a notification on a smartphone when dinner has finished cooking in an IoT-enabled microwave. However, while these benefits are largely based on people with disabilities engaging with specific devices, it's the ability to use low-cost sensors to collect data on how people with disabilities interact with online technologies which can yield important information about both disability and environment and – as the world continues to move towards a new connected reality – it's this that could have a profound impact on lives.

It is with both interaction and data collection in mind that this project focused on exploring an extremely important aspect of IoT use – the pursuit of education. IoT offers an opportunity to adjust and monitor the learning environment in real-time based on sensor feedback, remotely move objects around, and improve engagement through off-the-shelf products such as smartspeakers containing digital assistants. While this technology has great potential to improve the learning experience of the entire student cohort, it is perhaps particularly pertinent for those students with a disability. Students with disability are underrepresented in higher education making up between 8-14% of students in the United States and United Kingdom (Sachs & Schreuer, 2011), and to 5.58% of commencing students in Australia (Department of Education and Training, 2016). To date little specific research has been undertaken in the area. As such, the outcomes of this project are designed to be a starting point – to provide guidance on how IoT benefits the educational outcomes of students with disabilities. The scoping study aims to evaluate the educational benefits of IoT solutions and determine current access to them, yet also research any implications regarding barriers to this such as competing hardware and ecosystems. It also aims to provide support to future policy initiatives as the impact of IoT for people with disabilities continues to evolve.

1.2. Research aims and objectives

This research aimed to address the key question:

How does the Internet of Things (IoT) benefit the educational outcomes of students with disabilities?

Objectives included:

- To assess the educational benefits of current and emerging IoT products;
- To assess the benefits and risks of IoT within a single-interface, app-based interface and whole-of-ecosystem IoT classroom solution by competing providers;
- To determine the relevance and implications of IoT as it relates to the educational needs of people with disabilities;
- To undertake interviews with students with disabilities to identify the practical needs of students with disabilities in an educational context; and
- To provide recommendations and strategic guidance on appropriate IoT solutions with policy recommendations for Curtin University, the tertiary education sector and industry.

2. Consumer-based Internet of Things

2.1. Characteristics

In 1999, when the use of the term IoT was likely first coined by Kevin Ashton, the idea of devices connecting to us and each other was considered more of a theoretical concept. At that time, the Internet in the public realm was primarily experienced via a web browser on a desktop computer, and the need to connect other devices that could provide meaningful data in real-time was unavailable to the general public in practical terms (Ashton, 2009). However, in today's largely ubiquitous ability to connect to the Internet, the reverse is true – the concept of not being able to connect online at a time, a place and a device of our choosing would likely be considered unusual.

However, while connectivity is an essential part of the IoT device characteristics, for the purpose of this project there are four essential characteristics for a device to be considered a 'thing' in IoT terms (Palma, Agudo, Sánchez, & Macías, 2014):

- *The device must be capable of collecting and transmitting data: IoT devices need to exist in environments in which information can be collected and either sent to another device or directly to the Internet.*
- *The device must have the ability to operate with action-based responses: IoT devices can be programmed to act according to particular conditions.*
- *The device must have the ability to receive information: IoT devices must be able to receive information from the network.*
- *The device must be able to support communication: IoT devices by nature belong to a network of devices that can communicate with each other through other nodes in the same network.*

One of the practical examples where IoT differs from other devices on the Internet is that the data does not have to be provided to just one user – IoT information can also be used by others online, and largely in real-time. For example, a sensor that can read the outside temperature can transmit that data in real-time, and other devices in turn can then make use of that information to inform a variety of people for a variety of uses.

2.2. Initial challenges

While the practical implementation of IoT was considered unlikely in 1999, by 2000, as awareness of IoT as a concept began to resonate in academia, some companies took bold steps to attempt to bring IoT to the consumer market. One such initiative was provided by LG in the form of the Digital DIOS refrigerator (Appliance Design, 2000). The refrigerator was heavily marketed as being a refrigerator that featured built-in web browser and e-mail capability – it could detect when groceries needed replacing and could order new groceries for the consumer online. While, conceptually, the refrigerator seemed promising, the product was ultimately a failure.

The primary issue was that in most regions the refrigerator required dial-up Internet connectivity and, as such, this would tie up the one telephone line. This, in turn, meant that if people wanted to use the web or check their e-mail they'd be forced to use the built-in features on the refrigerator, and the primitive interface, and obvious ergonomics, made it uncomfortable for people to use such features while standing in their kitchen. Furthermore, the refrigerator required the user to manually enter the locations for each object so it knew which products were present or missing and, even if the refrigerator was successful in detecting the absence of a product, at that time there were few online grocery stores in existence, let alone one that could automatically order a replacement. The $US20,000 price tag was also considered prohibitive (Appliance Design, 2000).

Fast forward to 2015 and manufacturers were well positioned to again experiment with the IoT space. Smart toasters, connected thermometers and fitness collars for dogs were some of the less common devices launched that year (Burgess, 2015). However, only a year later, at the 2016 Consumer Electronics Show (CES) in Las Vegas, the world's largest consumer technology event, it was demonstrated that IoT was not only for the unusual and quirky – there also were major manufacturers, including Samsung, LG and Amazon, that were actively creating products for the IoT space, including smart washing machines, smart lighting and even the return of the smart refrigerator (Anonymous, 2016). At CES 2017, the catchphrase of the conference was 'Alexa everywhere', a reference to Amazon's digital assistant being built into a range of connected devices including cars, lamps, ceiling fans and security systems (Kastrenakes, 2017).

Products highlighted in CES tend to appear in retail stores during the course of that year, suggesting that most of the products exhibited at CES are well beyond a proof-of-concept stage. However, while most homes at the time of writing are unlikely to have invested much in such IoT equipment, there are many who do view it as a rapidly emerging and profitable industry. The global IoT devices market is forecast to grow from $US7 billion in 2014 to $US45 billion by 2019, increasing at a compound annual growth rate of approximately 44 per cent (Roby, 2016). Based on the push by both large and small manufacturers in recent times to embed IoT in our everyday devices and the potential for large profits in the process, it's likely that IoT will form a significant part of our daily living in the not-too-distant future.

2.3. Rapid growth

Given that the original focus of consumer-based IoT in the early part of this century was largely unsuccessful, it is important to note that in many ways the feature set of devices today remain similar to first-generation IoT products. For example, current models of smart refrigerators have a similar feature set such as identifying and ordering groceries online. The important difference, however, is that current consumer-based IoT devices are broadly effective in meeting consumer needs. As such, it is important in the context of this research to understand the reasons for this recent change.

The first major difference between the initial offerings and modern-day IoT is connectivity. Through the use of faster networks and the ability to access those networks from anywhere – be it in our homes via fixed broadband or remotely via wireless broadband – the increasing view of the Internet being an essential service ensures that most consumers have a choice of connectivity options supporting IoT in our homes, cars and even clothing (G3ICT, 2015).

The second issue that has largely been addressed is the ability to obtain specific information from our environment. While the original LG refrigerator required manual entries to explain how each sensor connected to a particular grocery item, sensors are now able to accurately draw on a variety of cloud data to assist with that process. An example of this "deep learning" ability to analyse in depth a very specific occurrence is the smart hairbrush which can provide a variety of information about the hair and scalp beyond brushing technique, and compare the data with other users online (Bradshaw & Waters, 2017).

The third issue that has impacted on the recent uptake of IoT in the last few years is affordability. With the emergence of cheap sensors, there has been a proliferation of novel applications aimed at providing personalised services – from location and routing to daily energy consumption (Gupta, Holloway, Heravi, & Hailes, 2015). The affordability of increased ways to monitor our environment, combined with affordable consumer devices to interact with it – such as the $US50 Amazon Echo Dot smartspeaker (Figure 2.1) or the $US35 Raspberry Pi credit-card sized computer (Figure 2.2) – demonstrate that the convenience of IoT does not have to be viewed as expensive or a luxurious addition to the home.

Figure 2.1 Amazon Echo Dot smartspeaker

Figure 2.2 Raspberry Pi computer in case

The final difference, and arguably the one which highlights why 2015 marked the start of IoT significantly entering the mainstream, is the improvement in how consumers interact with devices (Choudary & Narayanan, 2017). The clunky interface of the LG refrigerator has been replaced today with smartphone apps and the more conversational digital assistants thanks largely to computer speech recognition that, in many instances, is close to rivalling human speech recognition – and it is getting better all the time (Mitchell, 2016; Dores, Reis, & Vasco Lopes, 2014).

For example, the first popular consumer standalone smartspeaker was the 2015 release of the Amazon Echo, containing the Alexa digital assistant. This has significantly contributed to a rapid rise in IoT popularity, with Amazon creating a conversational way to interact with IoT. Amazon have also invested in a $US100 million fund for start-ups to create products around voice applications, demonstrating a cohesive strategy to wrest control of this space (Choudary & Narayanan, 2017).

Although IoT is a relatively new product category in the consumer space, these factors also highlight why there is interest in this from a retail perspective. With IoT products now being used by retailers as in-store kiosks and interactive displays – via tablets, scanners, wireless printers and radio frequency identification tags (RFID) – interest in IoT has now appeared on both sides of the shop counter. In essence, IoT benefits retailers in three critical areas – customer experience, supply chain and the provision of new channels with related revenue streams (Amata-Mccoy, 2016). With the conversational user interface of Amazon's Echo via the popular Alexa – and more recent offerings in the form of the Google Home smartspeaker (Figure 2.3) and Apple's forthcoming HomePod – interest in the applicability of IoT is likely to continue growing in prominence in both commercial and retail settings (Roby, 2016).

Figure 2.3 Google Home smartspeaker

2.4. Benefits and issues

While there are many benefits for consumers associated with the arrival of IoT in the public realm, there are also a number of issues that need to be considered as IoT solutions continue to be embraced. The broad benefits of IoT for consumers can be placed into six categories (Borne, 2014) as follows:

- Tracking behaviour for real-time marketing: the ability to quickly assess and benefit from, the target market. For example, if our IoT-enabled devices determined it was raining in our current GPS location, advertisements relating to umbrellas and information on the nearest store could be provided so that we could respond to the situation in real-time.
- Enhanced situational awareness: the ability to understand and make changes to our real-time environment. For example, features such as updates on

traffic based on movement and GPS sensors in cars and smartphones allow us to take a quieter route home from work.

- Sensor-driven decision analytics: the ability to use big data to record lots of information at once which can then be analysed. For example, information collected from telescopes analysing space phenomenon (Lenz, Meisen, Pomp, & Jeschke, 2016).
- Process optimisation: For example, the use of sensors to monitor the speech rhythm, pitch and tone of a lecturer to determine the optimal requirement for student engagement (Heng, Yi, & Zhong, 2011).
- Optimised resource consumption: the ability for an electrical appliance to complete a task based on its ability to determine the optimal point at which the costs are cheapest. For example, a smart washing machine assessing the cost of power and water.
- Instantaneous control and response in complex autonomous systems: For example, a series of sensors monitoring different aspects of a patient in a hospital, adjusting medication and treatment in real-time as sensors assess data sent and received from each other (Chiong, 2017).

While these benefits and related examples provide a number of scenarios where IoT can be beneficial, there are also significant issues in reliance on IoT – primarily privacy and security.

The issue of privacy has become particularly concerning in the consumer space with the rise of digital assistants. While IoT in the form of sensors that provide anonymous data are not necessarily a significant privacy issue, the focus on using always-on devices that are always listening to possible commands has clear privacy implications. For example, the Alexa digital assistant in the Amazon Echo is always listening to surrounding audio so that it can begin interactions with the word Alexa. As a result, private conversations and noises can potentially be transmitted to Amazon all the time while the device is turned on. Likewise, smartphones are also able to constantly monitor our surrounding audio and location. While there is no suggestion that companies such as Amazon are using personal conversations for malicious purposes, there is ongoing debate about the trade-off required between IoT ease of use and privacy concerns (Bradshaw & Waters, 2017). In essence, developments in the rapid growth of IoT in relation to privacy should focus on being proactive and preventative rather than reactive and remedial (Weinberg, Milne, Andonova, & Hajjat, 2015).

Security, while separate to privacy, is often considered to be a related issue (Bian et al., 2016). With smartphones constantly broadcasting our GPS location to a variety of sources – including the operating system manufacturers, telecommunications providers and others depending on smartphone permissions – there is significant concern about who has access to this data and how it is being used (Lin & Bergmann, 2016). In addition to user controls there are also issues of authentication methods and the vulnerabilities of IoT to hacking (Weber, 2010). For example, if a malicious person were able to hack into a consumer-based IoT system, they could potentially disrupt settings relating to settings in the home and adjust the temperature of the refrigerator or even the entire home, both of which could have potentially serious health implications, without the individual even being aware of the changes taking place. While this is just one example, there is growing concern that there is not enough protection provided in policy and legislative frameworks to address such issues. Furthermore, it is unlikely that most households would have the technical knowledge to implement effective security solutions (Skarzauskiene & Kalinauskas, 2012; Weber, 2010).

In addition to consumer security issues there is also the issue regarding the authentication of the data collected by devices. In the context of this research, the ability to both collect data and rely on its validity and authenticity are critical if the data is to be used effectively (Lin & Bergmann, 2016)

A final issue that is particularly relevant in the international context of IoT is interoperability, highlighted by an aspect of IoT referred to as WoT. While IoT and WoT are often used broadly as interchangeable terms, WoT differs slightly in that the focus is on ensuring that new technologies need to be coordinated into a multi-vendor ecosystem. In essence, WoT simplifies the creation of IoT through its consideration for interoperability and therefore makes IoT applications easier to implement (Zhao & Qi, 2014; Lin & Bergmann, 2016). This is particularly highlighted in the dominance of the Amazon Echo as a smartspeaker – many current IoT products on the market at this time are only compatible with the Echo and cannot be used with other products such as the Google Home.

Furthermore, the Amazon Echo currently has restrictions that prevent many of its features from working outside the United States, meaning that international consumers are likely to end up in a scenario whereby IoT-enabled devices contain useful features for consumers but the smartspeaker required to use them cannot be purchased nor operated locally (Kastrenakes, 2017). To address this issue, organisations such as the W3C are currently focusing on progressing WoT so that a coherent and interoperable infrastructure is created for sharing, finding and accessing sensors and their data, potentially addressing issues related to the large number of protocols supported by the various sensors from a huge number of sensor manufacturers (Guinard, 2015).

2.5. Products relevant to this research

The number of IoT-related products are wide and varied. Importantly, the connected nature of IoT makes it difficult to limit the discussion to a single product or even a single product category. Therefore, for the purpose of this research, it can be broken into two broad category types – industrial IoT (which is geared to helping enterprises perform efficiently and reliably) and consumer IoT (which includes wearable devices and home automation) (Scardilli, 2015). In essence, industrial IoT is the part that is responsible for generating and communicating with us and other devices, while consumer IoT focuses on providing a human-friendly user interface for people to gain access to the data.

Within the industrial IoT area, data is provided by sensors and actuators. A sensor provides inputs about its current state (internal state + environment), while an actuator is a device that is used to affect a change in the environment such as the temperature controller of an air conditioner. Such devices are generally quite specific in what they can do as the number of tasks are limited by the resources available– these are often very constrained due to limitations of size, energy, power and computational capacity (Sethi & Sarangi, 2017). While there are a diverse range of sensors and actuators that can provide a range of data, many IoT-related products make use of the smartphone for two reasons – it is a collection of many different types of sensors, and most people already have one in their possession or one can purchase one for a relatively affordable price (Hortelano, Olivares, Ruiz, Garrido-Hildalgo, & López, 2017; Gupta et al., 2015; Roby, 2016; Thomas et al., 2013). Indeed, smartphones can contain sensors such as a GPS location sensor, movement sensors (accelerometer, gyroscope), camera, light sensor, microphone, proximity sensor and magnetometer.

In addition to the popularity of sensors in smartphones, IoT-based projects are often reliant on other sensors for measuring temperature, pressure, humidity, medical parameters of the body, chemical and biochemical substances, and neural signals. A class of sensors that stand out is infrared sensors. These predate smartphones and are now being used widely in many IoT applications – in cameras, as motion detectors, to measure the distance to nearby objects, to determine the presence of smoke and gases, and as moisture sensors (Sethi, 2017).

However, in order for these sensors and actuators to communicate data, communication methods need to be implemented. Initial IoT projects focused heavily on the use of RFID (Huang, 2013; Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012; Rashid, Melià-Seguí, Pous, & Peig, 2016; Weber, 2010; Zhao & Qi, 2014) and on its benefits – its short range and low power. Near field communication (NFC) is also emerging as another popular IoT data communication method for short-range due to it becoming an increasingly popular feature in modern smartphones (Palma, 2014). For a greater range, Wi-Fi and Bluetooth are also popular methods of IoT communication (Hortelano et al., 2017; McDonald & Glover, 2016).

However, while smartphones are a popular choice for IoT projects, they are only applicable for specific projects due to the devices being largely self-contained, thereby limiting their IoT use to what is built into the product. As such, there are low-cost IoT kits available which can provide a degree of flexibility in connecting sensor and actuators with the ability to record and communicate the resulting data. Two such popular IoT kits relate to the Arduino (Cornel, 2015) and the Raspberry Pi range of devices (Traeg, 2015). The Arduino is entirely focused on executing a specific task even if that task involves reading multiple sensors or controlling multiple components via output pins. The typical Arduino device has a very small amount of RAM, about 2KB, and 32KB of flash memory for application storage. For data that needs to be preserved, there is also 1KB of EEPROM storage.

By contrast, the Raspberry Pi is a credit-card sized fully fledged computer. As such, it is capable of running operating systems such as Linux off an SD card and has a variety of connectivity options such as USB, networking capabilities and video that can output to composite or HDMI (Traeg, 2015). In essence, both devices are capable of recording and storing sensor data and providing connectivity for that data to other devices.

However, while such devices are no doubt useful, in order for consumers to be able to understand and respond to IoT data, consumer devices with an easy-to-use user interface are required. Consumer-based IoT products generally contain one of three types of interface:

- A built-in user interface such as a screen that provides connectivity. For example, a display built into a refrigerator (Appliance Design, 2000) (Anonymous, 2016).
- The use of a smartphone with an associated app or digital assistant (Bradshaw & Waters, 2017; Kastrenakes, 2017).
- A smartspeaker standalone digital assistant such as the Amazon Echo, or a digital assistant built into other products (Kastrenakes, 2017).

An example of a current model IoT device with a built-in user interface is the Samsung Family Hub smart fridge. This features a large touchscreen that not only provides information on the contents of the refrigerator and interactions with the sensors and actuators, but also provides a mechanism to control other IoT devices in the home.

However, the second interface, the smartphone-based interaction for IoT, is by far the most popular. This makes it a relatively straightforward mechanism for manufacturers that want to create IoT-enabled products that consumers can control running either Google Android or Apple iOS on the iPhone or iPad. In this scenario, manufacturers develop the app which can generally interact with the device via the home network.

The third user interface is the use of a digital assistant. There are currently two popular smartspeaker models – the Amazon Echo and the Google Home, with a third, Apple HomePod, scheduled for release towards the end of 2017. The smartspeakers work by allowing consumers to provide voice commands to the smartspeaker which in turn interacts with the IoT device and provides verbal feedback – additional information is also sent to an app as to the effectiveness of the command and current device status. Smartspeakers have become popular due to their ability to provide information quickly such as weather information, playing music and performing basic tasks in the form of alarms and timers. Amazon Echo also has its own apps, known as skills, which allows third-party developers to add additional functionality to the smartspeaker.

Although the industrial and consumer aspects of IoT only represent a fraction of its possible uses, these aspects provide effective representation as to how IoT relates to disability and its current implementation in education.

3. The Internet of Things and disability

3.1. The Internet of Things as an assistive technology

The initial discussion in defining the characteristics of the IoT argues that conceptually it is about addressing the limitations of people – that the core need for an IoT future relates to the fact it is difficult for us to collect large amounts of data and assess its importance in real-time in a way that is helpful (Ashton, 2009). As previously discussed, IoT addresses this limitation by using industrial IoT to collect and broadcast data, with consumer-based IoT providing a mechanism for us to understand and use it in a beneficial, assistive, way. While the term AT is generally used to describe specific hardware and software that provides access to information and communications technologies for people with disabilities, the fact that such technologies have the capacity to provide assistance based on human limitations suggests that IoT is, in principle, a form of AT in itself (Hennig, 2016).

As such, the role of IoT in supporting people with disabilities is a profound one, and at the heart of it is the significance of connectivity – the connectivity of physical objects that people use and how they can facilitate everyday life. Currently, over a billion people (15 per cent of the world's population) are estimated to be living with disability (World Health Organization, 2017). With a strong correlation between the increase in incidence of disability in an ageing population and a lack of support services, there is a risk that, without a connection to society, people with disabilities may become socially isolated or overly reliant on family and friends for support. As such, IoT as a connected AT can offer people with disabilities another part of the solution – a connection to assistance and support, effectively another avenue to achieving a good quality of life and facilitating participation, both socially and economically (Domingo, 2011).

In practical terms, the benefits of IoT are achieved via a network of interconnected physical devices which offer the opportunity to connect people more comprehensively and naturally to their surroundings, and in turn can allow more efficient exchange of information between devices and people (Kiryakova, Yordanova, & Angelova, 2017). As such, it can be argued that the potential benefits of connected things are limitless, especially for persons with disabilities (Haouel, Ghorbel, & Bargaoui, 2016).

While the benefits and issues of IoT fall into similar categories that have been previously discussed due to the way they provide assistance to people broadly, there are a number of ways in which IoT can be used for disability-specific applications.

3.2. The Industrial Internet of Things and disability

One such benefit is the ability for sensors and actuators to provide disability-specific monitoring – this can lead to significant improvements to the health and well-being of people with disabilities. An example of this is highlighted in a project created by AT&T and Premorbid in which a wirelessly connected wheelchair has the ability to increase user independence and freedom – the concept uses IoT to easily monitor the wheelchair for comfort, performance, maintenance requirements and location, with adjustments made in real-time (AT&T, 2015).

A second example of an industrial IoT benefit is the ability for IoT to assist people with disabilities in the achievement of everyday tasks independently such as going shopping. One example focuses on a system used to help a group of vision impaired people to find their way in a store. The store's RFID system used software to guide the vision impaired people and assist them with scanning products to determine the relevant item (Domingo, 2011). Another retail example is a pilot system developed to assist wheelchair users to interact with shopping items placed beyond their arm's length – with the help of augmented reality, IoT and RFID technologies, this allowed the user to digitally interact with the physical items on the shelf (Rashid et al., 2016).

However, the primary focus of industrial IoT applications for people with disabilities is currently centred on e-health, particularly in relation to monitoring the health of the ageing population (G3ICT, 2015) and outpatient medical needs. The focus in this regard is on providing proactive support to people with medical conditions and potentially extending both their quality and length of life (Dores et al., 2014).

Examples relating to the application of IoT in e-health include the ability to provide real-time monitoring of the health of seniors in aged care facilities based on an intelligent monitoring system. This includes the use of sensors and actuators to monitor temperature, and assess vital signs such as heart rate and movement. While care givers are able to respond immediately to any adverse change in conditions, seniors also have the ability to get attention if they are in distress (Huang, 2013).

Another example of IoT in this regard has been applied to tracking patients in e-health/telehealth applications to monitor patients once they are discharged (Chiong, 2017) . A point of particular interest is that while the monitoring system is similar to the aged care example, the implementation of the model infers that medical staff are able to provide improved individual support to outpatients based on IoT feedback such as distance travelled, temperatures in their location, and food intake. As such, the non-intrusive sensors are able to assess if outpatients are following the prescribed treatment and, in addition, identify key factors that may have an impact on their health based on lifestyle patterns.

In all these examples, the use of IoT data is used in a largely passive way, either without the individual's specific awareness in the case of e-health or collated to assist in user choice such as the shopping example. However, the broader benefit of IoT for people with disabilities comes in the ability to assess data based on their own needs in their own way and, in this regard, it is necessary to review the applicability of the IoT user interface as it relates to people with disabilities in the consumer space.

3.3. Consumer-based Internet of Things and accessibility

As previously discussed, there are essentially three types of user interface common to consumer-based IoT products – a built-in interface, or interaction via a mobile device such as a smartphone or a standalone device such as a digital assistant smartspeaker. The ability for people with disabilities to interact with IoT, and technology in general, depends largely on two factors – the accessibility of the interface and the use of accessible content to work with on this interface.

To make an interface accessible, disability-specific AT generally needs to be built into the product. Examples of this (Hollier, 2016) can include:

- Screen reader: a text-to-speech application that reads out computer and Internet-related information to assist people who are blind or vision impaired.
- Screen magnifier: a magnification tool to enlarge screen content.
- Themes: high-contrast themes to allow people with visual impairments to change the colours to a more comfortable setting (such as white-on-black) and increase the size of mouse pointers and text.
- On-screen keyboard: assistive keys enable people with mobility impairments to 'type' by using a pointing device to select letters and words on the screen.
- On-screen alerts: visual messages can appear in place of audible sounds to help people who are Deaf or hearing impaired.

With regards to IoT devices that have built-in interfaces such as smart refrigerators, there are currently few that have any such AT features built-in, nor are there mechanisms to add features due to the proprietary nature of the interface. Furthermore, even if devices such as a smart refrigerator were to have an AT such as a screen reader to support people who are blind, it is unlikely that, due to the proprietary operating system of the device, the tool would be familiar. This would therefore mean that it would require the user to learn yet another way to control and interact with the device.

However, there is an initiative that may provide an access solution – the Global Public Inclusive Infrastructure (GPII) created by Raising the Floor. The purpose of GPII is to "… ensure that everyone who faces accessibility barriers due to disability, literacy, digital literacy, or aging, regardless of economic resources, can access and use the Internet and all its information, communities, and services for education, employment, daily living, civic participation, health, and safety" (Raising the Floor, 2017). The concept of GPII focuses on the use of cloud-based user preferences that include disability-specific AT requirements. For example, when a user approaches a device such as a ticket machine, the user has a method of identification so that the user interface of the device recognises that assistance is required and offers this in real-time. For example, in an IoT context, the GPII could provide support in that a compatible device with a built-in interface, such as a smart refrigerator, could potentially change its interface based on the user's profile. For example, the interface could be set up with high contrast and large print for a low vision user, or the touchscreen buttons could be lowered for a person in a wheelchair. However, the concept of GPII remains elusive at this point in time. As previously discussed, privacy and security concerns are also present – people with disabilities would need to share information about their disability-specific needs with unknown third parties, and this raises concerns. In addition, the large-scale network required to support the sheer volume of devices is not currently available (Hollier, 2013).

The use of smartphones and other mobile devices as an alternative user interface for IoT is therefore currently the most popular, and the most accessible, option available for this purpose (Apple, 2016; Google, 2016; Hollier, 2016). This is due to the two most popular mobile and tablet operating systems, Apple iOS and Google Android, containing a wealth of accessibility features. As such, interaction between a smartphone and IoT device can be achieved via an app or a digital assistant in an accessible manner. Furthermore, there are a number of disability-specific benefits in the use of a smartphone to gather information and interact in real-time. For example, the use of parking sensors in a shopping centre can provide useful information to a smartphone app so that a person that needs a disabled parking bay can quickly identify which ones are available and which one is closest to the shop being visited (Lambrinos & Dosis, 2013).

Another important benefit of the smartphone as a way to interact with IoT that is of particular significance for people with disabilities is related to affordability. Traditionally, it has been expensive for people with disabilities to purchase the required AT – these generally needed to be obtained from a third party, then installed on the relevant device (Hollier, 2006). However, modern mobile devices generally have AT built-in – even budget mobile devices tend to have the same accessibility features – thereby providing both affordability and choice for people with disabilities to engage with IoT (Hollier, 2016).

However, while smartphones and apps are an effective way to engage with IoT, much of their success depends on the need to ensure that the content within the apps is accessible. To achieve this, the apps need to be created in compliance with the W3C Web Content Accessibility Guidelines (WCAG) 2.0 (Brown & Hollier, 2015). If this is not achieved, it is likely that the apps will not work with the built-in AT and render the app, and in turn the functionality of the IoT, inaccessible.

Another, and the newest method for interacting with IoT, is interaction via a standalone device such as a digital assistant smartspeaker. At this time, the products in this category include the Amazon Echo and Google Home. With Apple’s HomePod due for release shortly and Microsoft indicating plans for its own smartspeaker, this is likely to become an increasingly popular method for IoT engagement.

While the smartspeaker itself does not contain much in the way of AT, it differs from the built-in IoT interface in that it is viewed as more of a complementary device rather than a replacement for a device such as a smartphone. As such, the smartspeaker yields several benefits, particularly for people with vision impairments who can request and receive information in audio, and for people with mobility impairments who can use verbal commands to engage with devices in scenarios where using a smartphone may not be as quick or as convenient. As a result, the ability to perform tasks such as setting a timer, finding out the weather, playing music or performing a web search can be achieved more easily and in a timely manner.

Importantly, both the Amazon Echo and Google Home have the ability to provide responses in both a spoken manner via the smartspeaker itself, or visually by displaying the equivalent text in a smartphone app. As a result, there is potential for the output of smartspeakers to appeal across a variety of disability groups based on their preferred way of receiving information. However, at present, there is little choice for users as to which way the smartspeaker outputs this information, meaning that the benefits cannot currently be realised in a consistent manner, nor in a public space due to the on-screen output being tied to the app on a personal smartphone. As such, there is a need for manufacturers to consider a standardised approach.

3.4. The Web of Things and disability

As discussed previously, the WoT has the potential to improve the interoperability and standardisation of IoT interaction. Research regarding this includes work undertaken by the W3C which has begun to specifically assess ways in which improvements can be made to ensure that people with disabilities can enjoy the benefits of IoT. In particular, web standards could extend the open web platform to resolve many of the accessibility issues currently associated with IoT accessibility, in a similar way to how the W3C provided standardised guidance in the form of WCAG for addressing accessibility issues in the creation of web content (Brown & Hollier, 2015). As such, using IoT principles, WoT can potentially provide a robust application layer for innovation to thrive on, while also addressing current accessibility issues.

A significant part of this fledging international work is highlighted in the exploration of IoT accessibility issues and associated user cases (World Wide Web Consortium, 2017). One such example discussed is the use of IoT in home automation products and services which could improve the quality and reduce the cost of custom-made solutions for ambient assisted living. However, it is also important to note that a lack of accessibility consideration is likely to have the opposite effect – it would exclude people with disabilities. Specifically, if a "… digital control for the heating system could be even less accessible than the physical knob if it is not designed with adequate consideration. This includes the design of the user interface as well as the protocols and APIs in the background" (World Wide Web Consortium, 2017). This example highlights that an IoT future can have a significant detrimental impact if accessibility is not considered at all levels of implementation.

To therefore assist in providing guidance on such issues, W3C has proposed five initial key WoT accessibility requirements and related examples that should be considered for ensuring that people with disabilities can have effective IoT engagement. The examples (World Wide Web Consortium, 2017) are as follows:

- Interoperability: for example, a connected television can be controlled by a smartphone with a screen reader.
- Accessibility support: for example, a connected projector provides access to the presentation data in addition to the video output.
- Configuration: for example, a profile with preferences, such as large text, could be sent from one device to another.
- Privacy: for example, a connected refrigerator suggests shopping lists but does not share specific dietary and health needs.

- Security and safety: for example, a connected pacemaker is safe from manipulation and failure.

These W3C examples highlight the significant potential for people with disabilities if accessibility is considered. In addition to these everyday task-oriented benefits, it also has the potential to provide connected social engagement (Akhtar, 2016) and holistic solutions such as the benefits in e-health previously discussed.

However, while it is clear that the accessibility of the web, smartphone apps, and other mobile technologies have changed how we perceive and interact with others and our environment (Sullivan & Sahasrabudhe, 2017), it is important to consider that the benefits and issues of IoT are extending beyond the home and medical applications. One such area of great significance is the applicability of IoT in the pursuit of education, and its likely impact in supporting the learning needs of students with disabilities.

4. The Internet of Things and education

4.1. The creation of new learning environments

The implications of IoT as an AT due to its ability to provide connectivity to people has great promise in many aspects of daily life, including in an education context. Using the benefit of connectivity, IoT can allow educators to create an environment that supports the acquisition of knowledge in a new, natural and efficient manner consistent with students' needs and expectations (Kiryakova et al., 2017). However, unlike other fields, the use of IoT needs to be both helpful and discrete as, alongside the benefits of enhanced learning, there is also the risk that the implementation of IoT solutions in the education space can disrupt learning. As such, the implementation of IoT solutions in education must be carefully considered.

In recognition of this, most initial IoT solutions have focused on the discrete use of sensors and actuators in the classroom – this has led to a number of education initiatives and partnerships in recent years and has resulted in the installation of industrial IoT to provide a regulated, non-intrusive and consistent learning environment. One such example of a corporate initiative is the company Xively, which was awarded a contract to IoT-enable UK schools as part of DISTANCE, also known as the Internet of School Things project, a consortium founded to advance education through technology (LogMeIn, 2013). This initiative included implementing both environmental IoT and designing a customised user interface for monitoring the data.

Initial efforts in the IoT education space have focused primarily on the learning environment rather than specific interactions with students, on allowing solutions to be helpful and non-intrusive – this included room temperature adjustment, optimising the use of resources such as determining the number of students in the classroom, and the reliability of equipment. Another example is the implementation of equipment monitoring in a media classroom whereby the status of equipment, maintenance requirements and environmental factors such as temperature were monitored using RFID (Zhao & Qi, 2014).

While such projects have led to the creation of a complex network relating to both environmental adjustment and teaching equipment, its implementation has also been broadly successful in integrating communication, calculation and control into a complicated and dynamic education system (Li & Li, 2014). For example, a practical example of this in use was a study of classrooms at a number of universities in Spain whereby control was accessed through NFC and the information shared via radio frequency. The collected data lead to the creation of a control classroom tool that displayed the status of all the classrooms graphically and also connected the data with social networks (Palma et al., 2014). The research noted that while RFID was a more common method for collecting data, a number of these universities – including the University of Extremadura where the study was based – relied on NFC for identification due in part to the ability for staff and students to develop applications. The Arduino hardware kit was also used in the project and Xively provided support in relation to the coordination of teacher schedules with associated equipment (Palma et al., 2014).

In an attempt to expand the concept beyond just classroom equipment, several IoT projects have investigated the concept of a smart campus to determine if other IoT-related aspects can be brought together cohesively in order to have an even broader impact on learning outcomes (Lenz et al., 2016). One such concept that focused on flexible, media-rich and remote learning is the concept of the LMS iCampus. With significant investment in sensor networks, mobile technologies and associated data processing, this project focused on the potential for significant pay back in terms of connectivity between learning, research and the surrounding environments within which students live. The concept also aims to collect enough data so that students could be supported based on their individual needs (Thomas et al., 2013). Navigation in such an environment could be provided by Bluetooth beacons which could use the location of students in different ways, for example to automatically direct them into different virtual collaboration spaces based on the group to which they are assigned (McDonald & Glover, 2016).

A more detailed explanation of how this could work is highlighted in a second project whereby the emphasis is placed on a mobile social network that continually provides data on the needs of a student. For this research, a smart classroom prototype was designed to provide seamless tele-education. The prototype integrated voice recognition, computer vision, and other technologies and turned a physical classroom into a natural user interface to provide a tele-education experience like in a real classroom. An architecture based on the web service technology was proposed to overcome the weakness in extensibility and scalability. In addition to using sensors in smartphones as previously discussed, this project included data such as friendship network structure by using mobile phone data. The social contexts, such as call logs, text messages, location, proximity and time, were taken into account. The location-based services were triggered when users entered or left the range of the campus. While the project was more focused on a proof of concept rather than specific social interactions, it demonstrated that the combination of IoT technologies could interpret both physical and social elements that could potentially impact on educational outcomes (Yu, Liang, Xu, Yang, & Guo, 2011).

However, while the ability to combine significantly different data into a cohesive education model is enticing, such projects also raise important issues relating to privacy and security. If a tertiary institution has access to a user's location, text messages and social media presence, there is significant potential for that data to be misused or the individual to be misrepresented and, although the projects tend to limit data collection to on-campus activities, such concerns remain. It is important to remember that while IoT can provide improved connectivity to devices and each other, it should not be at the expense of individual freedoms. Furthermore, the complexity of the smart campus learning networks may require IoT solutions to be both intrusive and complex, and therefore more difficult for the user to operate – this is a common risk of larger IoT solutions that try to include all aspects of a student's life (Kiryakova et al., 2017).

4.2. The expansion to learning for all

While the use of IoT in terms of equipment monitoring and big picture concepts of a smart classroom are likely to be important, the critical aspect at this time is that educational institutions understand how to leverage the IoT so they can enhance the quality of education in a practical and individualised way (LogMeIn, 2013). As such, with regards to the education needs of people with disabilities as it relates to IoT, it is the use of smaller individualised projects that have the potential to yield the most benefit. While these are limited at this time, there are some applicable examples. One example includes the creation of a learning system that uses RFID technology to identify different materials such as a child's toy sheep, with the RFID-tagged toys then being used to help young D/deaf children learn how to use sign language (Domingo, 2011). This works through software that enable a child to use a RFID reader to scan an item's tag, capture the unique identifying number and send it to the computer's software via the USB connection. While this implementation of IoT is a relatively simple one when compared with the large networks previously discussed, it demonstrates effectively how IoT as a concept can support the education outcomes for people with disabilities.

While not specifically related to people with disabilities, there are other individualised research projects that demonstrate how IoT can be used in education to achieve a specific purpose. A project was designed to improve student engagement in computer and electrical engineering experiments used sensors and actuators connected to the Internet, Bluetooth or GSM networks. As a result of these technologies and cloud-based data gathering, students were able to participate in the creation of practical, up-to-date innovative technical approaches which in turn provided a richer education experience (Pantilimonescu et al., 2014). This project demonstrates how the applicability of IoT can significantly enhance learning outcomes beyond traditional teaching methods.

While the implications of IoT in a specific teaching context are important, there is one particular project which offers promise in how an IoT project could be implemented to support people with disabilities in the classroom, and support their learning outcomes in real-time. This project examined the focus of 197 non-disabled students across 14 recorded lectures and considered how both environmental factors and the delivery of the information by the lecturer affected the focus of the students. Five parameters from the physical environment and 22 features from the lecturer's voice were analysed. Tools used to conduct the research included NFC and RFID to locate students, cameras and microphones to monitor student interest in the lecture via an emotion-monitoring system used in distance learning, and a variety of sensors in smartphones and other devices to monitor which factors affected student focus (Uzelac, Gligoric, & Krco, 2015).

The results of the research suggest that the mean formant frequency and the standard deviation of number of autocorrelation peaks (both extracted from the lecturer's voice), the average of the absolute deviations of noise levels, the level of CO_2, and the humidity all affected the focus of students (Uzelac et al., 2015). Importantly, the research trial concludes that "the received results ensure us that it is possible to implement a smart classroom system that would be able to determine in real-time if a classroom environment is optimized to maximize student's ability to concentrate on a lecture at a given moment. In addition, received results can be used as a basis for a more generalised system that would be able to automatically optimize a learning environment in real-time" (Uzelac et al., 2015).

The implications for such a study with regards to people with disabilities suggest that this non-intrusive use of sensors and actuators has the potential to adjust a classroom environment in real-time. This thereby provides maximum support, both in terms of the environmental factors in the room and in improvements in the delivery of the educational material itself. This research also suggests that it is possible to monitor the needs of people with disabilities beyond the classroom – this is seen in both the smart campus model and the e-health implications of outpatients described previously. Further, from this detailed monitoring beyond the classroom, there is also likely to be improvements that can be made back in the learning space for people with disabilities. However, such assessment would need to consider all privacy and security implications.

While it can be seen that most efforts in the IoT education space are focused more on the use of industrial IoT, the recent popularity of standalone digital assistants has been trialled in the library of a secondary school with some notable results. It was seen that the use of an Amazon Echo provided benefits to students in relation to quickly finding out information and educational material, allowing more time to staff (as many of the basic questions were answered by the Echo), and, anecdotally, making students politer due to the specific way a statement had to be phrased for the Echo to understand it (Scardilli, 2015). From the perspective of people with disabilities, it is likely that the inclusion of specifically established smartspeakers in learning environments could potentially be useful for similar reasons.

However, while demonstration of IoT in an education context does highlight potential benefits from both technological and educational standpoints, it is critical to determine how this relates specifically to students with disabilities. As such, this research will now focus on how students with disabilities at Curtin University understand the implications of IoT, their perceived benefits and issues of these associated technologies, and how IoT could be used to improve their educational outcomes.

5. Perspectives from Curtin University students with disabilities

5.1. Research methodology

While the literature provides great insight into the potential of IoT, it is important to also understand the perceived benefits, issues and practical nature on which IoT could be implemented in a university classroom context. This in turn also has implications for other uses of IoT in the wider education sector and within industry in an employment context.

In order to gain such an understanding – particularly as to how the rapid evolution of IoT can be applied to, and perceived by, people with disabilities in an education context – in 2017 a series of qualitative interviews were conducted with students with varying disabilities studying at Curtin University. The research commenced in March 2017 with the commencement of the literature analysis, and creation of the information sheet, the consent form and the interview questions. Due to interest being expressed by the W3C, the research questions were formed by Dr Scott Hollier with support from Shadi Abou-Zahra from the W3C Web Accessibility Initiative. Ethics approval was sought and approved in August 2017. Five students participated in the research with hearing, mobility and print disabilities respectively.

5.2. Interview analysis

The interview questions focused on four specific categories – the awareness of students to particular IoT devices, their use of IoT, the way in which IoT could be used in an education context, and the perceived limitations and issues associated with IoT use. The students also discussed how to overcome any perceived concerns in order to facilitate implementation of IoT in the university setting in the future.

5.2.1. Students' awareness of particular IoT devices

In relation to a conceptual awareness of IoT, most participants provided a clear definition of the concept, with the final participant providing a similar description once the context of the question was established. This suggested that all students had a clear understanding of IoT as a broad concept. However, in terms of use, very few had any smart devices in the home and the awareness of products such as smart ovens, smart lighting and smart televisions were limited.

5.2.2. Students' use of particular IoT devices

The primary use of connected devices related to computer-based interfaces via Microsoft Windows, an Android smartphone and, in some cases, a game console. While the sample size was relatively small, it was interesting to note that there were no Apple smartphones used by the students.

Students responded that IoT devices in the home were generally not as popular. Google Home was used by one participant, with some awareness by others. The participant that used Google Home also used Google Chromecast, and made the observation that a 'wish-list' for IoT would be to have the Home provide live captioning by listening to the broadcast and outputting the recognised screen to the Chromecast along with the video. Further, while there was little familiarity with Amazon Echo, most likely due to its lack of availability in Australia, the use of Alexa as a digital assistant was familiar to one participant. In addition, while the use of a standalone digital assistant was limited to only one participant, the use of digital assistants in smartphones were common and their importance in a disability context was generally recognised as making things easier – this includes the AT features built into the students' Android-based smartphones. Of note, participants were generally only familiar with the accessibility features directly relevant to their own needs.

5.2.3. Students' use of IoT devices in education

In terms of IoT in an education context, all participants agreed that IoT could be conceptually useful in an education context if control was tied specifically to the smartphone or possibly to a specific app. While all participants acknowledged that IoT in the classroom was unlikely to be something implemented in the near future, there was significant speculation as to how a smartphone and specific apps could be used to control IoT in a positive way.

The first suggestion was for the whiteboard to display its contents on a smartphone app, with the contents being able to be saved and edited. This would have the resulting benefit of having notes written by the lecturer immediately available on the preferred device of the student.

A second participant raised the potential of using sensors attached to lecturers and students to monitor performance and assess concentration levels. The participant even volunteered to be involved in such an experiment. This point was of particular note given a similar approach was identified in the literature review.

The participants also debated how they could provide input into the environmental factors in a classroom such as lighting and temperature. A common suggestion was that this could all be controlled by an app, but only during the times of the particular class. Participants agreed that there would also need to be an aggregated system so that if a class of students all wanted to change the temperature, the app would adjust in favour of the most requested option. However, it was acknowledged that students with disabilities would still need to have their specific requirements met, and that these might differ to those of the other students in the class.

Another point raised was in relation to adjusting existing infrastructure to include IoT solutions. It was suggested that Curtin University LMS Blackboard, which at present is only able to record lectures, should be expanded in functionality – examples included providing whiteboard content for students studying online, and enabling the provision of both recorded lectures and synchronised content.

5.2.4. Students' perceived limitations associated with IoT use

While many benefits were discussed, there were also many concerns raised by the students with regards to IoT in general and in an educational setting. The first of these was concerns regarding interoperability, that is determining whether the IoT equipment would work on their particular device, and with their particular AT needs. The concern is that if an IoT classroom solution is locked to a particular ecosystem, it may not allow students with disabilities to use their preferred AT solutions.

Privacy and security also featured highly among the concerns of the students. In particular, students were concerned about the potential outcomes if classroom-based IoT were hacked, leading to classes being disrupted as heating, lighting and critical classroom equipment started to malfunction or perform in an unexpected manner. This was a key factor as to why the students suggested that a timed, aggregated app could be used to ensure that students could only adjust an environment when it was actually their class, and that access to IoT was not instantaneous for the person changing things.

Another concern raised was that IoT could become a distraction rather than a solution. One student indicated that if students are relying on their smartphones to adjust the environment, it may also lead to phone-based distractions such as looking up social media rather than paying attention to the lecture.

The other major issue was in the ability for effective implementation. One student made the point that while the current official Curtin University app is great in providing class timetables and assignment content, it does not provide assignment due dates and as such cannot be completely relied upon. In the case of an IoT solution, it would be important to ensure that the solution worked effectively from the start – and on the preferred device of the student – without the need of multiple solutions to achieve a specific outcome.

5.2.5. Going forward

To bring the benefits and issues together into a cohesive way, all students agreed that the highest priority for any IoT solution in an education context for students with disabilities is the need for training. This includes training for staff as to how the IoT equipment can benefit education outcomes, and training for students to ensure that there is effective support to maximise the use of the equipment controlled by the device of their choice.

Overall, while the student sample is small, the data provides some clear messages for the use of IoT going forward. Firstly, despite the relatively recent addition of IoT to homes, there is general awareness of the concept of IoT and the potential benefits it can provide in an educational setting, both in terms of students broadly and students with disabilities specifically. For example, as discussed in the literature, the ability for both the lecturer and students to be monitored in real-time to maximise the learning outcomes for current and future classes is likely to have some significant benefit to the learning outcomes of students, particularly students that find it difficult to maintain attention.

Another aspect that is highlighted as a potential benefit of a standalone digital assistant such as the Google Home to the educational setting is in relation to lecture captioning. While the ability to immediately display the text-to-speech output as text captions synchronised to a video may seem challenging, all the components of such a solution are possible based on current technologies. Given the current constraints relating to time and cost involved in creating captions for students that are Deaf or hearing impaired, a trial of such a solution could be considered.

However, it was also noted that, for any IoT solution to succeed in an education context, two things must be achieved – the ability for students to successfully engage with the equipment in a secure environment, and the provision of training to ensure that both the teaching staff and students understand its benefits and how best to interact with it.

6. Conclusion

The purpose of this scoping study has been to provide a starting point on how IoT can benefit the education outcomes of students with disabilities. While the adoption of IoT in the education context has been relatively small to date, and in the context of disability even more so, the rapidly improving consumer-friendly nature of IoT within the past 2 years provides the potential for significant benefits to the learning outcomes of students with disabilities.

While the concept of IoT is not as new as generally believed, particularly for consumer-based products, there are several factors which have enabled IoT to reach a point where it is both useful and effective. These factors include the popularity of smartphones, the inclusion of AT features in popular consumer devices, the conversational nature of digital assistants and associated smartspeakers, and the affordability of IoT equipment such as sensors built into smartphones. Indeed, for IoT to be effective in an educational context, it is first necessary to use sensors and actuators that can collect, transmit and store data that relate to the education experience. This can include physical elements such as heating and lighting, classroom equipment such as output from the whiteboard, and even the monitoring of students and the lecturer in real-time. While the ability to do these things has been possible for some years – as noted by previous e-health and smart campus projects discussed in the literature – the practical implementation of IoT projects to assist students with disabilities has only been possible more recently. From the standpoint of educational institutions, it is these recent improvements to affordability for IoT equipment that now make it a practical reality for implementation.

Students that participated in this research were broadly familiar with IoT concepts and reflected the discussion in the literature that their smartphone and digital assistants provided effective mechanisms to engage with IoT. Suggestions as to how this could be achieved were similar to trials performed in other studies, and included the use of sensors and actuators to adjust the environmental controls of a classroom and the monitoring of the lecturer and students in real-time to determine how learning materials could be improved, both in terms of their delivery and reception by the students.

However, much of the discussion by the students related to how current learning issues could be theoretically fixed through the use of an IoT solution. Firstly, the students indicated that lecture recordings were limited in that they didn't convey data from the whiteboard, and that IoT could potentially provide this information to the LMS or app so that students with print disabilities or students that needed to learn remotely could get access to all the same learning materials. Secondly, the use of a standalone digital assistant such as Google Home, combined with a video display IoT device, could be used to provide real-time captioning through Google Chromecast. This could also potentially be delivered in various other accessible formats.

While these suggestions provide significant merit for further research, all students indicated that they had concerns about privacy and security. Another concern was interoperability. While all students that participated in the study used Android-based smartphones and Windows-based computers, they all agreed that IoT would only be an effective option if all students could use their preferred device with their preferred AT solution. This raises the importance of ongoing WoT work conducted by organisations such as W3C.

Importantly, regardless of the IoT solution being used in class, all students agreed that it is imperative that staff and students have training to ensure the effective ease of relevant and accessible IoT in the classroom. Such training would involve a focus on what IoT features were available, how the control mechanisms worked, and the benefits the technologies could deliver.

While most of the research into IoT solutions generally focused on the classroom itself, related projects discussed in the literature suggest that there may be benefits to monitoring students with disabilities outside class. One example might be the use of sensors attached to students to provide an improved understanding of student learning conditions such as eating and sleeping habits. However, any implementation of this would need to be discrete for the user, so that the monitoring did not interrupt the learning process, and would require privacy concerns to be clearly addressed.

Overall, the research suggests that IoT can have an important role to play in supporting the needs of people with disabilities in their education. As this area continues to grow with new and emerging products, additional research and practical trials of IoT equipment in the classroom are likely to provide additional insight into the benefits.

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