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A Participatory Design Framework For Customisable Assistive Technology

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A Participatory Design Framework for Customisable Assistive Technology

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Abstract

High product costs and device abandonment negatively affect people with disabilities who require Assistive Technology (AT), and poor product design is a root cause. The purpose of this research is to develop and demonstrate a participatory design framework for customisable AT, which addresses the need for low-cost assistive products that satisfy a broad range of consumers' needs.

This framework addresses two main gaps in the literature. First, user involvement in the design process of medical and rehabilitative products helps create products that are more effective but, although methods to involve users exist, there are currently scant techniques to translate the research data into design solution concepts. Second, adaptive mass customisation offers a way to reduce a product's cost by making it useful to more people and adaptable to a user's changing needs. Although the creation of one-off, tailored AT devices is discussed in the literature, there are no methods to support the development of customisable or adaptable AT.

Two-phases of participatory design research are described in the thesis, and make up the body of the design framework. First, a Delphi study is used to facilitate AT professionals working with individuals with disabilities in reaching a consensus on important design issues relating to a specific type of AT. An adapted morphological matrix is then presented as a novel way of applying the results of a Delphi study to concept generation. The second phase facilitates the involvement of AT users with disabilities in a series of participatory design workshops to create a final product design and prototype. The research approach was exploratory and Assistive Technology Computer Input Devices (ATCIDs) were employed as a sample technology domain to develop and substantiate the framework.

Three key contributions resulted from this work; a wide range of problems and design issues related to ATCIDs; a method for using touch panel technology as a customisable ATCID; and, most pertinent due to its transferability, a participatory design framework for customisable AT with recommendations for participatory design practice involving individuals with diverse disabilities.

Declaration

I certify that this thesis which I now submit for examination for the award of Doctor of Philosophy is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any Institute.

The work reported on in this thesis conforms to the principles and requirements of the Institute's guidelines for ethics in research.

The Institute has permission to keep, lend or copy this thesis in whole or in part, on condition that any such use of the material of the thesis be duly acknowledged.

Signature _____

Date _____

Acknowledgements

Abbreviations

AAC - Augmentative and Alternative Communication

ALS - Amyotrophic Lateral Sclerosis

AT – Assistive Technology

ATCID – Assistive Technology Computer Input Device

BCI – Brain Computer Interface

CAT – Comprehensive Assistive Technology (model)

DFMA – Design For Manufacture and Assembly

EEG – Electroencephalography

EMG – Electromyography

EOG – Electrooculography

EU-MHADIE – European Union - Measuring Health and Disability in Europe

FORTUNE –Forum of User Organisations Training for Usability and Networking in Europe

HAAT – Human Activity Assistive Technology (model)

HADRRIAN – Human Anthropometric Data Requirements Investigation and Analysis Project

ICF – International Classification of Functioning, Disability and Health

IQR – Inter Quartile Range

LED – Light Emitting Diode

MMG - Mechanomyogram

MPT – Matching Person with Technology (model)

NI – Northern Ireland

NPSDD – National Physical and Sensory Disability Database

OT – Occupational Therapist

PA – Personal Assistant

PC – Personal Computer

PD – Participatory Design

PT – Physiotherapist

QFD – Quality Function Deployment

ROI – Republic of Ireland

RSI – Repetitive Strain Injury

S&LT – Speech & Language Therapist

USAP - Usability, Safety, Attractiveness Participatory design model,

USAT – Usability Scale for Assistive Technology

USB – Universal Serial Bus (as in a USB key or memory key)

VOCA - Voice Output Communication Aid

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Chapter 1

Introduction

This thesis is about designing technology that meets the needs of people with disabilities. The introduction frames the work by justifying why this is important from a human and a societal perspective, and presents the key concepts that motivated the research questions and design.

1.1   Disability and the social model

About 15 percent of the global population has a disability [1] and, due to improved healthcare and longer life expectancy, this statistic is expected to rise [2-4]. A universal definition for disability does not exist [5] but, at present, many leading global and national bodies, including the World Health Organisation and Ireland's National Disability Authority, advocate an explanation which is grounded in the social model of disability [6]. The social model dictates that anatomical impairments manifested by health conditions or injury are not the agents of disability; instead, it asserts that environmental, technological and social barriers act as negative mechanisms to obstruct, isolate, exclude and effectively disable individuals from full participation [7, 8]. This assertion challenges the traditional medical model. Formulated in the 19th and 20th centuries by clinicians [9, 10], the medical model considers disability as a health condition or illness. It describes a person's functional impairments as the root cause of any disadvantages experienced [11] and focuses on curing

impairments and aiding people to conform and adapt to their surroundings. Essentially, the two models differ in their attitudes to societal responsibility versus that of the disabled individual.

The modern social model underpins this research, primarily because it emphasises a humanitarian and sociological perspective - and also because it was developed directly by people with disabilities [12], rather than formulated by the perceptions of a group of clinicians.

Reflecting the social model, this research adheres to the International Classification of Functioning, Disability and Health (ICF), and defines disability as a decrement in functioning that occurs when an individual with a health condition encounters barriers in their environment [13]. In order to grasp the definition's meaning, it's important to understand exactly what these barriers are and how they interfere with an individual's ability to fully participate in their culture. Armed with this understanding, specific and actionable ways to break down and clear those barriers can be more easily generated and implemented.

People with disabilities identify negative attitudes and social barriers to be the greatest obstruction to their well being [14, 15], and this is especially evident in the areas of employment and education. Employment is one of the fundamental ways that people participate is society; it provides avenues for assuming valued social roles [16] as well as opportunities to develop relationships at work and in the community [17]. However, in 2006, the Irish Central Statistics Office found that only four percent of persons aged 15 years and over with a disability are in

paid employment. Another Irish study showed that students with disabilities represent less than one percent of the total undergraduate population [18]. In parallel with this, although the historical perception of disability as taboo [19] is undoubtedly waning - stigma, expressed through people's negative attitudes towards an individual's bodily condition, is still regarded by people with disabilities as a block to societal inclusion [20, 21].

In addition to social obstacles, material barriers can hinder participation too [7]. Examples are readily found in the built environment, where kerbs, steps and heavy doors can make life in a wheelchair difficult to negotiate. Fortunately, legislation is helping; Irish building regulations [22] now present technical guidelines for accessibility and use requirements for people with disabilities.

Material barriers are found in mainstream technology too. For example, touch-screen phones can be challenging for people with visual and dexterity impairments because they provide few sensory cues and are very sensitive. Consumer electronic products like television remote controls and digital cameras are often loaded with functionality and have complex software architectures, making use difficult not just for people with cognitive disabilities, but also for older people not so accustomed to digital technology.

Fortunately, technology is not solely a barrier. Conversely, when designed and used appropriately, technology can serve as a powerful integrator [23, 24], enabling greater independence [25] and effectively closing the gap between individuals with and without disabilities.

1.2 Disability and technology

For most people, technology makes things easier. For people with disabilities, however, technology makes things possible.

Mary Pat Radabaugh
-former employee at the IBM Disability Support Centre.

Industrialised nations are currently experiencing the fourth technological revolution, based around information technology and web-based communication [26]. Although the very concept of technology seems ever evolving, its origin is ancient [27]. A common definition was formulated in 1937 by Bain [28], when he described technology as a term for all tools, machines, utensils, weapons, instruments, housing, clothing, communicating and transporting devices, as well as the skills by which we produce and use them. During the third technological revolution, which began in the mid - 20th century [29], and the present fourth revolution, our methods of learning, working and communicating have shifted enormously due to the introduction of the personal computer and mainstreaming of the internet. For the most part, technology changes the way people do things, but for people with disabilities, the right technology can, as Radabaugh stated, *make things possible*.

- <u>Assistive technology</u>

Assistive technology (AT) is an umbrella term used to describe technologies, equipment, devices, services, and environmental modifications used by disabled and/or elderly people to overcome barriers to independence, full participation in society and safe, easy activity accomplishment [30].

This definition of AT, devised by Hersh and Johnson [30], is supported by the Technology-Related Assistance for Individuals with Disabilities Act Amendments of 1994 (P.L. 103-218), known as the Tech Act and is used in this research because it advocates the social model. The Tech Act refers to AT, not as a medical intervention, but as an enabler for people with disabilities to gain greater control over their lives, participate and contribute more fully in their homes, schools, communities and work environments, interact with people who do not have disabilities, and benefit from opportunities that are taken for granted by people who do not have disabilities.

Not only can AT reduce the social and material barriers that people with disabilities encounter - it can also reduce personal and government expenditure by endowing individuals with greater autonomy and independence, and facilitating a more inclusive workforce. A 2011 report by the Disability Rights Network in the USA documented case studies to support their statement that 'workers with disabilities can be employed and be paid equally with the appropriate job development, training, work support, and assistive technology' [31] (p. 34). Further evidence of this comes from the USA National Council on Disability, who conducted a 19-month survey to better determine the cost-benefit of AT devices and services [32]. The study found that AT enabled 62 percent of working-age persons to reduce dependency on family members. Fifty-eight percent were able to reduce dependence on paid assistance, and 37 percent were able to increase earnings. Fifty percent were able to avoid entering a nursing home. Of the 42 users of AT who reported having paid jobs, 92 percent reported that AT enabled them to work faster or better, and 67

percent reported that AT had enabled them to obtain employment. When asked to estimate the impact of equipment on their quality of life, AT users reported that without the equipment, their quality of life on a scale of 1 to 10 was about 3; however, as a result of the equipment, it jumped to 8.4 points [32]. This study is out of date, having taken place in 1993, but given how much technology has advanced over the last 20 years, it is like that the results would still show a large, if not larger, effect on the lives of people with disabilities.

In another study, Pennsylvania's Initiative on AT conducted a multi-stakeholder survey involving 372 participants. When asked how AT equipment or services had helped them over the previous two years; they found that 38 percent and 56 percent said it helped them to be included in a school and community setting, respectively; 72 percent said it allowed for greater independence; 37 percent stated that it aided their employment opportunities; 52 percent said it reduced dependence on a carer; and 75 percent stated AT improved their quality of life [33]. There is no recognised figure available for the cost benefit of AT, but evidence is linked to the reduced requirements for state-subsidised care, welfare payments and special-needs education costs, along with a larger tax-paying work-force.

So, it's evident that AT can act as a social integrator and improve a person's ability to participate, but there are problems, as described below.

- Problem 1: The cost of AT

The cost of AT is relatively high when compared with similar mainstream products, and this can make it difficult for individuals to access assistive devices [34-36]. This higher price is caused in part by the fact that AT products tend to

target small, niche markets [37], and so suffer from poor economies of scale. The small market segments result from the wide array of unique consumer needs that products attempt to satisfy. An individual's needs can be influenced by a range of physical, sensorial and cognitive variables like dexterity, vision or hearing. To provide anecdotal evidence of this, although the following products used for comparison are not identical in functionality, a specialised AT joystick with five switches costs €350 (www.inclusive.co.uk), whereas a mainstream, gaming joystick with 12 switches costs €46 (www.pixmania.com), and a pushbutton AT switch costs €42 (www.inclusive.co.uk) whereas a mainstream, industrial pushbutton switch costs less than €1.00 (www.radionics.ie).[1]

Ways to reduce the price of AT are not evident in the literature, however, good design has that capacity. The literature shows that between 70-90 percent of a product's lifecycle costs, which includes all processes and materials used to create, use and dispose of a product [38], are established once a product design specification is completed [39, 40]. Optimising the AT product design process for cost could reduce the wide pricing gap between mainstream and assistive products.

- Problem 2: AT abandonment

AT abandonment is another significant problem. Studies show that between 30-80 percent of AT is abandoned by the user [41, 42]. A major factor which impacts on this is inappropriate design. Poor design leads to devices that are difficult to use, fail during use, and have poor aesthetics, which can make the user feeling stigmatized [41, 43, 44]. Lack of consideration of user opinion

[1] All prices last checked in April 2015

during device procurement, and changes in the user's needs over time are more bases for abandonment [41, 45]. These changes result not only from worsening impairments, but also as a consequence of user rehabilitation and improved anatomical functionality. Changes in user preference also contribute. The negative outcome of abandonment is that financial resources are inevitably wasted [46], while the disabled user experiences dissatisfaction and frustration.

At present, a hypothesis for a cure-all solution to the issues of costliness and abandonment is not clearly determinable in the literature, perhaps in part because there are so many disciplinary variables which affect these issues. These include the monetary resources available for the purchase of AT; the severity of disability experienced by an individual; the type of technology that is needed and obtainable; the changes in user needs; the availability of training; and the effects of family and other support systems.

At a high-level, this research aimed to address the identified problems of cost and abandonment by exploring and developing a design method for technology that is more sensitive to user needs. A framework for improved AT design was explored by synthesising theories from two disciplines: mass customisation from engineering, and participation from social science. The use of these two theories is justified below.

- Theoretical solution 1: Mass customisation

Mass customisation is the customisation and personalisation of products and services for individual customers at mass production prices [47]. Designing and producing customisable AT offers solutions to the problems of cost and abandonment in two ways. Firstly, AT devices that can be adapted to facilitate a

greater number of individuals' functional variables would have a larger target market, resulting in improved economy of scale. Funding constraints would, therefore, be less of an issue so more individuals could access the technology. The second benefit relates to how new products must be prescribed, purchased and used when individuals' needs change [41, 45]; appropriate customisable devices could adapt with these changes and reduce the associated frustration and abandonment. Furthermore, customisation of device aesthetics adds the opportunity for personalisation, self-expression and psychological ownership [48].

Currently, specific methods for designing mass customisable AT are not available, even though customisation has been cited as a desirable trait for AT [49-51].

- Theoretical solution 2: User participation during product design

The idea of involving users in the product design process of AT has been highlighted by a number of studies [52-57], but there are gaps in the literature. In 2008, Bridgelal Ram *et al.* [58] explained that although there is substantial evidence describing the benefits of user involvement, research concerning the process of involving users during AT development remains weak and poorly defined. In 2010, Allsop *et al.* [59] pointed out the need for a) guidelines and recommendations on existing processes and methods to involve disabled individuals in the design of healthcare technologies, and b) the development of effective ways in which users can be involved in the design of assistive and rehabilitation technologies.

1.3 Research aim

The aim of this research was to develop and demonstrate a participatory design framework for customisable AT, in order to address the need for low-cost AT products that satisfy a broad range of consumers' needs.

Users in the AT ecosystem include both experts who work with AT in a professional capacity, such as therapists and training providers, and end-users of AT who have disabilities. In response to the identified criteria for good practice in disability and design research, the intention was to develop a process that empowers participants while generating explicit and actionable design specifications for customisable AT.

The research is underpinned by the values of exploration and participation, whereby the researcher and AT users collaborate in order to ascertain and solve problems affecting technology use. The research is also defined as pragmatic because it explores and demonstrates the framework through the practical design of a new customisable product. These philosophies are integrated in a cycle of idea co-construction, co-reflection and co-evaluation, and in this way, the emergent framework is itself also a product of participatory research.

1.4 Research objectives

Objectives of this user-led participatory design research were:

1. To develop appropriate methods to collaborate with relevant user groups of AT.

2. To synthesise these methods in a design framework for customisable AT.

3. To address a process gap in the literature that exists between the states of *data collection and analysis* and *design action*.

In order to meet these objectives and demonstrate the framework, the practical development of a new AT device drives the research process. Assistive Technology Computer Input Devices (ATCIDs) were selected as the sample AT domain (this selection is explained and justified towards the end of the literature review). The focus on ATCIDs means a second set of objectives were also defined:

1. Determine problems / issues that users experience with ATCIDs.

2. Generate design criteria for ATCIDs.

3. Translate criteria to product solution concepts.

4. Develop an ATCID concept prototype with AT users.

1.5   Thesis Structure

This introductory chapter is followed by a literature review which investigates disability, AT and AT design. Chapter 3 then covers methods and includes details about the methodological motivations of the thesis, the research instruments used, procedures, participant sampling, ethical considerations, and the analysis processes. Chapter 4 describes the results from the research. These include problems and issues related to current ATCIDs, other design criteria for AT, and a customisable computer input device prototype.

Finally, Chapter 5 discusses the main findings from the research, and presents these three main contributions:

1. A participatory design framework for customisable AT.

2. Participatory design practice guidelines

3. Customisable ATCID design contributions, including a new method to use touch panel technology as a customisable switch, keypad, touch panel and joystick interface.

Chapter 5 also discusses the thesis' rigour, consistency and transferability to build confidence in the research.

Chapter 2

Literature Review

2.1 Introduction

This chapter contains a three-part literature review, as shown in Figure 1. In line with the social model of disability, people and their needs are the crux of this research, so the first part of the review contextualises people with disabilities and investigates the barriers to societal inclusion that they experience. Statistics from the Republic of Ireland are used to describe the landscape.

Along with medical intervention, AT is then identified as a way to reduce these barriers and satisfy people's needs, so the second part of the review examines AT and looks specifically at what makes a device satisfying or frustrating for the user. Users' journeys to technology adoption and abandonment are evaluated.

Design is established as playing a critical role in the success or failure of a device, so the third part of the literature review considers the AT design process and compares process models that emphasize the importance of end-users. Methods and theories for universal design, medical and rehabilitative technology design and relevant studies dealing with mass customisation and participatory design are evaluated. The scope of this section is bounded by the values of user-centred design and participatory research because, throughout

both the relevant social and technological literature, participation is identified as a compelling philosophy for the emancipation of minority populations, as well as a driver for the improved success of new product and system interventions.
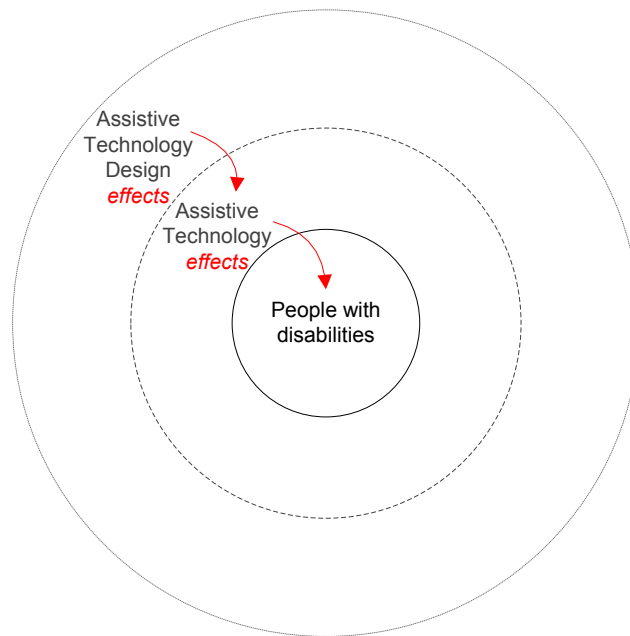
Figure 1 Literature Review Topics

After this is a review of AT computer input devices. Computer input devices are justified as a worthy sample AT domain through which to explore and develop a transferable design process. This section cites known problems with current ATCIDs and presents projected technological trends in the field.

Fundamentally, by evaluating studies and intertwining philosophies from the areas of both the social sciences and engineering design, this literature review exposes the multitude of disciplines that AT research encompasses and presents a foundation for this body of work. The review highlights the need for new research to provide an actionable design framework for customisable AT

which involves both users with disabilities and experts who use AT in professional capacity.

2.2 Disability and society in Ireland

In the introduction, disability was defined, and the social model of disability was established as a foundation for this research. This section presents an analysis of quantitative studies from the Republic of Ireland (ROI), which categorise disability and related social issues, to provide a snapshot of the national landscape of disability.

As mentioned, about 15 percent of the global population has a disability [4]. The 2011 census in the ROI found that almost 13 percent of the population, which is more than 595,000 persons, reported a disability. This is up from 9.3 percent in 2006. In 2006, the National Disability Authority and the Central Statistics Office carried out a National Disability Survey, the main sample of which was drawn from persons who reported a disability in the census [60]. Impairments were categorised as relating to seeing; hearing; speech; mobility and dexterity; remembering and concentrating; intellectual and learning; emotional, psychological and mental health; pain; and breathing. The most reported disabilities, cited by 56 percent of the participants, were related to mobility and dexterity.

Another resource that provides statistics about disability in the ROI is the National Physical and Sensory Disability Database (NPSDD). This database was established in 2002 to facilitate service planning and provision for people with a physical, sensory and/or speech and language disability. In order to be eligible

for registration on the NPSDD, people must meet certain criteria: they must have a persistent disability arising from disease, disorder or trauma and in the case of dual disability; they must have a predominantly sensory or physical disability; they must be receiving, or require, a specialised health or personal social service that is related to their disability and; they must be less than 66 years of age. Since many older people have disabilities and were not eligible to register, the figures are not directly indicative of the entire disabled population. Regardless of this, in the annual report of 2013, there were 24,391 people registered on the NPSDD [61]. The majority, at 47.5 percent, cited physical or multiple disabilities, including nervous system, communication, and musculo-skeletal system disorders as primary diagnostic categories [61].

Physical disabilities can affect participation in activities that require mobility, dexterity, speech and communication. These include autonomous self-care, education and social relationships [62]. Although it depends on the level and type of disability that an individual experiences, carers and other service providers often play a part in improving their quality of life. Physiotherapists, occupational therapists and speech and language therapists were most commonly engaged with, according to the NPSDD survey [61], but orthotists, dieticians, social workers, psychiatrists, psychologists, AT trainers, and public health nurses are all examples of service providers who work with individuals with disabilities to help them participate more fully in society. Of the NPSDD sample, it is noteworthy that 68.6 percent were using at least one assistive technical aid or appliance [63]. This statistic links to the second part of the literature review, where the use of AT is examined.

2.3 The user lifecycle of AT

When implemented appropriately, AT can reduce the social and material barriers that obstruct people with disabilities from full participation. In this section, the user life-cycle of AT is examined. The life-cycle of a product is the period of time between its formation and the point at which it is no longer available for use and involves the acquisition of raw materials; all production and manufacturing processes; and the product's use, retirement, disassembly and disposal [38].

This research is particularly concerned with the stages of AT product life-cycles that directly relate to the user, including product acquisition, training, use, adoption and abandonment. The design of a product effects its life-cycle, so in order to develop better design methods for better AT products, it's important to understand the life-cycle stages.

2.3.1 Contextualising AT

Before analysing the user life-cycle of AT products, this chapter contextualises the concept of AT. Cook and Hussey's [64] Human Activity Assistive Technology (HAAT) model proposes a framework for understanding how AT fits into the lives of those with disabilities. It is based on the human performance model [65] which is used to study the functional behaviour and performance of humans doing logical tasks. The model has four components: the human, the activity, the AT and the context, as shown in Figure 2.
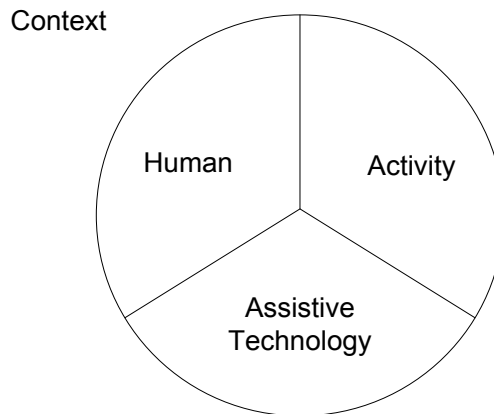
Figure 2 Cook and Hussey's HAAT Model

The activity refers to the procedure, operation or task to be undertaken by the AT user, and can be divided into a number of areas: activities of daily living, including eating, mobility, dressing and communication; work and education; and play and leisure including actions related to self expression and relaxation [64]. The human is the end-user of the AT, and this component is constituted of the user's physical and cognitive abilities and their previous experiences - including emotional ones. The context is the setting where the activity is undertaken and relates to society, culture and institution. Social context refers to other individuals who interact with the user, cultural context includes the user's experiences, family structure, heritage and community, and institutional context refers to policy and legislation. Finally, the authors define the AT component as the extrinsic enabler [64], providing the basis for improved human performance in the presence of disability. Essentially, the HAAT model provides a structure for classifying and building individual case studies in a holistic manner, encompassing criteria from law, therapy, engineering and psychology. Although both the HAAT model can undoubtedly help in the

construction of a design method for AT –it does not explicitly exist to inform the translation of data to design action. To better understand how this might be done, the next section begins the review of the user lifecycle of AT, and the first stage - product acquisition - is examined.

2.3.2 AT acquisition

People with disabilities acquire AT by different means. Often, public or private disability service-providers evaluate the needs of an individual, and prescribe and provide technology. Sometimes it is funded by the state, and at other times, individuals and their families carry the financial burden. The current economic climate has signalled budgetary cuts in almost every category of government funding in the Republic of Ireland, including disability services. For example, the disability allowance was cut by more than 4 percent in 2011 even though consumer price inflation was almost 3 percent [66]. Public funding was also cut for voluntary disability organisations [66] and the provision of special needs assistants in schools was discontinued. The economic downturn has also had an effect on AT acquisition. Previously, the government would very often have funded AT wholly or partly, whereas now, there are many cases where the monetary responsibility has shifted onto the individual with a disability and their carers. For this reason, it is increasingly important that AT is low-cost and that the selection and prescription processes are effective so that the investment is worthwhile. If purchasing decisions do not meet the needs of the user, resources are likely to be wasted either at a societal level [46], or, increasingly, at an individual level.

Although the issue of funding is one piece of the AT acquisition puzzle, other problems - relating to user satisfaction - have been identified as originating in this stage of the user lifecycle. Scherer and Galvin [50] found that the expectations a user has for a device are often not realised because their goals, perceived needs and preferences are not taken into account. This is a major issue since a user's perceptions of their goals and needs are tied directly to their quality of life. The World Health Organization Quality of Life (WHOQOL) Group define quality of life as an individual's perceptions of their position in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns [67]. Scherer and Galvin [50] argue for an process of AT selection that is collaborative and participatory, whereby a team that includes the user, their social circle, educators, therapists, doctors, employers and AT specialists, decide together on the best solution. They also posit that despite age or severity of disability, the user must be allowed to show his/her preferences to the greatest degree possible [50]. Other studies agree that goals and expectations should be discussed because these often differ among the group mentioned above [49, 68]. For example, some supporters may want an individual with a disability to access a computer for word processing while they, themselves, may wish to access it for social networking. In each case, the appropriate AT computer access solution may be different. Consequently, specialists who prescribe or recommend AT need to know about a variety of devices and be adept at facilitating the selection process. In addition to an understanding of the user's goals, the prescriber must take into account the users' unique physical, sensory and cognitive abilities, and

their environment [49]. These criteria for AT prescription resonate with the HAAT model in how they consider the person, activity, AT and context.

Reflecting both the categories of the HAAT model and the recommendations proposed by Scherer and Galvin, the Matching Persons and Technology (MPT) Model [69] is a tool which guides an AT assessment process that considers the person, the technology and the environment. The MPT worksheets help to determine goals and appropriate technologies, and guide discussion to identify specific AT intervention strategies [70]. The worksheets are completed with the individual with a disability and as such, advocate the involvement of the user in the decision making process.

Although therapists and specialists can use the MPT tool or similar guidelines to facilitate a holistic AT assessment process, other issues still exist within the domain of AT provision. In 2005, a Canadian focus group study [71] involving 18 AT users, providers and funders, found that problems and variability exist in the way people acquire and are funded for AT. Differences emerged in the availability of AT devices with regard to types, choice and replacement of equipment; the availability of AT services like professional assessment, training and follow-up; the referral and application process for AT; and the funder's knowledge of AT. From these results, the authors formulated recommendations proposing user participation during the decision making process; trialling the AT before purchase training; follow-up and maintenance service provision; and the continued opportunity to try and obtain newer, better solutions [71]. These recommendations reflect the social model of disability by placing the user's

involvement at the centre of the solution, and also support the idea of user participation in the decision-making processes that affect them.

This review suggests that although there are problems within the process of AT acquisition, the likelihood of device adoption is improved when there is communication between the therapists prescribing the AT and the disabled individual that intends to use the AT. This might involve the prescriber asking the user about their aims and expectations for their AT, and issues they have had in the past with both activities and technologies. When an AT user has a communication related disability, this collaborative process is more time consuming and challenging. However, different means of eliciting feedback can be used such as observing the user as they carry out an activity or utilise a piece of technology, or examining their body language during device trialling. To summarise, the literature shows that users and therapists should participate together in the decision making process, that training and maintenance assistance should be provided, and that follow up procedures should be protocol.

2.3.3 AT adoption and abandonment

Once an AT device is acquired, the next user lifecycle stage begins. This stage essentially involves the processes of use, adoption and abandonment. In this section of the literature review, studies that outline criteria for AT adoption and reasons for abandonment will be examined.

As mentioned in the introduction, even when barriers to obtaining AT devices are overcome, users often abandon - or stop using - their devices [72]. A USA

study involving 227 AT users found that 29.3 percent of AT devices are completely abandoned by service users [41]. However, other publications quote abandonment figures of up to 80 percent depending on the time period and type of technology [25, 41, 42]. Reflecting the recommendations for good practice in the AT acquisition literature, there is consensus among many authors dictating that consumer involvement in the use and maintenance of AT devices is important because devices are discontinued less frequently when users believe their opinions are taken into consideration [41, 42, 73].

Batavia and Hammer [46] recognised the following pattern in the user lifecycle of AT. A disabled individual is provided with an assistive device but recognises that it is inadequate to meet his or her needs even after attempted modifications. Subsequently, either the individual continues to use the device, remaining dissatisfied with it until it is no longer usable, or abandons the device at an early stage. Then, the individual chooses another device that satisfies the needs the previous device failed to satisfy. This pattern is often repeated two or three times before the individual finally acquires a device that adequately meets his or her needs. The authors state that a reason for this pattern is that consumers are not fully aware of their own needs with regard to AT [46]. This conclusion highlights the importance of professional guidance when choosing AT so that the likelihood of inappropriate device selection, user frustration and monetary waste is reduced.

Batavia and Hammer do not mention the issue of changing user needs [41]. A person may finally find an adequate device, but if their needs change, they must then enter again into the 'acquisition - use - adoption - abandonment' cycle. A

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user's physical needs can change for two reasons. The first is the degeneration of functional ability, but the second comes about if a person rehabilitates and enjoys improved function. For example, if therapy is successful and a person relearns to walk after being unable to, they may no longer need their wheelchair, or a user may find that they can manage a more complex device that will enable them to do more. However, even these positive occurrences of abandonment are tainted, as funding still needs to be sourced for a new device and additional training may need to be provided.

Additional explanations for AT abandonment include poor device performance, poor aesthetics, unreliable devices, difficulties during device use, environmental barriers, and fear of technology [41, 43, 44]. Device performance, reliability, ease of use and aesthetics relate to the design of a device, and where these are the reasons for abandonment, it's clear that if devices are designed with more careful consideration, abandonment would be reduced. Abandonment brought about by environmental barriers could be reduced through appropriate device selection, which fully considers and assesses the context of use for the AT. Also, design solutions could also make a difference by providing devices that are more adaptable to different environments. Fundamentally, the high rate of abandonment illustrates that a large percentage of AT devices may not be meeting consumers' needs and, consequently, there appears to be a need for more appropriate AT which is reliable, easily operable and aesthetically pleasing, and suits a range of users' needs.

Although not focused only on AT, Rogers' [74] Diffusion of Innovations theory defines discontinuance, or abandonment, of technology as a decision to discard

a product after previously accepting it. Among other criteria, Rogers [74], proposes that products perceived to have greater capacity for modification or customisation are rapidly adopted and slowly discontinued. He calls this criteria re-invention, and it is particularly appropriate for AT since changes in consumers' needs are a significant cause of AT discontinuance [75]. Also, many individuals with disabilities must make additions or alterations to their devices to meet their unique needs. For example, in disability organisations, rehabilitation engineers and occupational therapists will often work with service users to appropriately customise AT. This is frequently the case with power mobility aids where postural management in the form of body support systems must be individually designed and built into the generic frame of a wheelchair.

Kintsch [49] later developed a framework to conceptualise AT adoption, and highlights the necessity to customise AT, which supports Roger's [74] suggestion for re-invention. Kintsch [49] also states that devices must be durable and able to withstand large amounts of force from users; be lightweight yet able to sustain the impact from a fall to the ground; work in a range of different sorts of weather, temperature and lighting conditions; and interface with other technologies, be aesthetically pleasing, age appropriate, fashionable, and culturally and socially acceptable. In support of this, Lane and Mann [76] indicate that the attractiveness of devices is of great importance as they are often directly attached to the users' body and closely influence the users' appearance. Many devices are found to be discarded just because their users are unhappy with their appearance [76].

Stigma brought on by a disability was previously mentioned, but stigmatisation due to AT has also been found to be detrimental to a user's satisfaction with a device [20, 44]. For this reason, other people's acceptance or rejection of AT is a critical component of the success of a device in the long term. Specific areas that can contribute to stigmatisation include device aesthetics, gender and age appropriateness and social acceptability [20]. Further demonstrating the importance of aesthetics is Kintsch's [49] description of an anecdotal case where a schoolgirl 'was willing to try any alternative and augmentative communication device as long as it was red' [49] (p. 6). To combat this type of stigma, AT should be carefully designed so users do not feel singled out in their own social environment. In effect, devices should be transparent [44, 49]. Transparency here pertains to mainstream aesthetics, meaning that AT devices are better designed as mainstream, desirable products that do not look clinical, industrial or purely functional. This does not relate only to visual aesthetics, but also to other senses also. For example, in the case of AAC devices, digitised speech which sounds age and gender appropriate is preferable [77].

Ward [78] investigated qualities that people associate with good AT is a study involving 12 experienced AT device users. Device characteristics that users tended to prefer most were; effective improvement in users' functioning, affordability, operability, and dependability [78]. In the same year, Batavia and Hammer [46] carried out a Delphi study to identify a set of consumer-based criteria for the evaluation of assistive devices. The outcome was a list of 16 principles: affordability, consumer repairability, dependability, durability, ease of assembly, ease of maintenance, effectiveness, flexibility, learnability,

operability, personal acceptability, physical comfort, physical security, portability, securability and supplier repairability [46]. The definitions for these criteria are valid, but they are undoubtedly broad and generic. For example, affordability is defined by the authors as the extent to which the purchase, maintenance, and/or repair of a device causes financial difficulty or hardship to the consumer, and physical security is the extent to which a device is likely to cause physical harm, including bodily injury or infection.

As a consequence of the criteria's comprehensive and inclusive nature, the way in which a designer or clinician can apply them is unclear. Furthermore, Ward [78] and Batavia and Hammer's [46] studies are more than two decades old. In certain cases this would not be important, but the landscape of technology has changed immeasurably since 1990. Batavia and Hammer's study [46] is cited regularly in the literature even though the authors stress that the study is preliminary in nature because it used a small sample of consumers who were not necessarily representative of the population of long-term users of AT. This suggests that research is required to produce up-to-date, applicable criteria for the design and evaluation of AT.

Looking specifically at AT for computer access, since this domain of AT will play an important role in this thesis, Hoppestad [25] carried out a Delphi study in 2006 to develop criteria for assessing people with neurological impairments in order to provide them with computer access solutions. 33 Speech pathologists, physical therapists, occupational therapist, and educators participated in two electronic surveys. Prior use of AT, cognitive ability, sensory abilities, motor

skills, medical background, goals and contextual factors all emerged as important considerations [25].

In 2000, Angelo [72] conducted a focus group with six occupational therapists with experience in AT service delivery to identify essential components of a single switch evaluation during an assessment to enable optimal switch placement and switch use. 11 Items were identified; reliability of motor movements, volitional nature of movement, safety, movements that are easily performed, endurance, activities and positions the client assumes throughout the day and evening, efficiency of movement, previous successful movements, ability to perform timed response, ability to activate the access device within a given time frame, and time between switch closures [72]. These results are more specific and practical than Ward [78] or Batavia and Hammer's [46], and a clinician could apply them in their practice more clearly. This indicates that to produce applicable and actionable results from AT user research, the questions are better focused on a specific device or function, rather than a broad area.

The literature has provided a number of conceptual frameworks to guide good practice for AT selection and provision. Although much work has been done to produce a holistic approach to AT system understanding, the conclusions are broad. The broadness is useful because the outcomes can help conceptualise and frame AT in many different contexts, such as device evaluation, comparison, prescription or specification mapping. However, these concepts are not research tools for user-centred data generation and application in a design process. To address this, the next section examines technology design and focuses on methods to develop actionable design criteria.

2.4 AT design

This section of the literature review focuses on the design process of AT and is particularly concerned with literature where design methods resonate with the social model of disability. The product design process is investigated first, since the design of AT lies within this remit.

2.4.1 Product design and creativity

Product design is the generation and development of ideas through a process that leads to new products [79]. A key aspect to the modern model of product design is that in seeking a solution to a problem, there must be an overall, net beneficial change [80] and good practice advocates processes that aim to create positive, real solutions to evidence-based problems through the integration of visual arts, technology, engineering, environmentalism, marketing, ethnography, politics, morals and ethics. In this way, design is not only about the aesthetic, but also about the harmonising of multiple disciplines that constitute the entire life cycle of a product. Morris [79] argues that product designers must have the ability to take a defined perspective and look into the future; they must be capable in the areas of research and problem solving and should be empathic, communicative, imaginative, creative, analytical and logical [79].

Product design is practiced through many different philosophical approaches using many different models but the process traditionally involves these elements: research, concept generation, concept development, prototyping and testing. The traditional model of product design, also known as the rational

model [81], is linear and prescriptive and approaches these elements in a linear and systematic way. This rational design philosophy pairs with sequential engineering, whereby development processes are carried out in isolation, and the next stage cannot start until the previous stage is finished. Although, in theory, the rational model is a rigorous, repeatable and measureable method of design, real-life design is impacted upon by many extraneous factors. While planning and logic are required, designers must understand, explore, and create, based not only on research data, but also on intuitive judgment. For this reason, frameworks and theories in design need to support, and not minimise, the use of tacit, or implicit, knowledge [82]. This hypothesis is presented in the action-centric design model [83], which suggests that designers are guided by creativity and emotion, as well as research. Rittel [84] too recognised that design practice involves implicit knowledge, intuitive judgement, emotion and exploration. He argued that design is about more than a) problem definition, where the designer determines the problem and specifies the requirements that a solution should have and, b) problem solving, where those requirements are combined and synthesised into a production plan. He agreed with the architect Bazjanac [85], who said that design thinking and decision making are not linear and that problems addressed by designers cannot be analysed using a linear mental model.

Rittel conceptualised design tasks as wicked problems, defining those as 'a class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly

confusing' [86] (p. 141). The rational design model dictates that problems are definable and solutions can be scientifically determined, whereas Rittel says there is inherent indeterminacy in design problems [86].

Wicked problems are relevant to AT design because problems are arguably more 'wicked' in technology design when the target users are people with disabilities, since there are more decision makers involved in the adoption of a product, and the need states of end-users are more complex in comparison to the need states of mainstream technology users.

Buchanan [87] cites Rittel's properties of wicked design problems and proposes that solutions to wicked problems can't be true or false, only good or bad. Both acknowledged the impact of a designer's implicit knowledge in solving wicked problems by suggesting that there is always more than one possible solution, and solutions depend on the weltanschauung of the designer [84, 87, 88]. The German word weltanschauung translates to 'world outlook', and each person, be it a designer, a product user or other stakeholder, has their own. A person's weltanschauung is described by the phenomenology philosopher, Husserl, as the 'unfolding of the all-embracing a priori' [89] (p. 155) [90], where the 'a priori' is, put simplistically, 'what has come before'. Individuals make meaning of the world around them, but since the individual's consciousness is informed by their unique combination of experiences and context, one person's meaning will not necessarily match the next person's. Weltanschauung is a term that acknowledges this inherent subjectivity in an individual's point of view. Subjectivity in a person's outlook is part of their creative process, and this helps

to make some sense of why a gap in the literature exists between research data generation and design solution conceptualisation.

Although it doesn't make reference to the subjective nature of the design process, the United Kingdom Design Council's Double Diamond [91], shown in Figure 3, uses more expansive language to describe the stages of a design process, compared with the rational model. It invites the designer to explore and investigate many possibilities and seek different solutions to a problem by practicing divergent thinking and selecting the most appropriate answers through convergent thinking [92].
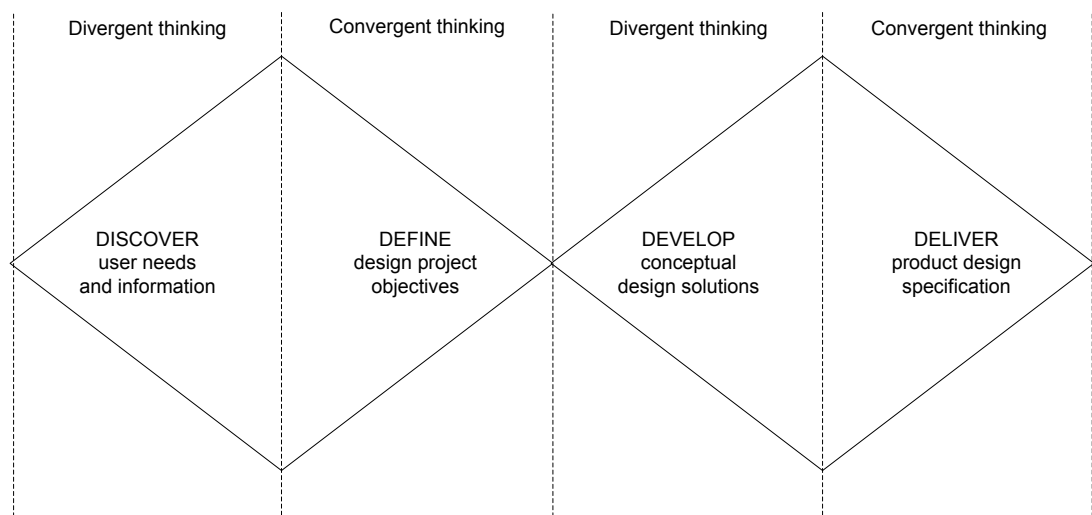
Figure 3 Depiction of the UK Design Council's Double Diamond design model

Divergent thinking [92] is the process of generating multiple ideas relating to a given topic, or exploring many possible solutions to a problem. It is about drawing on ideas from different disciplines to formulate new thoughts and concepts. It is non-linear and spontaneous, and brainstorming, mind-mapping and analogical thinking [93] are three examples of tools used for divergent thinking. Brainstorming is about generating lots of ideas about a certain topic or

problem, mind mapping is similar to brainstorming, though the links between ideas are always documented, and analogical thinking is about purposefully transferring an idea from a different context to the one under investigation. The psychologist Sternberg quotes Martindale about this idea in 'The Handbook of Creativity', saying that 'creativity involves the realisation of an analogy between previously unassociated mental elements' [94] (p. 137). Analogical thinking is an approach to associative thinking, which plays a role in divergent thinking. Associative thinking involves connecting previously unconnected ideas [95] to create new ones, and it happens when people, including designers, reflect on a situation from a new perspective by considering information that is not directly related to that situation [96]. The scientist, Henri Poincaré said the following about the importance of associative thinking in creativity in 'The Foundations of Science':

> To create consists of making new combinations of associative elements which are useful. [97] (p. 286)

The Double Diamond [91] model is based on two phases of divergent thinking, and convergent thinking [92]: discovering user needs, defining the most relevant needs and the design objectives, developing concept solutions and delivering a design specification [See Figure 3]. During the convergent thinking stages of 'define' and 'deliver', the ideas generated through the divergent thinking stages are organised and analysed so the best answers or solutions can be justified. The term *lateral thinking* [98] is often used interchangeably with the combined processed of divergent and convergent thinking.

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These creative thinking approaches help to guide the design of new products. The next section investigates product design approaches related to the type of products that might be designed using these tools, and may be useful for someone with a disability.

2.4.2   Universal design

Universal design, also known as inclusive design, echoes the social model of disability. It advocates that environments should be designed so that they can be accessed, understood and used to the greatest extent possible by all people, regardless of their age, size or disability [100]. There are benefits to both users and producers when universal design is considered in product development processes. First, because products are designed so that many different people may use them, it is socially ethical and inclusive. Secondly, for the producer, it can help to increase profits because the target market is larger.

Seven principles of universal design were developed in 1997 by a working group of architects, product designers, engineers and environmental design researchers in the North Carolina State University [101]. These principles were largely influenced by ergonomics [102], also known as human factors. Ergonomics is concerned with the assessment and design of products, systems and processes that consider the interaction between those entities and the people who use them [103]. A typical physical ergonomics issue is workplace design to ensure office workers sit in healthy positions in relation to their desks and computers.

The first principle of universal design – 'equitable use' - demands that the design is useful and marketable to people with diverse abilities, and that the same method of use should be allowable for all users. The second, 'flexibility in use', states that the design should accommodate a wide range of individual preferences and abilities, and that a choice of methods of use should be provided to facilitate a user's accuracy, precision and pace. The third principle – 'simple and intuitive use' - proposes that the design should be easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. Unnecessary complexity should be eliminated and information should be arranged consistent with importance. The fourth – 'perceptible information' - recommends that the design should communicate necessary information effectively, regardless of the user's sensory abilities. Different modes of communication, such as pictorial, tactile or verbal, should be used to facilitate use by people with various sensory limitations. The fifth is called 'tolerance for error', and advises that designs should minimise hazards. The sixth principle – 'low physical effort' - advocates that the design should allow efficient and comfortable use with minimum fatigue. The final principle is called 'size and space for approach and use', and states that designs should be appropriate regardless of the user's body size, posture, or mobility. In summary, universal design advocates the design of products that are suitable for everyone, so mainstream and assistive technologies become one and the same.

Hersh [104] came at this from a different perspective, and highlighted that an assistive product is more likely to develop a large market sector if it has additional applications for people without disabilities. This concept reflects the

concept of universal design, approaching the idea from the AT side, rather than from that of the mainstream. Universally designed AT would have a positive effect on the cost of the product and possibly negate the risk of any stigma associated with AT.

The Cambridge Engineering Design Centre has taken the concepts of inclusive design online to increase awareness of the processes and benefits of inclusive design. At their website[2], they have compiled a number of methods to assess the utility and usability of products, which can be implemented at different stages of the design process. The group champion user participation for better inclusive product design and advise the use of various design approaches, including the implementation of customisable and modular design to minimise the difficulties of adaptation to particular users. This advice reflects the ideas of flexibility and adaptability, which were proposed as criteria for better AT adoption [46].

To some extent, many products - even those that have not been purposefully universally designed – show evidence that a variety of users have been considered. Products like chairs and doorways are often designed using precedent and anthropometric data. Typically, the aim is to design products which facilitate use by the 5th-95th percentile sizes of a given population because this range of data can be used to approximate the requirements for a large percentage of the population [105]. Anthropometry database software, like PeopleSize, can help to ensure new products physically fit a large percentile range of the market population. However, this system of anthropometry is

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[2] www.eng.cam.ac.uk/inclusivedesign/index.php

lacking, especially for the design of products that involve a high level of user interaction, because it generally deals only with physical size and proportion. In reality, there are many other characteristic variables that affect how an individual understands and interacts with a product. Different types of cognitive, sensorial and physical functions are used during the operation of products, and within these three categories, there are a great number of sub categories such as dexterity, muscle strength, flexibility, vision and intellectual ability. In the case of mainstream products, much of this is taken for granted by a designer, because essentially, they are designing for someone with similar abilities to themselves. However, designing products that can be used by people with disabilities requires extra data. This fact was recognised in a study called the Human Anthropometric Data Requirements Investigation and Analysis (HADRIAN) [106], which presents information about 100 people's anthropometry, joint constraints, reach range and a selection of other specific measurements. Although a useful starting point, there are still gaps in the HADRIAN data, specifically in relation to sensorial and cognitive abilities. The small sample size must also be considered as a limitation to the study. Additionally, instructions are still needed for the application and use of the data in a product design context. For now, a designer's implicit, knowledge, along with their experience is a major element in translating data variables into design solutions.

So, universal design is one approach to creating products or systems that suit a variety of users. A good example of universal design is the automatic sliding door; no matter the size, strength or mobility of the user, they will be able to

pass through the doorway. However, it's not always plausible to implement universal design so that one single product suits everyone. Barriers to universal design include high cost, the type and variance in users' preferences, and inadequacies in available technologies. The next section examines the concept of customisable design as a different approach to creating products that can be used by a variety of users.

2.4.3 Mass customisation, modular design and design for manufacturing and assembly

The literature explains that adaptability and customisation are desirable traits for AT [42, 46, 49, 50], due in part to the fact that people with disabilities have very specific needs, and that disabling conditions tend to change over time. Mass customisation is the customisation and personalisation of products and services for individual customers at mass production prices [47]. The approach involves postponing the task of differentiating a product for a specific customer until the latest possible point in the supply chain [107]. It aims to exploit economies of scale by producing and selling standard mass produced items, known as modules [47], in various permutations, in high volumes and at a relatively low cost. Mass customisation is a relatively new idea which has come about from developments in the information technology domain [108].

Gilmore and Pine [108] identified four distinct approaches to customisation: collaborative, adaptive, cosmetic, and transparent. Two are applicable in AT design. Collaborative customisation involves dialogue with individual customers to help them articulate their needs, identify what fulfils those needs and, finally, make customised products for them [108]. The collaborative

approach recognises that customers make decisions about products based on multidimensional trade-offs like cost, size, comfort, perceived value and functionality. Adaptive customisation advocates the provision of one standard, customisable product that is designed so that users can alter it themselves [108]. This is more reflective of universal design and fits with AT design because disabled users' needs tend to change over time and, furthermore, disabled users often need different devices to accomplish tasks depending on the context. An example of this is the area of computer access, where many individuals with disabilities use a variety of devices such as joysticks, touch panels and trackballs, depending on the type of computer program that they are accessing.

The AT literature makes reference to customisation. Scherer and Galvin [50] stated that AT designers must develop tools that are highly customisable. Hersh [104] proposed that modular software architectures should be used to allow the addition of further modules and ensure problems are isolated to reduce negative impact on functionality. Rogers [74] also advocated re-invention, which is another term for customisation, as a design principle for improved product adoption.

Modularisation is an element of mass customisation; here, a designer separates a system into independent parts or modules that can be combined in different ways to offer a large quantity of products [109]. A product's architecture is the scheme that describes how its physical modules are associated with functional elements to form different products [110]. Modular product architectures influence both cost and ease of service because assembly and disassembly are

simpler, maintenance is more straightforward, and larger, more differentiated target markets can use the product [111]. Ulrich and Eppinger [112] propose four steps to establish modular product architectures: develop a scheme for the components and functions; regroup the components in modules; sketch the design; and identify strong relationships in the model to redefine the modules. Functional specifications for the product are used to develop the initial scheme, and the module specifications largely define the interface characteristics [109]. Interface characteristics in tangible product design usually refer to the physical coupling specifications, and these depend on the physical and functional design of the individual modules.

In modular design for mass customisation, the group of products that can be created around the same 'product platform' is called the 'product family' [113]. An example of a product platform is a car motor made by a given car manufacturer. The product family might then include various car models built around that motor. The product platform is universal to the product family since all products require it. As such, more product platforms are required than the other modules that add-on to create the various products in the product family, and so, the product platform benefits from better economy of scale. To make the most of this economy of scale, the product platform is generally designed to include much of the functionality and expense. There is little evidence of research dedicated to the use of mass customisation and modularisation in AT design, but this thesis argues that mass customisation and modular design make particular sense for AT since expense is an issue, and because of the diverse needs and desires of users with disabilities.

Design for Manufacturing and Assembly (DFMA) [114] is an approach for designing products so that they are easy to manufacture and assemble. The key principles are listed below in but these essentially drive design decisions based around the compatibility between a part's design and its manufacturing chain; optimisation of aspects like cost, flexibility and environmental harm; the reduction of the number of assembly operations and; the design of parts for easy feeding, grasping and insertion.

DFMA Principles

1) Simplify the design and reduce the number of parts
2) Standardise and use common parts and materials
3) Design for ease of fabrication.
4) Design within process capabilities and avoid unneeded surface finish requirements
5) Design for parts orientation and handling
6) Minimise flexible parts and interconnections
7) Design for ease of assembly
8) Design for efficient joining and fastening
9) Design modular products
10) Design for automated production

Table 1 Principles of Design for Manufacture and Assembly

Since a cornerstone of modular design is simple assembly, DFMA is useful theory for mass customisation. Well-implemented DFMA impacts on the cost of a product because labour, tooling and time-related costs can all be significantly reduced. DFMA is not a science, but a designer can use the principles of DFMA to guide them in making trade-offs as they conceptualise a product solution. DFMA principles can also be used to identify and eliminate inefficiencies in an existing design.

The principles of DFMA are not only relevant for cost during manufacture. They are also applicable and useful to implement in the design of;

1. Products that an end-user assembles themselves, like IKEA furniture.

2. Products that may need to be disassembled and reassembled for cleaning, maintenance or repair, like an electronic or motorised item.

3. Modular customisable products that demonstrate adaptive customisation, whereby someone beyond the factory doors may assemble, disassemble and reassemble a product's components in different orientations to provide different functions. Examples of this type of product include Lego, baby chairs that adapt to fit bigger children, and furniture that can be customised to suit different spaces [See Figure 4 and Figure 5].

Figure 4 Tripp Trapp® Chair by Stokke

Figure 5 Dieter Rams' Universal shelving system for Vitsoe

Such modular, adaptive, customisable products are designed to satisfy diverse needs that different people have. Though the concept of mass customisation did not originate in the AT design industry, it is especially relevant to AT because of the very different needs people with disabilities have. Broadly speaking, someone without a disability can adapt fairly easily to using a product designed for a person other than themselves. However, someone with a disability may not find it as easy to adapt to using a product designed for a person without a disability - or a product designed for someone with a different disability to him or her. People with disabilities have needs that require more attention and thought before they can be well met.

Though not detailed in this thesis, there are many more approaches, methodologies and theories for product design. Tomiyama et al. [115] reviewed design methodologies for education and industrial purposes. The author had previously categorised design methodologies that generate a new design

solutions as either creativity-based, combination-based, or modification-based [116]. Creativity-based design follows the ideas described earlier in this section around intuitive approaches, lateral thinking, brainstorming and learning about user experiences and other relevant knowledge related to the product area. The double diamond model also fits within the creativity-based category. Combination-based design methodologies apply design knowledge to achieve product solutions more rationally and systematically. Their paper cites Pahl and Beitz's rational model [81] and Value Engineering as fitting in this category. Tomiyama [116] states that modification-based design is practiced most regularly and is useful when the existing product or system solution is deemed to be close to the final solution. In modification-based design, components are added, removed, merged or exchanged. An example of a modification-based methodology is TRIZ [117], which is a Russian acronym for Theory of the Solution of Inventive Problems. It exists as a database of principles and parameters that were developed through the analysis of the global collection of patents and is typically associated with solving mechanical system problems. These principles and parameters help designers to find and solve contradictions in a design. Their list was extensive and included many others including the Taguchi Method [118], Life Cycle engineering [119], Quality Function Deployment (QFD) [120] and DFMA [114].

As well as design theories and methodologies, a primary concern to this research is the social theory of user involvement in the design process. The next section explains why.

2.4.4 User-centred design for AT

User-centred design [121] is a philosophy that advocates user involvement in the whole design process of new products, systems and services. During user-centred design, the researcher or designer collects and analyses primary and secondary data to learn about the needs of the user, and then interprets this information into design criteria so that the product is driven by real-world needs.

In the last decade, the trend for user-centred design in medical, rehabilitative and assistive technology design has grown. In 2002, Garmer *et al.* involved users to test the usability of an infusion pump with a new user interface [122] and subsequently involved users in focus groups to elicit usability requirements for ventilators [123]. In both these studies, nurses were the only participants. The authors selected nurses because they used the products most often. Of course, clinicians are not the only users of medical, rehabilitative and assistive technology. Shah and Robinson [124] examined and classified the user network of medical device technologies - including assistive devices - and categorised healthcare professionals, patients, carers and people with special needs as primary users. The typology of these categories, which are relevant to AT, included people with disabilities, their families and friends, physicians, and allied health professionals including occupational therapists, physiotherapists and speech and language therapists. Shah and Robinson [52] also carried out a literature review to highlight the benefits and barriers to user involvement in the design process, and found that time and monetary resources, as well as user

characteristics and strategic considerations all need to be considered when facilitating user involvement.

User participation in the design process can be facilitated by many different means. On-line databases like those found at www.usabilitybok.org, www.ideo.com/work/method-cards, www.designforusability.org, and www.usability.gov/methods contain information about methods for user-centred design. Focus groups, interviews, questionnaires, surveys, prototyping techniques and ethnography are categorised and explained.

Empathic design [125] is a user-centred design philosophy that guides the creation of user-centred products. It is based on the idea that observing people as they experience a task - rather than asking them questions - is a more reliable way of discovering insights into their needs. Empathic designers observe and gather data via note taking, photography, and audiovisual recordings. They may also ask users questions as they observe. After this, the observers then reflect upon and analyse the data to identify customers' problems and needs. They brainstorm for solutions and then develop prototypes.

Leonard and Rayport's [125] seminal paper on empathic design explains a number of different things to look for when observing people as they experience tasks, which can then provide clues for designing better products.

1. Triggers of use: What circumstances motivate people to use a product? These may not always be expected, and in that case, there may be an opportunity to optimise a product for that circumstance.

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2. Interactions with the user's environment: How does a product fit into a user's routine and environment?

3. User customisation: Do users change or personalise a product to suit their needs better? This is especially relevant for AT since users' needs are often distinct so products aren't appropriate off-the-shelf.

4. Intangible product attributes: What emotional or sensory experiences are manifested as a result of doing a task or using a product? These are often related to expectations as a result of past experiences. Leonard and Rayport exemplify an intangible product attribute problem with eco-friendly clothing detergents that are less popular because they don't produce the smell of clean clothes that people expect and are familiar with.

5. Unarticulated user needs: What are people finding difficult? Humans are good at adapting to situations and often accept things as they are. They may not recognise a difficulty as a problem to be solved, but it is the observer's job to identify and note these needs.

Like lots of design processes, there are parts that are more systematic and other that are fuzzier. The research steps are relatively systematic and logical, especially given the five observation focal points above. On the other hand, the translation of the research to product solution that happens during the brainstorming stage is fuzzier, and relies on the experience and lateral thinking of the researchers and designers.

Empathic design offers a useful approach for user-centred AT design, especially when users have disabilities that impair their speech since they are only required to go about their usual routine. At the same time, an issue with empathic design relates to the fact that people may act differently when being observed. An associated argument is that observing people doesn't facilitate the same level of participation or empowerment as when those people are asked about their experiences. During empathic design research, observers look for elements of a task that a person finds difficult, and this might be intimidating for certain people - including those with disabilities, given the fact that many tasks are inherently more difficult for a person with disabilities. There is another approach that endeavours to blur the lines between the researcher/designer and product users. The next section examines participatory design, an ideology which requires the user to play an even more active role in the design process.

2.4.5 Participatory design for AT

Like user-centred design, Participatory Design (PD] is an umbrella term for principles and practices that aim to create products and systems which are more receptive to human needs [126]. It advocates that users are involved throughout the design process. PD was initially developed within Scandinavian trade unions to help workers to be empowered by new technology, rather than disenfranchised and replaced by it [127, 128]. PD, like user-centred design, is a collection of methods and approaches rather than a single methodology. The difference between the two philosophies is summed up by Sanders [129], who says that whereas user-centred design is design *for* users, PD is design *with* users. Methods include design workshops, brainstorming, role-playing

scenarios, prototype development, storyboards, and ethnographic techniques such as focus groups, interviews and observation. Sanders *et al.* [130] (p. 2-3) propose the organisation of PD tools and techniques into groups related to 'talking, telling and explaining', 'acting, enacting and playing', and 'making tangible things'. These different groups of techniques support people participating in different ways, even if they have disabilities. For example, if a person can't physically pick up materials and make a tangible thing, they don't need to be discounted from a PD process.

The use of PD in the area of AT development is a contemporary phenomenon, and all studies found in the literature took place since circa 2000. PD, in the development of medical and assistive technologies, appears to be most commonly used in the area of human-computer interaction software design, but it is also evident in the area of technology design for both the elderly, and young children with disabilities [131, 132]. There are fewer studies available documenting PD for tangible products and PD involving adults with motor or communication disabilities. PD literature that is relevant to AT was categorised into four types, as described below. For clarity, *high-level* descriptions are more abstracted and describe overall goals or concepts, whereas *low-level* descriptions provide more details of the individual components of a concept and how they work in practice.

- Type 1: PD projects with high-level descriptions

These provide less detailed, overall guidelines in the context of solving one specific problem and designing one specific product. These are useful as references to guide method formulation. However, as there is little

methodological detail provided in a high-level description, replicating the project for the same or a different product would be difficult and assumptions would have to be made by the new designer.

- Type 2: PD projects with low-level descriptions

These describe more detailed methods in the context of solving one specific problem and designing one specific product. The focus in these papers is generally heavily weighted on the product under design. As a result, these methods are useful, but need to be evaluated and greatly adapted before they can be used in the design process of a different product.

- Type 3: PD frameworks with high-level descriptions

These provide less detailed, generic guidelines for application in the design process of many different unspecified products. These don't detail construct or procedural specifications and tend to be very flexible. They offer the reader descriptions of different tools they might find useful to include when formulating a method. As with Type 1, little methodological detail is provided so practical application is left to the designer.

- Type 4: PD frameworks with low-level descriptions

These describe detailed methods for application in the design process of many different unspecified products. They give clear *how to* instructions for a) applying the method described and, b) applying the findings to a product design conceptualisation process. These are rare in the literature but arguably the

most useful because they can be systematically reproduced and applied to design scenarios for different product domains.

Relevant PD literature is discussed below under these four headings.

2.4.5.1 Type 1: PD projects with high-level descriptions

Fischer and Sullivan [133] used PD to develop a human-computer interaction software concept for public transportation systems for people with cognitive disabilities in 2002. They brought together researchers, AT specialists, transport system workers, technology developers and urban planners to work on the project, they surveyed people who used public transport and observed students with disabilities as they learned how to use a public bus system. Observation is a research method more associated with user-centred design, but the overall project was labelled as participatory due to the contributions made by non-designers who had real-life knowledge of the domain. They describe their method at a high-level, proposing the following four steps:

1. Undertake field studies to figure out *how things are.*

2. Highlight problems that face the target audience (in their case, people with cognitive disabilities).

3. Generate scenarios about *how things could be.*

4. Design technologies that solve the problems.

2.4.5.2 Type 2: PD projects with low-level descriptions

Dawe [132] used PD as part of her methodology to develop a remote communication human-computer interaction software system with youths with

cognitive disabilities and their families. She carried out interviews with 20 parents and teachers of students with cognitive disabilities to develop an understanding of the role of AT and explored issues and hopes they had with regard to AT. She then led in-depth interviews with a group of parents and their young adult children who had cognitive disabilities. Finally, she used technology probes with the families to iteratively design the software. Probes are kits of objects that are given to participants to collect ethnographic information about their own lives [132]. Probes might include a notebook, pen, stickers, camera, Dictaphone or video camera, depending on the project.

Wu *et al.* [134] designed an orientation aid for individuals with amnesia using PD. They developed use case scenarios and created storyboards to use as stimulus to guide discussions. Moffatt [135] designed a daily planner for people with aphasia using brainstorming exercises and software prototyping.

Boyd-Graber *et al.* [136] developed a personal digital assistant system to support people with aphasia in communicating. Speech and language therapists who worked with individuals with aphasia assumed the role normally filled by users in PD. These 'proxy users' [136] (p. 151) were involved instead of the target users because of the difficulties in communicating with people who have aphasia and the high variability in aphasic disorders. The proxies were familiar with the communication devices available and all prescribed AT in their professional practices. During the process, the speech and language therapists were presented with prototypes for evaluation at various stages through the design process and interviewed. After this, seven individuals with aphasia were recruited to evaluate the final design. It is debatable whether proxy AT users

are a viable alternative to AT users with disabilities in PD. This is not to say that speech and language therapists don't have a valuable perspective on AT, but it is a different perspective to that of a user with aphasia.

In 2011, Allsop *et al.* [137] involved 21 children with cerebral palsy and 236 children without disabilities in the design of a joystick. This is one of the few PD studies that focused on a tangible AT device, as opposed to human-computer interaction software. The authors devised a quantitative electronic survey, where children were asked text-based questions about their aesthetic preferences in relation to joysticks. For example, they asked participants to state their favourite colour, and whether they like soft or hard materials. This method is arguably less effective and less empowering than an immediate interactive experience with visual and tactile stimulus where responses are rooted in discussion. The researchers also recruited undergraduate students to produce concept joystick designs. They presented the children with three-dimensional visualisations of these concepts and asked participants to select their preferred designs. No physical prototypes were used in the process. This intensifies the abstraction from a real experience to a participant's perception of the concept joysticks. The creative process that the undergraduates went through to translate the children's contributions to joystick concepts was not a part of Allsop *et al.*'s research.

Hussain [131] facilitated a PD study in 2010 to develop prostheses with children missing a limb in developing countries. Prosthetists and mechanical engineering students were engaged in two PD workshops. In the first, the principal investigator presented background research about the following

problem: children who used prostheses need a product to enable them to work in mud. The participants paired up and the teams were given a selection of stimulus images of local materials and asked to rank the pictures in order of what they found most relevant for solving the design task. They could also add to the set of stimulus materials by writing their ideas on post-its. They were then given a week to gather the top ranked materials. In the second workshop, they paired up again and used the materials to create prototypes and later test them. The principal investigator than took all the data and used that as stimulus for her own design practice of a new prosthesis.

In 2011, Chavalkul *et al.* [138] used a PD methodology to engage 12 people over the age of 65 years in the design process of novel packaging. Focus groups, interviews, questionnaires and observation were employed. Participants were asked about their health-related conditions, i.e., their disabilities, which affected their ability to open packaging. They were also asked to use Likert scales to rate 2D and 3D images of packaging concepts.

2.4.5.3 Type 3: PD frameworks with high-level descriptions

The following literature provides generic guidelines for the design process of many different unspecified products. Shah and Robinson [139] formulated a theoretical framework for the development of medical and assistive technologies. They concluded that two streams of user involvement are necessary to facilitate the participation of both end-users and professional users. Their framework advocates the use of a variety of tools, including interviews, surveys, focus groups, usability tests and observation. The FORTUNE project [140] was only concerned with the participation of end-users,

but it promotes the use of similar tools to Shah and Robinson's [139] framework. The USERfit methodology [57] is a collation of design method information and proposes the use of data capture tools like brainstorming, task analysis and empathic design. The author declares that it is a meta–toolkit rather than a detailed design tool. Though useful as a reference for AT design, Hersh [104] noted that USERfit is time-consuming to use. USERfit, FORTUNE and Shah and Robinson's approaches are all useful references for AT design practice, but their purpose is not to provide specific instructions to execute an AT design project. Though advocating a variety of user-centred design tools, they leave the selection and implementation specifications up to the reader.

Living Labs are partnerships of companies, public bodies, universities, product users and other stakeholders, who collaborate to create and test new health-related technologies and services in real-life contexts [141]. There are currently 370 members in the European network of Living Labs[3]. End-users are involved in all the stages of the product development cycle and though there is no prescriptive design methodology, five main principles guide all Living Lab programmes. The first is Openness and relates to multiple stakeholders with different perspectives working together to create ideas. The User Empowerment principle is about users having decision-making power. Realism dictates that innovation activities are carried out in natural, real-world settings. The principle of Value Creation proposes that solutions developed within the user-centred Living Lab programmes should have the potential to better meet the needs of consumers than those developed within traditional product-

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[3] Last checked in April 2015

centred approaches, and so they should have higher economic, business and consumer value. The fifth principle of Sustainability advocates engagement with the community where the living Lab operates.

Borges *et al.* [142] developed a PD framework for developing human-computer interaction software. Borges *et al.* [142] focused on conceptualising customised AT, which is different to customisable AT. Customised products aim to create a personalised solution for one user only, whereas customisable products aim to offer personalised solutions to many users. Borges *et al.* [142] name five phases in their method:

1. Team composition

2. Solution inception, where interviews are conducted with therapists and the end-user is observed in therapeutic sessions

3. Solution detailed specification, where functions are specified through focus group discussions, brainstorming and prototyping

4. Solution design, where interfaces are drafted with therapists

5. Evaluation, where the user and therapists propose improvements and create strategies to gain feedback on the concept over time

These phases provide a clear overview of a design process, but the process minutiae is left up to the design team that wish to undertake a new project using these phases.

2.4.5.4 Type 4: PD frameworks with low-level descriptions

Only one PD framework was found that had both a detailed description of the method, and applicability to the design process of many different unspecified

products. Demirbilek and Demirkan [143, 144] developed the Usability, Safety, Attractiveness Participatory (USAP) design model, and designed a door with small groups of three, four and six elderly participants. The USAP model involves the following five stages:

1. Concept development, which combines brainstorming, scenario building, sketching and unstructured interviews

2. Concept refinement, where participants are asked for feedback on concepts

3. Prototype construction

4. User trials

5. Final production and manufacture

USAP stands out in the literature because, although it still doesn't describe or break down the translation process from user-generated data to design solutions, they ultimately show how user needs relate to their design specification. They do this by using a modified quality function deployment matrix [143, 145] during the concept development stage to chart the relationships between elderly users' requirements, wishes and ideas, and the technical design specifications.

This review of PD projects and frameworks shows how PD has been used in AT design. However, there have been no studies undertaken to develop a systematic research methodology for the involvement of a variety of AT users, including disabled individuals and those working with them in an AT context.

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There is also ambiguity in the discipline since little evidence exists that describes how a designer should evaluate, interpret and use the outcomes of a participatory need-finding process in a practical product design process.

2.4.5.4 Translating PD research data to product design concepts

The literature contains information about different research tools that help generate and capture data during a PD process. It also provides evidence that product design concepts have been produced from PD projects. However, a gap exists between these two [See Figure 6], whereby a method for the translation of user input to technical design practice is absent from the literature.
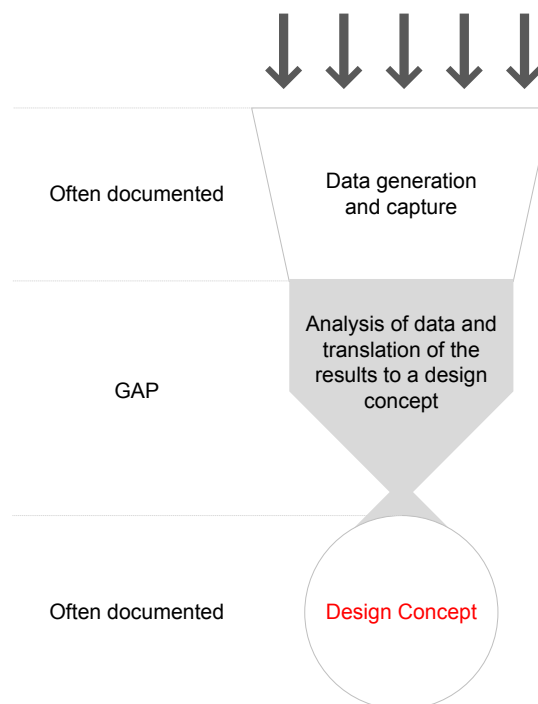
Figure 6 Analysis/Translation Gap

This thesis attempts to address this gap and develop a structure for gathering and translating participant input into design solution concepts. In order to practically address this gap, and integrate the concepts of mass customisation

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and participation by a variety of AT users in a design process, a sample product domain is proposed to drive and demonstrate the new PD method. This sample domain is discussed in the next section.

2.5   Sample AT product domain; AT computer input devices

To help develop and evaluate the new design framework, an AT product domain was chosen as a sample case to investigate. This section explains the importance of computerised AT and evidence is presented to support the selection of computer input devices as the investigation case. Relevant input devices and technologies are then described to provide an overview of the state of the art.

2.5.1   Electronic AT

Computerised AT, also known as Electronic AT, can help people with disabilities by improving the quality of participation experienced during social, academic and vocational activities [146-149]. Electronic AT includes communication aids, power wheelchairs, environmental controls, mobile phones and personal computers (PCs). Below, a number of electronic AT devices are discussed.

Augmentative and Alternative Communication (AAC) includes any method of communication that augments or replaces the usual methods of speech or writing for people with impairments that effect the production or comprehension of spoken or written language. [150]. There are many different types of AAC ranging from low-tech symbol and word boards that a user points to, to high-tech Voice Output Communication Aids (VOCAs). Communication

disorders can be caused by various congenital and acquired illnesses such as cerebral palsy, developmental delays, language disorders, autism, amyotrophic lateral sclerosis, multiple sclerosis, head or spinal cord injury, or stroke [151]. Unfortunately, the use of AAC often equates to a slow rate of communication and even practiced users can find it difficult to interact naturally with others. Alm [151] reported that delayed response time means conversation will often move on to a new topic before AAC users can make a contribution and other parties in the conversation may also become uncomfortable with the slower pace. Many AAC users will use only single word utterances for these reasons. VOCAs generally offer a recording function whereby the AAC user can pre-program lengthier speeches at a convenient time. Many users will have a recording for introducing themselves, communicating their interests, or asking regularly asked questions.

Environmental controls are a type of electronic AT used to remotely control electronic equipment like televisions, motorised window blinds, heating systems and alarms. The international standard, ISO 9999, defines environmental controls as 'devices for enabling remote control and operation of electronic and electrical equipment within the living environment to enable independent living'. These controls improve the quality of life for users with physical disabilities [152, 153] because they enable individuals to carry out activities that would otherwise necessitate the aid of another person.

Another popular type of electronic AT is the powered wheelchair. Individuals often use these when a manual wheelchair is inappropriate [154, 155], for example, if an individual is too physically weak due to muscular dystrophy or if

they have upper limb paralysis due to an acquired spinal cord injury. They may also be prescribed where repetitive manual wheelchair use has resulted in chronic shoulder and wrist pain [156].

Personal computers and the AT used to access them constitute perhaps the most important contemporary evolution for people with disabilities. Once the barriers hindering the control and accessibility of PCs are overcome, individuals with disabilities can learn, play, communicate and work in virtually the same manner as those without disabilities.

2.5.2 AT Computer input devices

Devices used to access personal computers and other electronic AT can be divided into three categories: input devices, output devices and software [25]. British Standard ISO 9241-410:2008 defines input devices as a means for users to enter data into interactive systems [157]. In the scope of this research, the interactive systems are electronic AT devices. The standards explain that input devices are essentially sensors that detect changes in user behaviour and transform them into signals that the interactive system interprets.

Keyboards and mice are the most typically used computer input devices but, as a result of certain disabilities, mainstream devices like these may not appropriate [158]. Depending on the individual, their arm movements may be too unpredictable or sudden, or they may not have the requisite strength or dexterity to operate a mainstream device. It is a frustrating phenomenon: disabilities will often emphasise a person's need for electronic AT but simultaneously hinder their ability to control and access a computer with a

mouse and keyboard. A wide range of specialised switches, keyboards, joysticks, trackballs, touch panels and other devices have been developed in an attempt to overcome this barrier to access, and maximise the abilities which users have [159]. These devices are referred to from here on as Assistive Technology Computer Input Devices (ATCIDs).

As mentioned above, people that use ATCIDs typically have a motor impairment, sometimes along with another type of disability. Motor disabilities can be caused by a disease or congenital disorder, or a traumatic injury. Diseases and congenital disorders include cerebral palsy, muscular dystrophy, multiple sclerosis, spina bifida, motor neurone disease including amyotrophic lateral sclerosis (known as ALS or Lou Gehrig's Disease), arthritis, Parkinson's disease and essential tremor. Motor impairments present in different ways. For example, cerebral palsy is an injury to the brain resulting in decreased muscle control. Common characteristics are muscle tightness or spasm, involuntary movement known as dyskinesia and impaired coordination known as ataxia [160]. Reduction in fine and gross motor control of the upper limbs can make targeting computer screen icons difficult when using a standard mouse and keyboard [161]. Speech impairments can range from mild to profound, where no recognisable words are produced [162].

Muscular dystrophies are a group of progressive genetic muscular diseases characterized by muscle weakness, muscle wasting and in some cases impaired speech [163]. Strength is an issue for people with muscular dystrophy, so moving a mouse around on a surface or pressing a key on a keyboard can be challenging. Multiple sclerosis is an inflammatory disorder of the brain and

spinal cord which can cause loss of balance, weakness, fatigue, cognitive impairment, spasticity, tremor, visual impairment, slurred speech, muscle stiffness, or impaired memory [164].

Alternatively traumas can result in spinal cord injury, acquired brain injury and the loss or damage of limbs. Each of these has their own presentation. Spinal cord injury can result in motor neurone disease, which again causes muscle weakness. The loss or damage of limbs will have different ramifications for computer access and control, depending on the limbs that can and can't be used.

The most appropriate ATCID for a user depends on more factors than functional characteristics like those listed above, and this is one reason that prescription is complex. Previous experiences, motivation, personal taste and the electronic AT they wish to access all impact on the appropriateness. However, when ATCID selection is successful, it has positive outcomes on the user's daily functioning [146-149].

Alternative devices could have been employed as the sample domain for this research, including feeding or dressing apparatus, mobility aids or hobby related tools. ATCIDs were ultimately selected because they make a wide variety of other electronic and computerised AT accessible. As the possibilities for work, education and social networking grow online, access to the internet via a computer is becoming an powerful equaliser for people with disabilities. There are many different ATCIDs currently available in the market. Anecdotally, there are currently 515 different electro-mechanical switches available on the

ableData.com website[4], which is a database of approximately 19000 AT products maintained for the National Institute of Disability Rehabilitation Research of the U.S. [165]. These switches differ in colour, size, texture, force required for activation, and method advised for interaction. However they all ultimately facilitate the same function as a switch. This highlights the fact that the domain might benefit from a mass customisation design approach. Additionally, the ATCID domain has been specifically identified as one which requires more flexible and universal solutions [166]. Finally, the growing issue of repetitive strain injury (RSI) has been linked to the repetitive movements necessitated by the use of computer input devices [167]. Studies have shown that RSI costs USA employers more than $6.5 billion annually [168]. This brings in the ideas of universality and opens the possibilities for a universal design to be produced.

The idea of adaptive mass-customisation is also applicable to this domain of AT. Currently, ATCIDs are often modified; in some cases, a tennis or stress ball may be attached to the lever of a joystick for more comfortable and satisfactory use. Also relating to customisation, Davies *et al.* [160] carried out a survey involving 60 youths with cerebral palsy, aged 13-25 years, to identify different computer access technologies in use and the choices made regarding mode of access. All participants used a computer. Forty percent of youths that have severe[5] cerebral palsy used a variety of ATCIDs, such as joysticks, touch screens and trackballs. Individuals were not limited to one type of device but often used a combination, depending on their needs for a specific program. This further

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[4] Last checked in August 2015
[5] Severe denotes a level of III-V in the Manual Ability Classification System

demonstrates the need for customisable ATCIDs that can be efficiently adapted by either the user or their carer.

This literature review has indicated that participation is an important part of design practice for AT. Belief in user engagement has also grown within social disability research [169]. In 2010, the University of Leeds and Maastricht University, in conjunction with the European Research Agendas for Disability Equality (EuRADE), carried out participatory research with 68 disabled people's organisations in 25 European countries to engage civil society organisations as change agents for future priorities in European disability research [169]. The findings of the study support the idea that there is a gap in innovation research pertaining to the accessibility of electronic equipment. One respondent specifically asked for 'special devices for different people with different kinds of disabilities to use computers, telephones, etc.' [169] (p. 248).

The next section investigates ATCIDs that are currently used by people who find mainstream devices inappropriate.

2.5.2.1 Product review of AT computer input devices

Before undertaking practical design research concerning a specific product domain, in this case ATCIDs, it is useful to examine the relevant contemporary benchmarks. At their core, all computer input devices detect changes in user behaviour and translate them into signals that the computer interprets. The interpreted signals then activate a function within the computer. A function might be typing the letter 't' on a screen. This could involve pressing on and activating the 't' switch on a keyboard, which is programmed to send a signal to the computer to depict 't' on the screen. Alternatively, a function might involve

opening an application by activating a switch on a mouse and selecting an icon on a screen when the cursor overlays that icon. Other functions might be playing a recorded message on a communication device or opening window blinds by activating a switch that is programmed to do one of those things. A function may also be about directing the movement of a cursor on a screen with a mouse, or directing a wheelchair with a joystick. Ultimately, no matter what type of input device is used, the fundamental objective is the same: to select and activate a computer function.

Table 2 shows a pictorial representation of some common ATCIDs.
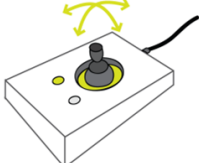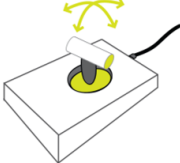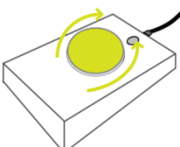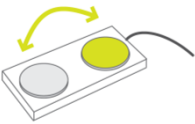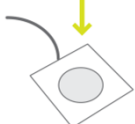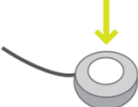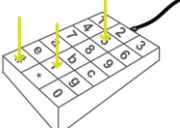
ATCID	Diagram
Proportional joystick	
Joystick	
Joystick with T-shaped lever	
Trackball	
Track-pad	
Toggle switch	
Pillow switch	
Flat pancake switch	
Switch (may be wireless)	
Cup switch	
Mini Keyboard (programmable / pre-programmed)	

Table 2 Pictorial representation of common ATCIDs

Switches are at the core of many types of ATCIDs, and perhaps the simplest and most basic ATCID is the mechanical switch. These are used for all manners of computer control, and work by turning on or off a circuit. Mechanical switches consist of two or more conductive pieces of material, called contacts, and an actuator, which connects or disconnects the contacts to close or open the electrical signal. The mechanism can be developed to respond to many mechanical stimuli, including changes in angular or linear displacement, air pressure or force. Examples include plate, lever, string and pillow switches. Switches are the fundamental components of many computer input devices including keyboards, digital joysticks and game controllers. A major disadvantage of mechanical switches is that they are designed to respond to the consistent motor activity of one body part or area [170], whereas in reality, the reliability of that body part may fluctuate over time due to an individual experiencing fatigue [171] or more permanent changes in functional abilities [41, 170, 172]. If switches are determined to be the most appropriate tool for the service user, switch sites and types need to be chosen. An optimal switch site demands minimal, isolated volitional movement from the user and should not induce fatigue [173]. The advantages of mechanical switches reside in their low cost, widespread availability, robustness and operational simplicity [170].

Like mainstream keyboards, assistive keyboards are simply an arrangement of switches that are programmed to activate functions on a computer. In comparison mainstream keyboards, assistive keyboards may have larger or smaller keys, they may have fewer keys, and the arrangement of the keys and overall shape of the device may also be different. As with switches, some assistive keyboards allow the

user or their therapist to associate keys with functions that they specify. An example of a programmable keyboard is the Gewa, shown in Figure 7. This connects to devices in a home through an infrared transmitter, much like a standard remote control for a television. There are 18 switches on the device, but for people who want to activate more than 18 functions, the device can toggle through levels, so up to 161 functions can be defined and accessed by the user.

Figure 7 Gewa Prog Control

Joysticks are another type of mechanical device that translate physical movements into electronic information. Digital joysticks are composed of a number of switches. Generally, a vertical lever is attached to a base with a flexible rubber sheath. The base houses a printed circuit board, which connects to several contact terminals on the underside of the stick. When the joystick lever is moved in a particular direction, it pushes down on a switch and closes the circuit. Analogue joysticks are more expensive but have the advantage of allowing proportional control. The more force the user exerts on the lever in a given direction, the more power is transmitted to the device being controlled. This is particularly useful in

the case of powered mobility aids; for example, if the user pushes the joystick further forward, the chair will move faster in that direction. However, analogue joysticks are more complicated and expensive than their digital counterparts because they use potentiometers rather than mechanical switches.

Touch panels, also known as track pads or touch pads are touch sensitive devices. By moving a finger or other object along the surface of the panel, the user can move a pointer a corresponding distance on the display screen. Clicking can be done with buttons or by tapping lightly on the surface. They can be held in the hand, placed on a desk, or mounted to a mobility aid. Many users find touch panels to be less of a strain on the wrist, hand and arm because there is less movement and resistance than that needed with a traditional mouse [174]. There are different types of touch panels, the most common of which are resistive and capacitive. Resistive panels are very durable and generally the most affordable type of touch panel [175]; they can be operated by a finger or a stylus, whereas capacitive pads are more expensive and require the electrolytes found on skin to function.

Resistive analogue touch panels consist of two thin glass or acrylic panels coated with Indium Tin oxide, which is an electrically conductive, resistive material. Spacers separate the two layers. One layer carries an X-axis and the other carries a Y-axis; these are determined by the orientation of bus bars printed on two opposite edges of each layer. When the two layers are placed together, it creates a single switch that is activated no matter where the panel is touched. A micro-controller can also be used to detect the location of the touch, based on the voltage drop sensed in each layer at the point where they make contact. These panels can

also be fixed onto, and calibrated with, liquid crystal display monitors to construct touch screens. Touch screens are used in some AAC devices, where users touch icons on the display to select their choice. Due to their sensitivity, touch panels are suitable for individuals with good motor control, but are not generally appropriate for people with visual impairments due to the lack of defined sensory cues.

Another ATCID is the trackball, which is essentially an upside-down roller-ball mouse. Users do not drag the device on a surface; instead, the whole device remains stationary while the user only moves the ball. The trackball sits on a base, which allows rotational movement. Two rollers inside the base touch the ball; one detects motion in the X direction, and the other in the Y. When the ball rotates, the motion is transferred to these rollers. The rollers each connect to a shaft, which spins a pierced disk. When a roller rotates, the attached shaft and disk spin. On either side of the disk there is an infrared Light Emitting Diode (LED) and an infrared sensor. The pierced holes in the disk break the beam of light coming from the LED and the sensor notes pulses of light. The rate of this pulsing is proportional to the speed of the trackball movement and radial distance travelled. This signal is translated into a digital signal read by the computer.

More high-tech and expensive ATCIDs also exist. Electroencephalography (EEG) is the recording of electrical activity along the scalp in order to measure voltage fluctuations resulting from ionic current flows within the neurons of the brain [176]. This technology can form part of a brain–computer interface (BCI) which can translate this information into signals that control external devices [177]. Such systems require sensors to detect brain signals, decoders to transform neural

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activity signals into useful commands, and an interface for the user [178]. EEG-based BCIs are not yet widespread due in part to their steep learning curve [170] and high-cost.

Electromyography (EMG] is a technique for evaluating and recording the electrical activity produced by skeletal muscles [179]. An electrode can be used to sense small muscle contractions in the face, jaw, neck, arm, or anywhere appropriate. A mechanomyogram (MMG) is a mechanical signal which can be measured by transducers when contracting muscles emit low frequency mechanical vibrations on the surface of the skin.

Electrooculography (EOG) is a technique for measuring the resting potential of the retina [180]. Electrodes, placed around the eye, sense when the eye moves from the centre position towards one electrode, [170, 181] and measures the potential difference occurring between the electrodes. This information can then be translated to digital signals to control a computer. Unfortunately, the integrity of these signals are affected by extraneous motion, perspiration, and other variables [182]. Electrolytic gels are also necessary and these can be irritating to apply and may dehydrate the skin over time.

Other technologies such as eye tracking sensors and infrared head mice are also available. These eye-tracking control systems use an infrared light source and a camera to calculate the offset between corneal reflection and pupil centre. The resultant gaze-direction is then translated into a signal to control an on-screen curser. Unfortunately, in addition to requiring a direct line of sight between the light source and detector, performance can be affected by ambient infrared sources

such as sunlight [183]. Furthermore, there is a lack of understanding around the safety of focusing an infrared source towards the eye at close range.

Speech or gesture recognition systems are other options, but these require a significant amount of time, motivation and stamina on the part of both the individual and therapist [184]. Unless modalities like BCI's, speech recognition and the other high-tech ATCIDs are developed to enable more easily learnt responses, they are unlikely to be useful at scale [160]. For now at least, traditional ATCIDs like switches, joysticks, track panels and keyboards are more widely available and used.

2.6   Summary

This literature review supports the need for an appropriate Participatory Design (PD) methodology for the development of customisable AT. The following gaps in the literature will be considered in the research design, and later used in the argument for validation:

1. Adults with communication and mobility related disabilities have rarely been involved in design research.

2. The PD literature is heavily biased toward human-computer interaction software development rather than **tangible product design.**

3. The **data translation stage** between *gathering and analysing user data* and *solution conceptualisation and design action* is seldom referenced and has not been systematically addressed in the AT design literature.

4. There is no evidence of methods for the **design of customisable, modular AT** in the literature, though the review has identified it as a promising idea.

The next chapter explains the methodology devised to address the above gaps.

Chapter 3

Methods

3.1   Introduction

The purpose of this research is to develop and demonstrate a participatory design framework for customisable AT, which addresses the need for low-cost AT products that satisfy a broad range of consumers' needs. In this chapter, the methodology underpinning the research is discussed and the chosen constructs are rationalised. The framework is described as two phases of primary research, where each involves a different set of stakeholders. These phases are described sequentially and for each, details are provided about the sampling, research tools, ethical considerations, procedure, and data analysis.

3.2   Design framework methodology and constructs

The research design for this thesis has a number of methodological influences, namely pragmatism and the philosophies of participation and exploration. Pragmatism is about the synthesis of practice and theory, and is put into effect through applied research. It dictates that practical action is required for the validation of knowledge or theory [185]. New knowledge is then judged by whether it works to solve the problem at hand. Pragmatism is especially important in research concerning product development processes because, although theory is valuable, an understanding and explanation of how one can implement a process

in a practical, industrial design context is essential for real world application. If pragmatism is not considered, the bridge between theory and action may be too vague, and so it will be difficult to apply the process again in the future. This bridge is particularly important in design research, because design is essentially the application of knowledge to create a useful system, service or artefact. The literature review highlighted this gap between theory and actionable design instruction. For example, a wealth of studies have developed criteria for successful AT evaluation [46], assessment [25], prescription [71], adoption [49], use [44, 72, 186], abandonment [41] and system design [30, 104, 187] but, although well founded and explained, the manner in which a designer or clinician can utilise the criteria is unclear. Proposing, as Batavia and Hammer [46] did, that a device should be affordable or durable is legitimate, but this type of broad proposition does not guide the application of the recommendations in a given context, whether that be product design, AT selection or evaluation. As a consequence, there is little evidence of these results being used in generating design specifications for AT. To address this, a pragmatic grounding aims to bridge this gap between theory and practice in an AT design context. The tools developed through this research aim to generate focused, actionable criteria for the design of specific AT devices along with a clear process for their implementation.

To investigate available methods for the design of AT, and to subsequently develop a design framework to facilitate the participation of different users, research enquiries were exploratory. The purpose of exploratory research enquiry is to find out what is occurring in an area with little understanding, to seek new insights, to assess phenomena in a new light and to generate ideas and hypotheses for new

research [188]. Although this research builds on existing user-centred approaches from the areas of human-computer interaction and healthcare, the development of the method is exploratory and carried out through the practice of designing a customisable ATCID with individuals who have disabilities necessitating ATCID use.

This research proposes that exploratory and Participatory Design (PD) research requires a qualitative approach because these types of investigations aim to understand and describe phenomena from a human perspective in a given environmental context. Qualitative research acknowledges human perceptions as an impacting factor in social science, allows exploration of these perceptions, and also emphasises the importance of the investigation's context. Qualitative research typically addresses questions like: what is occurring?; how is this occurring?; why is this occurring?; and what impacts the occurrence of a phenomenon? [189]. This is especially relevant when the purpose of the research is to design a new technology since 'what is occurring' in the technology landscape is dynamic, and so may not be reflected in existing theory. This dynamism is due to evolving and new technologies being brought to market all the time. The exploratory approach of qualitative research also offers the opportunity to identify new phenomena that may not be uncovered via a quantitative study, where the research questions are developed solely from existing theory. Previously unrecognised and unarticulated 'latent' needs that individuals experience with technology are examples of such phenomena. Latent needs are useful stimuli for design innovation [125], and qualitative exploration helps to identify and understand them. Quantitative research has a place in technology design too. In the early stage of benchmarking,

mapping device popularity is useful. Additionally, after the conceptual design phase, quantitative design engineering research is important to optimise manufacturing specifications.

The primary aim of this research was to develop a participatory design framework for customisable AT, which includes tools to generate actionable design specifications for new products. A stakeholder analysis was undertaken to determine who should be involved. As discussed in the literature review, Shah and Robinson [124] categorised users of medical and rehabilitative technologies. With this in mind, two groups were defined; 1) professionals who work in the fields of AT prescription, provision and training and, 2) disabled individuals who use AT. Though other stakeholders exist, like AT manufacturers and sellers, it was deemed that commercial biases related to cost, precedent products and perceived feasibility could impact negatively on the user-centred research outcomes.

Two different participatory methods were identified to facilitate the needs of these stakeholder groups. These methods were selected with respect to usability and ethical considerations from the participants' perspectives and, also, to commerciality from an industrial perspective since, if a design method is to be useful in industrial practice, the demand on operational resources like time and money [52] are critical.

These two methods, along with the literature review, formed a preliminary structure of work, as shown under 'Research Process' on the left hand side of Figure 8. Each stage informs the ones that follow; the literature review informs the method design and the Delphi study informs the PD workshop design. The

intention was to then create the three 'Research Outputs' shown on the right hand side of the figure. Again, each output informs the ones that follow. The criteria for the design of the customisable AT device informs the prototype design, and all of this culminates in the transferable PD framework for Customisable AT. The research described in the rest of this thesis populates the stages shown in Figure 8, through the practical design of a customisable ATCID.
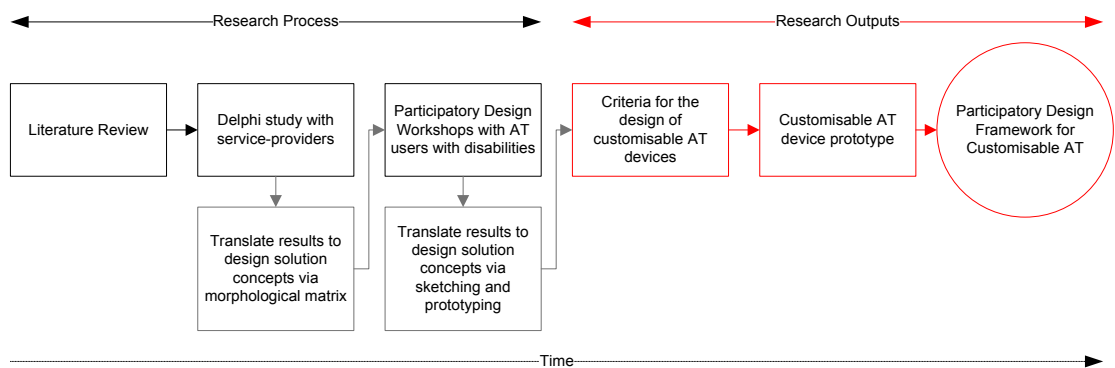
Figure 8 Research design structure

Professional, service-providing individuals participated before individuals with disabilities because their perspectives were likely to be broader and more general given the range of different AT devices and users with disabilities they engage with. Professionals' contributions aimed to provide a basis for the design of the product functionality and universal product platform [113] element. The process with the second group of participants, who have disabilities, aimed to specify requirements for product customisation modules associated with user-interaction.

Phase I involved professionals working in an AT context with people who have disabilities. The aim was to generate crucial design issues for a specific AT domain, in this case, ATCIDs. Two constructs constituted the method. First, participants

generated information by taking part in a Delphi study. Then, that information was applied to the product design process with an adapted morphological matrix. The integrated Delphi study and morphological matrix developed and used in this research are described in full later in this Chapter, but a general overview of the two individual constructs is provided here.

A Delphi study is an iterative, structured process which aims to collate judgments from a group of experts to develop consensus on a particular topic [190]. It involves a series of two or three questionnaires in conjunction with controlled management of participant feedback. Initially, open-ended questions are posed in a questionnaire and participants list their responses. The researcher then collates all unique results and returns them to the participants in the form of a second questionnaire, where they rate the importance of the responses. In this way, participants can reconsider the answers they gave in the first round and rate their own original responses lower if they find other responses in the collated list to be more pertinent. In some Delphi studies, the first questionnaire exists as a list of statements that participants are asked to rate. This is arguably a less participatory version since the experts are only assigning scores to concepts, rather than posing the concepts themselves. After this, the researcher collects and analyses the data to formulate consensus on a ranked list of results. A third questionnaire can also be created and implemented in the same way as the second.

The Delphi study was selected to gather and synthesise user input for four reasons. First, it fits well with the participatory ethos of the research as participants essentially design their own questionnaire and work together to reach consensus.

Delphi studies have been used previously as part of participatory research studies in other fields, including healthcare [191] and education [192]. Second, a Delphi study is a useful method to employ when participants are time-constrained and geographically disparate. Third, it's structured; this phase was not about understanding a social phenomenon, but about identifying problems that exist within a technological domain. Probing for emotional and rich, perception based data was not an aim with these professionals, so a systematic questionnaire construct was ideal. Finally, it is an anonymous process; participants never meet or learn the respective responses of other participants and all responses are treated equally. This is beneficial when, as with this research, the aim is to arrive at a consensus among stakeholders coming from different areas of expertise, and different levels within organisation.

Other research options that facilitate dialogue between participants in order to reach an agreement are workshops and focus groups. Although, theoretically, these methods encourage open communication in a setting where all participants are valued as equals, when different parties are involved, status and pressure can affect responses. Individuals may not want to speak out against a system, a purchased product, a decision that someone else has made, or a product that they have previously prescribed. The anonymous nature of the Delphi study supports the idea of equality and provides participants with a safe outlet for frank responses.

The second part of Phase I is based on morphological analysis [193], which is a method often used during concept generation to investigate and organise

alternative solutions for functions of a system or product [194]. The matrix can then be used to select permutations of these solutions to generate whole concepts. A morphological matrix is not a replacement for creative thinking; it just provides a frame for the designer's cognitive process and structures the development of design alternatives. Typically, the format for a morphological matrix is a grid of columns and rows. The functions of a product are listed in a column on the far left of the matrix, and each row is populated with design solutions depicted by annotated sketches or text. Once the matrix is established, the designer can combine the individual solutions into larger conceptual designs.

Phase II involves a workshop-style method based on PD. PD workshops were selected for both social and technical reasons. First, from a social perspective, PD focuses on empowering people through their involvement in the processes and procedures of design. Academics and disability organisations [195, 196] both support the idea of user participation in disability research because it is anti-oppressive [14]. PD workshops provides a space for shared learning where the researcher's role, as a facilitator, is different, but of equal status, to that of the other participants. PD workshops also offer an opportunity for empowerment; participants feel they are contributing to a project that has scope to benefit both themselves and others. Empowerment can also come from gaining new knowledge or skills through the PD process.

From a technology design perspective, PD workshops allow for the iterative design of a new product with those who will use it. Participation is relevant because successful AT design requires an understanding of the end-user's goals,

requirements and preferences [69] and this is something that only the end-user themselves can fully understand [104]. As mentioned, PD involves collaborative activities where users participate in various design activities and situations [197] to generate ideas and produce concepts which meet real needs - and the PD workshop is a flexible format where research tools, like brainstorming and design games, can be modified to allow users with varying abilities to participate.

As discussed in the literature review, PD has been used in the development of healthcare technologies, but there is little evidence of defined and actionable methods to involve the various stakeholders involved in the AT arena. This thesis aims to address that gap. The rest of the Methods Chapter is laid out in two parts: Phase I involves professional service-providers, and Phase II involves AT end-users who have disabilities. The phases' applications for ATCID design is demonstrated here, but they were constructed to be transferable, and to guide the conceptualisation of other types of medical and rehabilitation technologies that could benefit from a customisable architecture. Examples include postural support devices, mobility aids, personal hygiene aids, feeding apparatus and other tangible AT.

3.3   Phase I: Clinician perspectives on ATCID design issues

The aim of the Phase I was to construct and present a method of involving professionals working with individuals who have disabilities in the design process of AT. This group's experience of ATCIDs was investigated through the application of a Delphi study. Allied health professionals, including occupational therapists, physiotherapists, and speech and language therapists, as well as rehabilitation

engineers and AT trainers and technicians all took part. These individuals work in different capacities to select, prescribe, modify, assess and offer training in AT.

3.3.1 Sampling

In the literature, a group of Delphi study participants is referred to as a panel of experts [198] and the quality of the results depends on their level of expertise, as well as the research design and the process by which consensus is identified. The pragmatic foundations of this research lead to experts being defined by their hands-on experience of working in the field.

Professionals were recruited from two AT service-providing organisations, one in the Republic of Ireland (ROI) and the other in Northern Ireland (NI). The first, Enable Ireland, is a leading provider of services to over 3,700 children and adults with physical disabilities in the ROI. They work in partnership with service-users to help them achieve independence, choice and inclusion in their communities through rehabilitation services, help with employment and AT provision and training. Enable Ireland also offers a range of individualised therapy for service users including nursing, occupational therapy, physiotherapy, social work, psychology, speech and language therapy and complimentary therapy. There are approximately 1,000 employees, 355 of which are full-time. The second organisation, The Cedar Foundation, delivers a range of similar services and aims to empower and support people with disabilities throughout Northern Ireland to be fully included in their communities. Both organisations were selected due to the nature of disability they provide services for, their culture of AT provision, their

people centred approach to service provision, and their advocacy of the social model of disability.

The inclusion criteria stipulated that they currently work, or have worked, with adults using ATCIDs; are involved in the selection, prescription, modification or training of AT devices as part of their job description; and agree to participate in the research voluntarily. Should the method have been used during the design process of a different type of AT, for example, a postural support aid, the inclusion criteria would have been similar, but participants would work with individuals who use that specific type of AT. The literature proposes that a minimum of 13 participants is adequate for validity in a Delphi study but that the reliability is not significantly affected with more than 30 [190]. Consequently, sampling aimed to invite at least 45 people to allow for attrition. A non-random, purposive sampling technique was used to facilitate the recruitment of the panel.

Gatekeepers from the two organisations nominated 18 individuals from a variety of professional areas. These participants were then asked to nominate and provide contact details for three other people within their organisation, who shared their profession, to consider taking part. This snowball sampling technique [199] was used because it is an efficient way of identifying people who meet inclusion criteria. It also embodies the participatory philosophy of the research methodology because the initial participants effectively partake in the sampling process. Snowball sampling meant a further 11 individuals were nominated by the original 18. Out of the 29 individuals who were invited in total, 14 responded to the first questionnaire. This equates to a recruitment rate of 48.3 percent. The retention

rate for the second questionnaire was 100 percent. Of these 14 participants, more than 70 percent had 10-15 years experience. Occupational therapists had the largest number of representatives (n=6) and made up 43 percent of the total. At the time of the Delphi study, all participants worked with clients who required and used ATCIDs. Table 3 shows the gender, profession, location and experience of the participants.

	%	n
Gender		
Female	71	10
Male	29	4
Profession		
Occupational Therapist	43	6
Speech & Language Therapist	14	2
Assistive Technology Trainer	14	2
Physiotherapist	7	1
Clinical Engineering Technician	7	1
Clinical Engineer	7	1
Electronic Technician	7	1
Location		
Republic of Ireland	64	9
Northern Ireland	36	5
Years of Experience		
1 to 5	14.3	2
5 to 10	7.1	1
10 to 15	71.4	10
15 to 20	0.0	0
>20	7.1	1
Working with individuals using ATCIDs		
Yes	100	14
No	0	0

Table 3 Demographic Profile of Participants in Phase I

3.3.2   Research tools

Phase I has contains two constructs, a Delphi study which generates input from clinical and professional AT users, and an adapted morphological matrix which allows the designer to interpret and translate that input into product solution concepts. These are detailed below.

3.3.2.1 Delphi study

The initial Delphi questionnaire first posed a series of demographic questions to verify that the participant met the inclusion criteria and for descriptive purposes of the sample. The questionnaire then asked the participant to list responses to six questions. Stimulus statements were used to frame the six questions, as shown in Table 4, and the purpose behind each of them is described thereafter.

ASSISTIVE TECHNOLOGY	**Stimulus Statement: Durability, dependability and repair-ability are traits that relate to the longevity and functionality of a device. When an assistive technology computer input device (ATCID) breaks or stops working, it can have a negative effect on a service-user's relationship with their technology.** Question 1: If you have witnessed ATCID failure, or have had to request or carry out maintenance on an ATCID, please list the most prevalent parts of the device that require attention. You may also mention parts specific to a particular type of ATCID. Question 2: If you are aware of reasons that have caused an ATCID to fail, please list these reasons.
	Stimulus Statement: Flexibility and customisation are ideas which attempt to accommodate the changing needs of a service user by reducing the need for device replacement. Customisation also allows for fitting the device to a user's specific needs. Question 3: Please list the key characteristics/variables you associate with a service-user's abilities and an ATCID, e.g. range of movement. These may be the variables you look at if you carry out AT or disability assessments.
ACTIVITY	**Stimulus Statement: Simplicity, learnability and operability (satisfactory device activation) are terms which relate to the need for a service-user to receive training. Simple, successful operation of an ATCID is paramount to user satisfaction, but training, whether ongoing or at device introduction, is often required.** Question 4: What are the requests/needs, which you are asked to facilitate with regard to ATCID use and training?
HUMAN	**Stimulus Statement: Effectiveness (the extent to which an AT device enhances functional capability or independence) and personal comfort are traits of AT that impact upon service-user preference and acceptability.** Question 5: Please list what you perceive to be desirable traits of an assistive technology computer input device (ATCID) in relation to user preference. Please be as specific as possible. Question 6: If you, in your personal, professional capacity, experience any frustration with ATCIDs (when selecting, assessing, training, affixing, removing, cleaning and so on), please list what frustrates you.

Table 4 Delphi Study Questions

The questions were developed and arranged under the HAAT model [64] headings, which are, 'Human', 'Activity' and 'Assistive Technology'. Each question could arguably fit under multiple headings but the purpose of this was to ensure that all elements of the HAAT model [64] were considered.

The first three of the six questions come under the AT heading. The first asked participants to recall and relate their experiences of device failure and malfunction. For the researcher or designer, these experiences are essentially a list of specific, product-related issues that require attention and development. The second question asked participants to identify reasons for the failure and malfunction of a device. These reasons help the researcher to understand the context of the failure points listed in the first question and, subsequently, generate appropriate design solutions. The third question asked about the characteristic variables of an individual with disabilities that are associated with the use of a specific type of AT, in this case, ATCIDs. The aim of this question is to inform the researcher about which elements of a given AT device need to be customisable.

The fourth question comes under the Activity heading and aimed to generate information to enrich the whole product package and associated services by asking participants about client requests regarding AT use and training. The last two questions are grouped under the Human heading, since they ask the Delphi study participants about their AT related preferences and frustrations. The fifth question enquired into participants' perceptions of their clients' AT preferences. This is asked to supply general, overarching criteria for the product design specification. The sixth and final question is the most personal and subjective and asked

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participants to evaluate their experiences with devices and identify any frustrations they may have had. The intention of this question was to inform the researcher about real-life use contexts and associated issues, so they can develop solutions. Although observation can help a researcher to understand real life problems, it is only individuals who are habitually working in a discipline or using a product that can recognise certain frustrations. Only they can indicate deficiencies and potential problems in the products they use [52], in part because even seemingly trivial or small issues can become amplified over time.

The second questionnaire of the Delphi study was subsequently produced from the responses of the first. The same six questions were presented to participants. Below each question, the associated responses from the initial questionnaire were given beside individual five-point Likert scales. Any duplicated responses were deleted, and issues that were similar but not identical were combined into single issues. Participants then ranked the options with regard to importance on the scale, with one indicating very unimportant and five indicating very important. In this way, panellists communicated their agreement and disagreement with the anonymous group data and a consensus on the issues was formulated. As there was potential for a large list of generated variables, a series of only two questionnaires constituted this Delphi study so as to retain panellist involvement and reduce the redundancy a third questionnaire might produce. Other Delphi studies in the field [25] also used a total of two questionnaires.

3.3.2.2 Morphological matrix
The second construct in Phase I facilitated the translation of the user responses from the Delphi study into design solution concepts. Concept generation is a

critical period in the design process since it dictates the level of innovation as well as the majority of the product cost [194]. This framework presents an adapted morphological matrix as a way of using information provided by AT users to drive concept generation. The adapted matrix developed for this research is shown in Table 5. It is different to typical morphological matrices in that, instead of organising alternative ways to carry out a known product function, the matrix arranges alternative solutions relating to the Delphi study results.

The first column acts as a container for key responses from the Delphi study. The second column defines components that each issue could relate to and the third explains the functions that the components fulfil or, where appropriate, the function associated with the issue. The last column contains the alternative solutions proposed, by the designer, for each issue. Populating the matrix with useful content is reliant on accessible knowledge about current technologies available for exploitation. To help generate ideas for alternative design solutions, each issue was considered from the following perspectives:

1. What changes could be made to get around this issue?

2. What design features do other products (that don't exhibit the issue) have?

3. What materials or technologies could be employed to negate the issue?

This phase was about generating solution concepts, but not about selecting the optimum solutions. Phase II then absorbed the design concepts generated in Phase I and incorporated them into the design and prototyping process.

Delphi questionnaire			Morphological matrix			
Data generated by participants			Interpretation of data and translation to design criteria by the designer			
			Design Issue	Relevant Component	Definition/ Function	Design Solutions
ASSISTIVE TECHNOLOGY	Stimulus statement	***Durability, dependability*** and ***repairability*** are traits that relate to the longevity and functionality of an AT device. When an X (*assistive technology computer input device/ATCID)* breaks or stops working, it can have a negative effect on a service-user's relationship with their technology.				
	Question 1A	If you have witnessed X failure, or have had to request or carry out maintenance on such a device, please list the most prevalent parts of the device that require attention. You may also mention parts specific to a particular type of X *Answer*	Prevalent parts of an X which malfunction (Issue 1, 2, 3…)	?	?	Ways to reduce or negate the issue (idea 1A, 1B…, 2A, 2B…, 3A, 3B…)
	Question 1B	If you are aware reasons that have caused an X to fail, please list these reasons. *Answer*	Reasons Xs malfunction or fail	?	?	Ways to reduce or negate the issue
	Stimulus statement	***Flexibility*** and ***customisation*** are ideas that attempt to accommodate the changing needs of a service user by reducing the need for device replacement.				
	Question 1C	Please list the key characteristics/variables you associate with a service-user's abilities and an X. These may be the variables you look at if you carry out AT or disability assessments. *Answer*	Characteristics of a service-user associated with selecting an X	?	?	Ways to make the product customisable with regard to the service-user characteristic.
ACTIVITY	Stimulus statement	***Simplicity, learnability*** and ***operability*** are terms that relate to the need for a service-user to receive training. Simple, successful operation of an *ATCID* is paramount to user satisfaction, but training, whether ongoing or at device introduction, is often required to facilitate this.				
	Question 2	What are the requests or needs which you are asked to facilitate with regard to X use and training? *Answer*	Service-user needs regarding X use and training	?	?	Ways to enrich the product package
HUMAN	Stimulus statement	***Effectiveness*** (the extent to which an AT device enhances functional capability or independence) and ***personal comfort*** are examples of traits of AT that impact upon service-user preference and acceptance of AT.				
	Question 3A	Please list what you perceive to be desirable traits of an X in relation to user preference. Please be as specific as possible. *Answer*	Desirable traits of an X	?	?	Ways to enrich the product package
	Question 3B	If you, in your personal professional capacity, experience any frustration with Xs (when selecting, assessing, training, affixing, removing, cleaning and so on), please list what frustrates you. *Answer*	Participants frustrations associated with Xs	?	?	Ways to reduce or negate the frustration

Table 5 Phase I: Delphi study tool & morphological matrix for solution generation

3.3.3 Ethical considerations and procedure

The interdisciplinary nature of the research had ramifications for ethical approval procedures. Perhaps unsurprisingly, the engineering department had traditionally different ethical concerns to the disability service providing organisation. However, the process of completing a range of different applications helped to inform the methodology early on. Ethical approval for the study was obtained from Enable Ireland, the Cedar Foundation and Dublin Institute of Technology. Dublin Institute of Technology and Enable Ireland's ethics committees approved two separate applications and The Cedar Foundation granted approval based on these [See Appendix 1 for approval letters]. Ethical considerations for the Delphi Study concerned consent, confidentiality, anonymity, data protection, beneficence and nonmaleficence.

The flow chart in shows the procedure for Phase I, where each stage informs the next. The procedural steps are then unpacked.
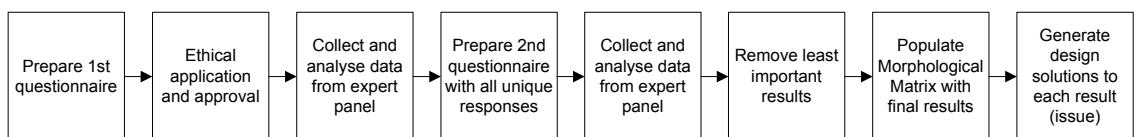
Figure 9 Delphi Study; Procedure Overview

The questionnaire was designed and prepared and, once ethical approval was granted, a softcopy of an information pack was sent to the e-mail addresses of the professionals who were nominated by the gatekeepers [See Appendix 2]. This included an information sheet explaining the research, an invitation to partake, instructions about what to do if they would like to accept, a consent form, the researcher's contact details, a demographic profiling form and the first Delphi

questionnaire [See Appendix 3]. They were also offered the option to receive the pack in hardcopy by post, or to make arrangements to complete the questionnaire over the phone. Those who agreed to take part in the research returned the consent form and questionnaire. The individuals who were nominated by these participants (via the snowball technique) were then sent the same packages with the omission of an invitation to nominate further participants. After receiving the consent forms and completed questionnaires, data from the first questionnaire was analysed and the second was created. The group of respondents were then sent copies of the second questionnaire to complete and return. Participants could fill these out electronically, or alternatively, they could request a hard copy or print one out themselves and scan or post it back. Participants were asked to respond within two weeks. After this, a reminder was sent to anyone who had not responded.

Due to the nature of the Delphi method, the responses were anonymous and of equal value to those of other participants. A code was assigned to each individual who was invited to take part. These codes were inserted as headers on their questionnaires. This provided a way of tracking received questionnaires anonymously. The code list linking the participant's name to their code was secured in an encrypted file and a hard copy was stored in a secure locker in Dublin Institute of Technology. The participant's name was deleted from the code list when the final questionnaire was received or if they decided to withdraw from the research. At such point, all information provided became anonymous.

Delphi studies do not ask participants to engage in a potentially dangerous activity, but the ideas of 'doing good' and 'doing no harm' still apply. The study asked

participants to anonymously fill out two questionnaires, so immediately there was a time demand. Measures were taken to minimise this. First, participants were provided with instructions and an estimate of the time it would take them to complete the questionnaires. The layout was designed with clarity and consistency in mind; concise versions of participants' responses were listed in the second questionnaire [See Appendix 3], and every second row was shaded to improve the legibility of the list. The second questionnaire was created using a Microsoft Word macro to allow participants to fill in the Likert scales by clicking on fields rather than typing in x's or similar denotations.

Once the study and data analyses were complete, the results were disseminated as a PDF brochure to all participants and gatekeepers, closing the loop of participation. These results were then used in the morphological matrix to generate product solutions.

3.3.4 Data analysis

Responses generated from the six questions in the initial Delphi study were entered onto six Microsoft Excel spreadsheets. Duplicated responses were deleted and any issues that were similar but not identical were combined into single issues. The second questionnaire then presented the refined issues beside individual five-point Likert scales. As mentioned, participants ranked the options with regard to importance on the scale with one indicating very unimportant and five signifying very important. Responses from the second questionnaire were entered onto new spreadsheets. Data analysis then consisted of calculating the median and inter-quartile range for each issue. Issues that contained missing data were also included and their respective numbers of responses were taken into

account when calculating the descriptive statistics. The median indicated the level of importance at which half of the responses lay above and half lay below and the inter-quartile range supplied information about the dispersion of responses. A small inter-quartile range indicated low variability among responses and high consensus, and a large inter-quartile range signified high variability and low consensus. Issues with a high level of importance and a high level of consensus were deemed most essential to the research. After this analysis process, the issues were divided into four groups according to their essentiality: primary, secondary, tertiary and other. Primary issues were those with a median importance of at least 4.5 on the Likert scale and an inter-quartile range of equal to or less than 1. In other words, a minimum of 50 percent of the panellists rated these issues as very important and at least 75 percent of the panellists rated them as important or very important. Secondary issues had a first quartile of at least 3.5. This meant that at least 75 percent of the panellists rated them as important or very important. Tertiary issues were those with a median value between 4 and 4.5 and a first quartile of at least 3, so 50 percent of the panellists rated these as important or very important and at least 75 percent felt neutral about the issue or believed it to be important or very important. Other issues were any that fell outside of these criteria. Because a Delphi study strives for consensus, responses from participants of different professional fields were collated and analysed together. Consequently, descriptive demographic information about the sample was collected but no cross tabulation analyses were carried out.

3.4 Phase II: Participatory design workshops with AT users with disabilities

3.4.1 Sampling

The purpose of Phase II was to facilitate the involvement of AT users with disabilities in the design process of customisable AT. A purposive criterion-based sampling technique was used to recruit AT users who had a range of different disabilities and had experience with different types of ATCIDs. Gatekeepers were identified within the same two AT service provision organisations in the ROI and NI to instigate participant recruitment. This prevented the risk of coercion by the researcher and protected the anonymity of individuals' who did not wish to take part. The gatekeepers had managerial positions in the organisations' AT departments. There was a lack of service-users who fit the inclusion criteria in the NI organisation, so the Central Remedial Clinic in the ROI was approached and they agreed to be involved. A gatekeeper was identified there to instigate recruitment.

In order to take part in the research, it was deemed necessary that an individual; had engaged with their service-provider more than three times; had a disability which necessitates the use of an ATCID; used an ATCID regularly (>5 times per week); agreed to participate in the research voluntarily; was fluent in the English language; was over 18 years of age; did not have a marked hearing or visual impairment; had the stamina to participate in two full-day workshops (not consecutive days); had the cognitive ability to participate in the proposed group activities; and did not have a psychiatric illness which could interrupt the workshop.

The intention was that between three and four service-users from each organisation would take part in the workshops. The literature posits that between three and six individuals make up an optimum PD team for activities because all participants are more likely to actively partake [200, 201]. However, since the pace of communication among this type of cohort was likely to be varied due to the use of augmentative and alternative communication aids [128], a smaller sample of three to four was proposed for each workshop to allow adequate time for each individual to contribute. In total, eight individuals with disabilities participated in the workshops. Table 6 shows the demographic details of the participants in relation to their participation in the workshops. For anonymity, their names were replaced with codes P1 – P8.

Participant Code	Gender	Age	Medical Condition	ATCID used	Verbal
Workshop 1 (2012), 3 Invited, 2 Participated					
P1	Female	35	Acquired Brain Injury	Joystick & Switches	No
P2	Male	18	Cerebral Palsy	Joystick & Switches	Yes
Workshop 2 (2012) 2 Invited, 1 Participated					
P3	Male	24	Muscular Dystrophy	Joystick & Touchpad	Yes
Workshop 3 (2013) 6 Invited, 5 Participated					
P2 *attended workshop 1*	Male	19	Cerebral Palsy	Joystick	Yes
P4	Male	25	Cerebral Palsy	Joystick	Yes
P5	Male	42	Cerebral Palsy	Head Mouse	No
P6	Female	24	Cerebral Palsy	Headstick and touch screen	No
P7	Female	52	Cerebral Palsy	Trackball & Compact Cherry Keyboard	No
Workshop 4 (2014), 3 Invited, 1 Participated					
P8	Male	20's	Cerebral Palsy	Switches, keypad & Joystick	Yes

Table 6 Demographic Profile for Phase II by workshop

Table 7 shows the gender, age, medical condition and verbal status of the participants.

	%	n
Gender		
Female	37.5	3
Male	62.5	5
Age		
18-25 yrs	50	4
26-35 yrs	25	2
36-45 yrs	12.5	1
46-55 yrs	12.5	1
56+	0	0
Medical Condition		
Cerebral Palsy	75	6
Muscular Dystrophy	12.5	1
Acquired Brain Injury	12.5	1
Verbal		
Yes	50	4
No	50	4

Table 7 Cumulative Demographic Profile of Participants in Phase II

The range in participant sample-size across the four workshops came about due to recruitment and attrition issues, along with findings from previous workshops. For the first workshop, three agreed to participate on the selected workshop day. However, one contacted the gatekeeper on the morning of the session to say they were unable to come. The second organisation had fewer clients who met the inclusion criteria but two agreed to participate on the arranged date for the second workshop. Again, on the day of the workshop, one participant did not arrive and contacted the gatekeeper later to apologise for not coming. For the third workshop, a much larger number (n=6) of individuals were invited and all agreed to participate. Five participated on the day. Three of the five were non-verbal and there was a large range in cognition and communication levels. The workshop was more chaotic than the others and the exercises did not work as well as in the

workshops with fewer participants. There were long delays between individuals' contributions, as they had to wait for everyone else to communicate before their turn. For the final workshop, three people agreed to participate, though only one did so. One of the others was ill and the second called to apologise for their absence. The participant gave positive feedback about his experience at the end of the day, however since this was his first time participating, a lot of the workshop was spent reviewing the process to date, and much of the information he provided would have been more useful at an earlier stage in the design process.

It wasn't clear as too how a participant would feel if they were the only one present, but none of the participants expressed negative feedback about this. One participant explained that he was 'more comfortable in a one-to-one situation' because this is what he was used to in school or with a therapist. He stated that he would 'probably be very quiet if there was someone else' present.

3.4.2   Research tools

> If more rigorous methods can be described as 'measure twice, cut once', participatory design methods can be described as 'explore, approximate, then refine'.

> [202](p. 168)

Phase II involved a series of four PD workshops. The phase was crafted with respect to the Delphi method in that the results were generated in an iterative way. The findings of each workshop were used to develop device concepts and, additionally, inform structural amends of subsequent workshops. Four workshops were proposed to facilitate the following stages involved in the product design process: concept generation, concept development, prototype development, and prototype evaluation.

This phase aimed to facilitate the involvement of groups of participants from different AT service-providing organisations. The first and third workshops were to take place with one team, and the second and fourth workshops with another. The intention of alternating the workshops was to encourage the integration of the two groups as one unified design team, while minimising the time and effort demanded from any one participant or organisation. Participant attrition was a more marked issue than anticipated, so the plan to alternate participants didn't materialise. The workshops did alternate between the two service-providing organisations, however.

All workshops were informed by the literature [203-205] and structured as four basic sessions: an introduction called 'Warm Up', a design discussion session called 'Discussion', one of two design activity sessions called 'Design Dishes' and 'Prototypes', and 'Evaluation'. At the end of each workshop, the data was interpreted. Questionnaires, video recordings, photographs and notes were developed into a series of 2D sketches and visualisations, and 3D models and prototypes. The specifics of the next workshop's activities were then finalised. Details of the five research tools follow.

3.4.2.1 Workshop tool 1; Warm Up

This stage helped to pre-empt difficulties that might have emerged later in the session. The aim here was to put participants at ease through an appreciative welcome, informal introductions and initial everyday conversation that didn't focus on the research topic. After this, the research topic was introduced and background on the study and its purpose was provided. Everyone's roles were also laid out during this stage.

Since this research uses PD principles, roles are a little different to traditional focus groups. The workshops are about omni-directional teaching and learning, so the facilitator's role is to ensure that everyone has a chance to contribute, to guide the session, to listen - and also to share some of what they know. This last element wouldn't typically be an important feature of focus groups, where the participant's role is to contribute their point of view, and by doing so, to teach the facilitator something.

Ethical considerations were also mentioned, including recording information, confidentiality, anonymity, informed consent, timings and the researcher's independent academic status. It was acknowledged that differences of opinion might arise, but that there would be no wrong or right answers during the sessions.

After this, an informal presentation was given by the facilitator about the fundamental ideas of the research project and the design workshop process. This part serves two purposes. The first purpose is to improve the likelihood of useful design outcomes emerging from the workshop by adequately preparing the participants. Essentially - in order to contribute to the conceptualisation process, participants need to know some basics about the product design process and the scope of the project. The second purpose is to support participant learning and empowerment by imparting knowledge about design. Craig *et al.* [206] facilitated design thinking workshops with people with spinal cord injuries and began workshops with a similar activity, which revolves around the question 'what is design?'. No actionable design results come from Warm Up, but it important to

frame the workshop for participants. This is the foundation for subsequent activities. In this research, the Warm Up presentation was about

1. AT

2. Computer input devices

3. ATCIDs

4. The product design process

5. Universal design

6. Mass customisation

7. Participatory design

In an effort to make the activity engaging, the presentation was visual and interactive. Everyday/common object analogies were used to help explain more complex theories. For example, automatic sliding doors were used to explain universal design and, then, participants listed types of people that might find traditional doors difficult to open and sliding doors more useful. Deli-counter sandwiches and custom cars were used to help explain mass customisation and participants engage by designing and specifying the components of their favourite sandwich or the type of car they'd like.

3.4.2.2 Workshop tool 2; Discussion

This tool was also used in all four workshops. 'Discussion' was based on the format of traditional qualitative focus groups. The discussion guide structure is shown in Table 8. An overview of this was provided to participants at least a week prior to the workshop so they could reflect and prepare answers if they wished. This was especially important for individuals using VOCAs, since they might have liked to pre-record answers.

A flip chart was used to document the responses and create mind-maps around these responses. Brainstorming around the questions aimed to build a set of criteria for concept generation and development.

Insight Areas		Primary Question (what the designer wants to know)	Probing Questions (how the facilitator develops the question and response)
What activities do they undertake using their ATCIDs, and where do they use them?	1	What activities do you do with your ATCID?	Tell me about what you use your ATCID for. Do you use it when you are communicating with friends? What are you controlling and what are you doing? For education/learning? What do you control and do? For hobbies/leisure? What do you control and do? Do you control a communication device or your wheelchair? Have you always used your current device? If no, what else have you tried? Tell me about that.
	2	Where do you use your ATCID?	Maybe you use it in an office, in college, at home or maybe outside? Tell me about your different experiences in those places.
Understand how participants view their current ATCIDs?	3	What do you like about your current ATCID?	Tell me about when and how you use your ATCID? Do you like something about the way it looks or feels? What? Was it easy to learn how to use? What can you tell me about that? Is it comfortable to use? Tell me how so?
	4	What do you dislike about your current ATCID, if anything?	
What are the future hopes of participants regarding ATCIDs?	5	What would you like to imagine for the future, regarding the way that you control your computer/ wheelchair/communication device?	How would you like to control your computer, wheelchair or communication device? What sort of things can you imagine in the future? Try not to think about a specific technology or device; instead, try to think about what YOU would like to do with your body or mind!

Table 8 Discussion Guide Structure

3.4.2.3 Workshop tool 3; Design Dishes

Design Dishes were used in the first and second workshops for concept generation and development. A variety of 2D and 3D materials were presented as generative design tools [207] and participants were asked to pick and choose elements which they believed represent something good about ATCIDs.

This idea originated from design consultancy IDEO's tech box [208], whereby designers collectively add to and use a locker of various toys, materials, gadgets and fabrics to inspire creative thought and develop product concepts. Sanders [207] then developed the technique to involve non-designers. From her work, generative design tools refer to the use of specially devised materials to facilitate non-designers in communicating design solutions to a particular design problem. The results of these activities can then be used as stimulus for designers. The Design Dishes tool devised for this research is also inspired by the use of inspiration cards in software [204, 209]. Inspiration cards, developed by Halskov [209] are small (6x8cm) cards with a printed image, title, description, reference and space for comment. Halskov [209] proposed that two of the following types of inspiration cards should be combined and used to create ideas or solve problems: Technology Cards, which show a specific technology or an application of a technology, and Domain Cards, which show information about the domain that the design project relates to, like people, places or situations. So, in the case of Sanders' and IDEO's generative tools [207], physically making is a key component and participants use the materials provided to literally make things. Halskov's Inspiration cards [209] may be written on, and the information on them is combined and developed by participants. The Design Dish exercise developed in this research draws on these two methods but it is more accessible for participants

with various physical, communicative or cognitive disabilities. Participants were tasked with solely selecting from an array of artefacts and then, where possible, communicating reasons for their choices. In the case of this ATCID related research, objects and materials which were presented for discussion included various non-toxic texture swatches [Figure 10] like memory foam, silicone, plastics and metals, colour swatches [Figure 11], a selection of forms made by the researcher out of extruded polystyrene foam [Figure 12], miscellaneous objects [Figure 13], and sets of cut-out images of other ATCIDs and mainstream computer input devices mounted on foam core [Figure 14]. (If the PD workshop was taking place to facilitate the design of a different type of AT, the materials presented should be relevant for that product.)
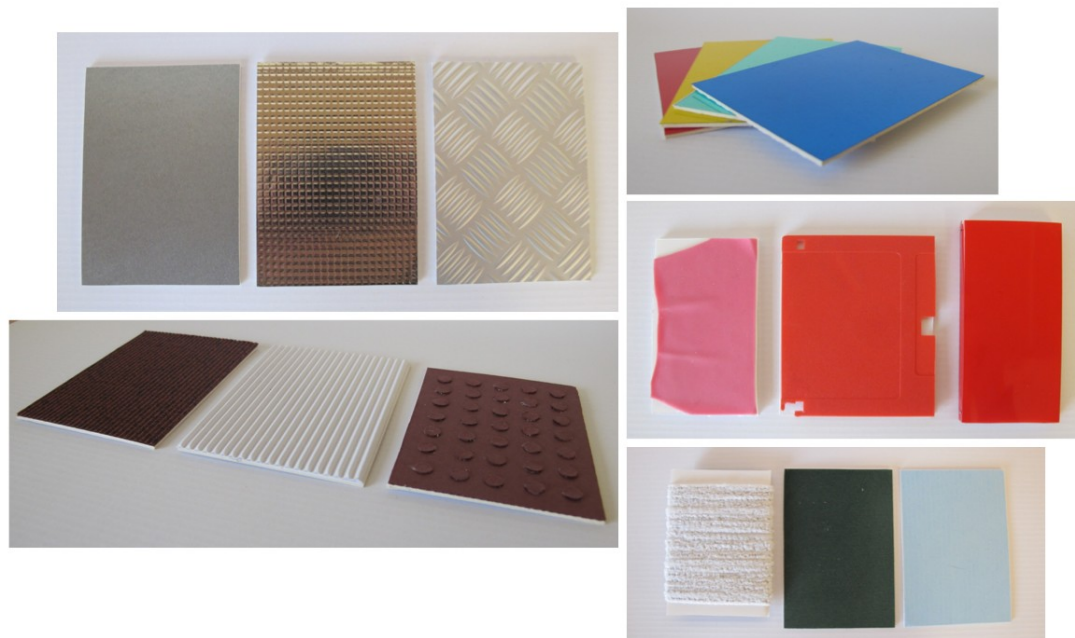

Figure 10 Texture Swatches for Design Dishes Tool

Figure 11 Colour Swatches for Design Dishes Tool

Figure 12 Extruded Polystyrene Forms for Design Dishes Tool

Figure 13 Miscellaneous Artefacts for Design Dishes Tool

Figure 14 Relevant Technology Images mounted on foam core for Design Dishes Tool

Figure 15 Workshop Materials Set and forms

All these different media [Figure 15] were provided so that the exercise might be more inclusive; for example, if an individual had a visual impairment, they would be able to make selections based on tactile qualities rather than colours or someone with a motor impairment might choose something that is easier to grasp. Labels and branding were hidden with marker or erased with Photoshop software so brand names could not be identified. Participants were asked to touch, view and experience the artefacts, and then select items that they associated with a satisfactory ATCID and collect them in the large dishes provided. At the end of this exercise, each participant has created a 'design dish' – analogous to a 3D mood board - containing images, textures and representations of things they associate with a successful ATCID. Participants were then asked about the reasons behind their selections. Ultimately, the aim was to use these artefacts as stimulus for further discussion. Though these abstract items were far abstractions from ATCID

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prototypes, the intention was that the Design Dish exercise would provide information that could be used during the design process.

3.4.2.4 Workshop tool 4; Prototypes

Prototypes were used in the third and fourth workshops for concept development and evaluation. This workshop tool is a guide for an analytical, critical and creative process. To prepare participants for the process and manage expectations for the items they would see, the facilitator explained that the purpose of product prototyping is to learn more – rather than show off a product one might purchase. The new ATCID concepts were then explained in terms of other ATCIDs using images of analogous products. 3D prototypes were presented, described and demonstrated where possible. The question guide for Prototypes is synopsised below.

Process Aims	Primary Question (what the designer wants to know)		Probing Questions (how the facilitator develops the question and response)
Analyse	1	Can you describe what you see?	Size, shape, colours...?
	2	Can you describe what it does?	
Critique	3	What does it remind you of?	Is it like another ATCID? Is that good or bad? Why?
	4	How does it look and feel?	What's good about the way it looks? Why? What's bad about the way it looks? Why?
	5	Where does it fit among Xs (ATCIDs)?	*(Use Design Dish mainstream/AT device cut-outs to map where it fits in the category.)* Probe with 'Why?' questions.
	6	This prototype is different to your own device. How does it compare?	*(Use side by side visuals to compare prototype to analogous devices.)*
Create	7	How do you think the design could be improved?	*Using answers from the fifth Delphi Study question (desirable traits of an ATCID) to check design spec,* e.g. is a design that doesn't make the user stand out? Is it an appropriate size so you think?
	8	What should it do?	
	9	Could you imagine yourself using it?	What would be different? Any thoughts on something you'd prefer?

Table 9 Prototypes Guide

3.4.2.5 Workshop tool 5; Evaluation

Evaluation was devised as a part of all four workshops. First, the results of the day were summarised and presented to check participant agreement. A short evaluation questionnaire was then used to ascertain the participants' views about the day.

3.4.3 Ethical considerations and procedure

Dublin Institute of Technology and Enable Ireland's ethics committees approved two separate applications for the PD workshops. The Cedar Foundation granted approval based on these. [See Appendix 1 for approval letters]. When it emerged that the Cedar Foundation had issues recruiting service-users, the Central Remedial Clinic in Dublin was approached and they granted ethical approval for the second phase of the research. Garda clearance and the equivalent Northern Ireland police clearance (NI Access) were also approved for the researcher. Sources used to develop the workshops in terms of ethical considerations were: Guidelines for Undertaking Research involving Service Users, Staff or Families in Enable Ireland [210] and the National Disability Authority Guidelines for Including People with Disabilities in Research [211]. Like Phase I, ethical considerations for the PD workshops concerned beneficence and nonmaleficence, consent, confidentiality, and data protection.

After ethical approval was granted by DIT, Enable Ireland and The Central Remedial Clinic, the gatekeepers identified and informally invited between three and seven individuals to take part. After they accepted, information packs were sent to them in hard and soft versions via the gatekeeper [See Appendix 4]. The packs included an information sheet explaining the research, a description of; what they should expect during the workshops; information about the activities; workshop locations and dates; data protection; video recording; a formal invitation to partake; a copy of a consent form; a confidentiality agreement; the researcher's contact details; the details of how the researcher would contact them and their personal assistant to confirm their acceptance; and the details of transport

reimbursement procedures. Participants received preparatory information before the workshops. All information provided to participants was designed to be easy to understand and the project goals were explained prior to the workshops for transparency. Participants were encouraged to ask for further information if they so wished.

The first and third workshops took place in a function room in Enable Ireland and the second and fourth in The Central Remedial Clinic both in Dublin. These were accessible locations that were familiar to the participants. The environments for the workshops were set in accordance with ISO9241-9:2000(E) and prepared prior to the participants' arrival by the researcher. A large work surface was set up with chairs for the researcher, the participants and their Personal Assistants (PAs). The work surface was accessible for those using wheelchairs. A laptop and projector were arranged for information presentation and a flip chart was used throughout the day to record participant feedback. The workshops were recorded with video and audio recorders.

Promoting an atmosphere of informality and fun was an important element of the PD workshops to foster a creative and open design environment, and also to lessen the likelihood of fatigue [212] by maintaining participant interest. The researcher attempted to create a positive, playful environment that was both relaxing and motivating [213] by keeping everyone informed throughout the sessions, organising a number of breaks and mixing the research activities with both game and discussion formats.

The workshops aimed to encourage participants to critically analyse their technology experiences. At the same time, it was anticipated that participants may

need to be protected from inheriting a feeling of decreased satisfaction with their technology. The intention was that they should leave the design sessions feeling empowered by the process, and not disenfranchised by their imperfect devices. The discussion guide was prepared to serve as the stimulus for discussion, but follow-up questions were based on participants' responses. Though there needs to be a balance between criticism and positivity, it was acknowledged that the researcher should sensitively probe for further description of an experience, and elicit information without directing an individual into negative criticism of their AT.

Though the procedure was generally consistent across the four workshops, some elements evolved in accordance with the learning outcomes of previous workshops, the progress of the ATCID design, and the emergent information requirements for further design and development.

The flow chart in Figure 16 shows the procedure for Phase II.
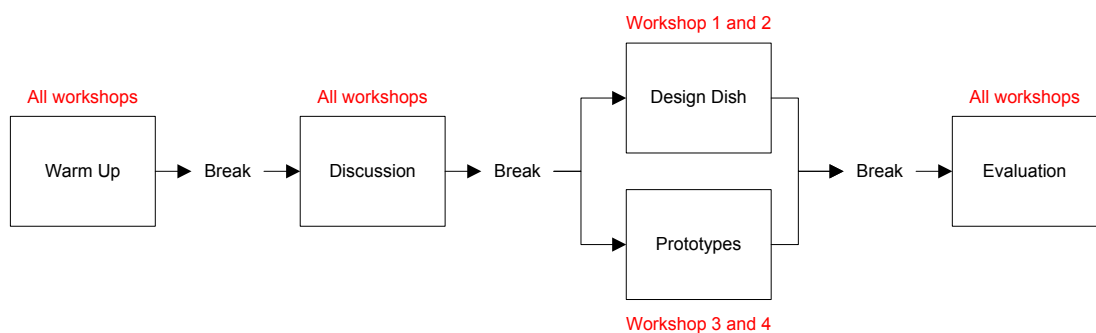

Figure 16 Participatory Design Workshops; Procedure Overview

Data collection and design activity materials were used during all workshops. The workshop spaces before the participants' arrival are shown below in Enable Ireland [Figure 17] and the Central Remedial clinic [Figure 18].

Figure 17 Workshop Space 1

Figure 18 Design Dish Stimulus in workshop space 2

Data was collected in a variety of media; with video and photographs, using questionnaires and on a flipchart. The videographer arranged a wide-angle shot from a mini camcorder on a tripod. Participants were made aware of this in the morning presentation and asked if they had any issues with the taping procedure. The videographer also took some close-up shots during the design activities. A flip-chart was used to document all responses during the day. The purpose of this was to confirm what the participants were communicating. The participants amended items on the flipcharts during the workshops. Coloured markers were used to document each participant's responses. A projector and screen were employed to present information and provide focus.

In each workshop, the researcher, participants, Personal Assistants (PAs) and videographer introduced themselves and settled around the workspace. A Microsoft PowerPoint presentation was used to display information and define separate activities and breaks. All participants and PAs filled out consent forms and confidentiality agreements, if they had not done so already. After each workshop tool or activity, the researcher reviewed the outcomes by summarising and reading aloud the participants' responses. Participants could then make amends or additional comments.

Physical hazards were unlikely because participants were only to interact with their own electrical equipment (power wheelchairs, communication devices) and non-toxic, non-electrical stimulus materials and prototypes.

Workshops took place in the participants' service providers' premises so accessibility and appropriate infrastructure were in place. Where necessary, participants were accompanied by their personal assistants (PAs) all of whom

were approved by the service providers. Their role was to take care of participants' personal care requirements as well as facilitating the participants to undertake the workshop activities. Additional staff from each service provider were working on the premises at each location. Should an accident have taken place, the service provider's regular protocol was to be followed.

During the introduction of each workshop session, the participants were informed that they could leave the room with their PA at any time. They may have liked to do this if they felt unwell, needed to use the toilet facilities, wished to take an additional break, or wished to leave the group. Additionally, a safeguard was put in place in case a participant became upset during a workshop due to unforeseen circumstances; in this instance a break was to be immediately arranged to assess the situation. Comparative to workshops in the literature, smaller group sizes were proposed to allow participants adequate time and space to contribute. Additionally, since PAs were also present, fewer participants meant the spaces would not be crowded or overwhelming.

In terms of beneficence, the workshops were designed to reflect the core values of Enable Ireland's strategic and operational plans, which had been provided by their ethics committee. Benefits to the service-providers and service-users in the plans focused on services provision rather than design research, but the constituent values can apply to both. At a high level, the research aimed to support service users in achieving inclusion and independence within their communities by contributing to the design and provision of better AT, since a primary purpose of AT is to help users become more independent. Another intent for the research was to provide timely, accurate and accessible information to service users and other

stakeholders throughout the project, and to work in partnership with all stakeholders. The research also aimed to empower service users through the use of a person-centred, participatory approach. Empowerment was not measured during the research but the workshops were designed to offer a two-pronged opportunity for service-user empowerment. Firstly, the workshops educated participants by introducing concepts from product design, a discipline they may not be familiar with. Secondly, the workshops served as a space for participants to contribute to research that aims to advance technology that may not just help themselves, but may help others too.

Confidentiality was another ethical issue. As with the Delphi study, codes were assigned to each participant, and these codes were used in place of names in the transcripts and during subsequent analyses. Participants' names exist on consent forms, but these are not associated with the results. Original soft data that associated participants to their contribution, i.e. video recordings and photographs, were stored on memory cards and disks in a locked cabinet in DIT. The data is to be retained for six years, after which point it will be destroyed mechanically. Sensitive data was not a focus of the discussions during the workshops. However, if a participant were to disclose any data of a sensitive nature, this would have been omitted from the analysis process.

3.4.3.1 Sketching and prototyping between the workshops

Between each workshop, the researcher undertook sketching and prototyping tasks. Sketching was used as an aid for brainstorming solutions, analysing ideas, identifying errors or problems as well as general documentation [214].

Prototyping had a very similar purpose, the main difference between them being that sketching is two-dimensional and prototyping is three-dimensional.

Although the idea of PD is to involve users directly in the design process, expecting to undertake all problem solving and concept development procedures during the workshops is impractical. The workshops were useful for gathering information, framing the context of problems [215] and conceptualising issues relevant to the device design. This information was then used to conceptualise and develop the detailed product solutions.

These design activities took place in the prototyping lab in DIT School of Mechanical and Design Engineering. Practices included sketching, paper prototyping, clay modelling, drilling, sawing and bending, 3D printing (fused deposition modelling) and laser cutting.

3.4.4 Data analysis

The raw data produced during the PD workshops came in the form of personal narrative anecdotes. Participants also created design dishes, but since these served as stimulus for discussion, narrative responses were still the key data. Michael Barry [216], who delivers a needs finding course at the Stanford Design School says that stories, or narratives, encompass the implicit rules that govern and organise people's lives and reveal what they find normal, acceptable and true. Narratives reveal much more than what a sentence might mean alone. Narrative data is qualitative, and qualitative analysis typically aims to reveal rich, contextual descriptions of that data, known as 'thick description' [189] (p. 56). Ritchie and Lewis [217] offer guidance on interrogative qualitative data analysis. Key principles are shown below in Table 10. These "hallmarks" highlight that all results

should emerge from the data, and that the analysis process should be flexible yet well organised and documented.

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1) Analytical ideas are grounded in the data rather than superimposed.
2) Synthesis is captured so resulting concepts are traceable.
3) Data is broken into parts so that it can be sorted and ordered.
4) Data is ordered to facilitate searching for themes, patterns and connections within a case, and across different cases.
5) The analysis process is systematic and consistent across the data set.
6) The process is flexible so that unexpected data and patterns can be integrated as they emerge.
7) The process is documented and transparent in case the work is to be re-visited or continued.

Table 10 Hallmarks of interrogative qualitative data analysis [217]

Thematic qualitative analysis was deemed appropriate because it fits with the exploratory underpinning of the research process. The goal here was to identify themes to describe relevant AT needs and design issues that the participants had encountered, as well as themes that related to the PD process involving individuals with disabilities.

All data collection media - MP4 files, photographs and flip chart transcripts - were laid out for comparison and synthesis. The recordings were viewed and compared to the flip chart transcripts to ensure key points were not missed. The amended transcripts were then read three times. After this, the transcripts from the activities were coded. There are a number of names given to the coding and analysis process used, but Framework Analysis [218], and affinity diagrams [219], are two. This technique facilitated the development of a hierarchical thematic framework that was used to classify and organise the qualitative data collected during the workshop. Post-its were used first to visually construct the framework

analysis matrix. After this, Microsoft Excel was employed; themes were laid out in columns and the individual cases in rows. Cells were then filled with relevant data from the transcripts.

The coding process was iterative and took place in cycles. Initially, after the first workshop, a priori codes structured the framework. These were taken from the HAAT model that had been used to formulate the questions in the Delphi Study. Accordingly, human, activity, AT and context constituted the top level in the hierarchy. Typed transcripts were printed with line number notation and a large left margin. Individual parts of transcript text, annotated with their line number, were placed within each of the categories. This allowed for efficient referral to the text in context.

The second cycle involved inductive reasoning to define emergent codes from the transcripts. This involved systematically clustering the transcript content into reasonable groups. The transcripts were then checked against all codes which emerged during the process. The literature suggests that qualitative data analysis should result in the formation of between three and eight codes [220, 221], so the third cycle involved the synthesis and distillation of the codes. Themes that were relevant to the workshop format and design process were earmarked for exploration in subsequent workshops. One of the aims of this research was to discover what categories would be useful for future researchers. As the workshops and the design process played out, the original thematic framework evolved. The final hierarchy was made up of three themes, which are provided in the Results chapter.

This chapter has described and explained the constructs that initially made up the design framework for customisable AT. Next, the results of the framework constructs are provided. Since the design framework was further developed during its application, the final framework is given as a separate result at the end of the next chapter.

Chapter 4

Results

4.1   Introduction

This research has two types of results: the Participatory Design (PD) framework for developing customisable AT; and the product design-related results that came from exploring and applying the framework to the ATCID sample problem domain.

This chapter presents the results in order of how they were chronologically finalised, so the results from the Delphi study involving clinicians are presented first, the results from the PD workshops involving AT users with disabilities come second, and the design framework itself follows these two.

4.2   Phase I: Clinician perspectives on ATCID design issues

4.2.1   Delphi study results

The first questionnaire resulted in a total of 357 generated issues, across the six questions. Forty-three percent, or 154 of these were unique and included in the second questionnaire. A number of the original 357 issues were similar but not identical. For these cases, the issues were combined. For example, participants stated that cables *wear, tear, break, twist* and *fray* in response to the first question, so these were combined into a single issue. The number of unique issues was unevenly distributed among the six questions. After analysing and reviewing all responses, a total of 38 tertiary and other issues were removed from the final

results. The final list of results contains 116 criteria, representing 32.5 percent of the total initial responses. However, four individual issues from the omitted groups were reintroduced to the final results due to the possible bearing they could have on the design of a new product, or if they had been key results in relevant past studies in the literature. This was done to ensure the most complete set of results possible was presented at the time of writing. The number of issues generated and agreed upon as important are shown in Table 11, and the final sets of ranked results for all six questions are shown below in Table 12.

	First Round	Second Round		
		Number of Issues excluded from the results	Number of Important Issues that reached consensus		
Issues relating to:	Number of Unique Responses		Primary Issues M ≥ 4.5 and IQR ≤ 1	Secondary Issues Q1 ≥ 3.5	Total
Prevalent parts of an ATCID which malfunction.	24	11	1	12	13
The reasons ATCIDs malfunction or fail.	22	8	3	11	14
The characteristics of a service-user associated with selecting an ATCID.	30	5	8	17	25
Service-user needs regarding ATCID use and training.	19	1	3	15	18
Desirable traits of an ATCID.	35	2	10	23	33
Frustrations associated with ATCIDs.	24	11	1	12	13
Total	154	38	26	90	116

Table 11 Number of issues generated and refined during the Delphi study

Ranked Delphi Study Results

Issues relating to prevalent parts of an ATCID which malfunction
1. Cables wear, break, twist, fray or tear.
2. Connections between the cable and the ATCID wear.
3. Touch screens stop being responsive.
4. Devices have calibration problems or are difficult to calibrate.
5. Conflicts exist between the computer and ATCID driver.
6. Small parts get lost, e.g. clamping screws.
7. Mounts loosen.
8. USB and other ports break.
9. Internal electrical switch contacts fail.
10. Sensors fail.
11. Movement of ATCID becomes restricted due to dirt build up.
12. Keys/buttons lift away from ATCID.
13. Lightweight switches are continuously accidentally activated and break.

Issues relating to the reasons ATCIDs malfunction or fail
1. ATCID falls/is knocked or banged.
2. Inappropriate, rough and over-use of device.
3. Cables get caught or are pulled roughly from ports.
4. ATCID undergoes general wear and tear.
5. ATCID is poorly maintained.
6. Battery conditioning practice is poor.
7. Weak joints connect cables to device.
8. Battery life or charge is insufficient.
9. Batteries fail.
10. Software updates conflict with device drivers.
11. Poorly routed cables are exposed to damage.
12. Dirt, spills and dust contaminate the ATCID.
13. Movements of client cause mounts to loosen.
14. ATCID is poorly cared for when not in use, e.g. during transport.

Issues relating to the characteristics of a service-user associated with selecting an ATCID
1. Range of motion of the anatomy which controls the ATCID
2. Spasticity/muscle tone
3. Tremor
4. Control of movement, i.e. ability to make precise movements
5. Ability to repeat a movement without strain
6. Motivation and level of interest
7. Posture and client's position
8. Wrist and finger function, i.e. dexterity, sensory perception, proprioception
9. Physical stamina
10. Cognitive ability
11. Condition progression, i.e. improving or degenerating
12. Activity to be facilitated by the ATCID

13. Environment the ATCID is used in
14. Presence of pain
15. Concentration and attention
16. Grasp
17. Speed of movement
18. Muscle strength
19. Access to technical support
20. Funding constraints
21. Vision
22. Service user's level of independence
23. Service user's social network and their familiarity with the technology
24. Type of wheelchair being used, if one is used
25. What the ATCID will be mounted on and the requirements for clamps and mounts.

Issues relating to service-user needs regarding ATCID use and training
1. Correct positioning and mounting of the ATCID
2. Access to ATCIDs for trial period
3. Instilling the motivation to practice, explore and use the technology
4. Simple, written instructions for ATCID set-up and use
5. Pictorial instructions for ATCID set-up and use
6. Maintenance and care instructions
7. Information on how to adapt the ATCID for the service user's changing needs
8. Contact details of supplier and technical support
9. Instilling confidence in the service-user
10. Involvement of the service user's social network in training procedures, e.g. family/carers/teachers
11. Reviews of equipment
12. Basic IT training
13. Provision of demonstrations
14. List of frequently asked questions for troubleshooting
15. Recommendations for use in educational settings (for school staff and boards)
16. Introduction of the service-user to clients who have experience of the ATCID
17. Specific training around a task or feature
18. Regular meetings with the service-user

Issues relating to desirable traits of an ATCID
1. A good match between service-user's goals and the ATCID solution
2. Comfortable to use and does not cause strain
3. Does not impede movement of service-user
4. Adaptable to service-user's specific needs
5. User-friendly
6. Reliable
7. Easy to set up and dismantle
8. Long battery life
9. Easily rechargeable battery
10. Easy to operate

11. Re-adjustable
12. Attractive aesthetics
13. Sensitivity
14. Design is based on mainstream devices
15. Social acceptability, i.e. a design which doesn't make the user stand out
16. Versatility/flexibility/capability of the ATCID to be multi-functional
17. ATCID is intuitive to use, e.g. software has clear menus)
18. Comes with clear instructions
19. Easy to maintain
20. Durable/robust/sturdy
21. Quick to turn on
22. Easy to position
23. Has a universal connection, i.e. USB
24. Appropriate weight
25. Quick to install
26. Compatible with different operating systems
27. Up-to-date
28. ATCID provision is paired with access to local providers who can supply training, maintenance and repairs
29. Appropriate size
30. Appropriate tactile characteristics
31. Low cost
32. Portable
33. Wireless operation

Issues relating to frustrations associated with ATCIDs
1. The high cost of ATCIDs and access to funding for purchasing
2. Positioning in multi-care environment, i.e. clamps and mounts need individual adjustment every time; this is difficult to replicate
3. Limited access to customer support/technical assistance/product manufacturers
4. Cost of repair and short warranties without additional payment
5. Discrepancy of funding throughout the country
6. Time needed to repair devices, leaving service-users without ATCID
7. Devices are not plug-and-play, e.g. drivers need to be loaded from CDs
8. The system is not easily adaptable for suiting exact service-user needs
9. The ATCID needs to be modified for changing service-user needs
10. ATCID positioning
11. Lack of follow through by families and schools
12. Time needed to assess and train service-user
13. Products are specialist or niche

Table 12 Ranked Delphi Study Results

As shown in Table 12, cables were cited as the most prevalent part of an ATCID that malfunctions. Other important mechanical issues were loose mounts, broken ports, unresponsive touch screens and worn connections between the cable and ATCID. Keys and buttons were also found to lift away from devices. Software issues related to calibration problems and driver conflicts. Internal issues were cited as switch contact and sensor failure. Participants agreed that lightweight switches break because they continuously activate accidentally. Dirt build-up was said to affect ATCID use and small parts were cited as being easy to lose.

The top three reasons for ATCID malfunction or failure were related in some way to rough use: ATCIDs fall or are banged, they are inappropriately used, and cables get caught or are roughly pulled away from ports. Maintenance was another important issue, with battery conditioning, dirt, spills and dust contamination, and poor care during transport being cited specifically. Weak joints, poorly routed cables and insufficient battery charge were mechanical issues. Software updates were found to cause problems with previously installed ATCID drivers. Additionally, the physical movement of a user was problematic because it causes mounting devices to loosen.

Twenty-five issues relate to the characteristics of a service-user associated with selecting an ATCID. The most important physiological functions were range of motion, muscle tone, tremor, fine motor control, the ability to repeat movements without strain, and wrist and finger function, including dexterity, sensory perception and proprioception. Grasp, speed, strength and vision, along with motivation and level of interest, stamina and cognitive ability also rated highly. The user's posture and positioning, the presence of pain, and whether the user's

condition was improving or degenerating also featured prominently. Contextual issues related to the activity to be facilitated by the ATCID, the environment of use, the user's level of independence, their social network and their access to funding and technical support.

The top rated service-user needs regarding ATCID use and training related to device positioning and mounting, accessing the ATCID for trialling, and instilling the motivation to practice, explore and use the technology. Instructions in various media and other information on ATCID modification and technical support, along with reviews, basic IT training, demonstrations, and lists of frequently asked questions were found to be important. Peer support was also cited and participants agreed that it is helpful to introduce new users to individuals who have experience of the ATCID. Participants also wanted recommendations for the use of ATCIDs in educational settings for school staff and boards.

Participants agreed that the most desirable traits for ATCIDs are that a device matches the user's goals; that it is comfortable and does not impede their movement; and that it is adaptable to the user's needs. Reliability, battery life, and easy set-up and disassembly were also important. Device aesthetics were highly rated and the group agreed that designs should be based on mainstream devices. Appropriate sensitivity, weight, size and tactile characteristics were other desirable traits. Participants stated that ATCIDs should be flexible, multi-functional, robust, durable, portable, quick to turn on and install and easy to position and maintain. It also emerged that it is preferable when devices operate wirelessly and that ATCIDs should be compatible with various operating systems and have clear menus on screen.

The most significant frustration which professional users associated with ATCIDs was monetary cost. Device positioning in a multi-care environment was another major issue. This frustration relates to devices that must be used by a number of individuals with different needs – like in a school or training centre. As a consequence of this, therapists must regularly adjust the mounting device, but these adjustments can be difficult to replicate. The cost and time spent on ATCID repair and training along with limited access to technical support were other cited issues. Participants were frustrated by ATCIDs that are not adaptable for different users or a user's changing needs. They also disliked devices that are not 'plug and play', and cited funding inequalities and lack of follow through by families and schools as problems.

The morphological matrix in Table 13 is an extract of the matrix which was completed for this research. It shows the top ranked issue for each of the six Delphi questions and provides an example of how all issues were treated during the solution generation phase. (For clarity and consistency, the shaded area corresponds to the shaded area in Table 5. Further examples of concept generation can be found in Appendix 6.)
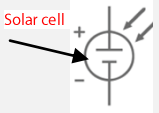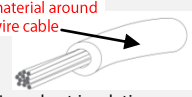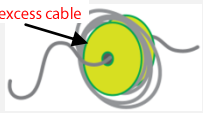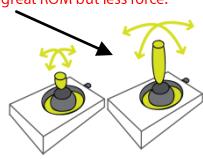
Design Issue	Relevant Component	Definition/Function	Design Solutions				
Question 1: These issues relate to prevalent parts of an ATCID which malfunction.			**Ways to reduce or negate the design issue**				
Cables wear/break/twist/fray/tear.	Cables	Transfer power and transfer signal.	Solar cell Take out cables & use wireless technologies (rechargeable batteries/ solar power & infrared transmitter and receiver).	Thick elastomeric material around wire cable Use robust insulating materials to reduce likelihood of damage to cables.	Make cables very rigid/flexible to reduce likelihood of torsion/breakage.	Spring-loaded disk retracts excess cable Eliminate loose excess cable - make cable retractable or wind/tuck it into something.	Port and jack along cable Have purposeful 'breaking point' along cable which can be reconnected; cable is less likely to tear, or damage ports and jacks at the computer interface.
Question 2: These issues relate to the reasons ATCIDs malfunction or fail.			**Ways to reduce or negate the design issue**				
ATCID falls/is knocked or banged.	Housing/Casing	Protects internal components and affords aesthetic qualities to the product.	Protect ATCID in robust casing.	Fix ATCID on mount.	Delicate components in elastomeric skin Use flexible materials with low Young's modulus for casing to endure bangs.	Make all individual parts robust for disassembly. That is, build in the ability for the ATCID to be broken apart and easily put back together.	
Question 3: These issues relate to the characteristics of a service-user associated with selecting an ATCID.			**Ways to make the product customisable with regard to the design issue**				
Range of motion (ROM) of the anatomy which could control an ATCID.	Physical interface where human movement is required to activate device; joystick lever, switch button, trackball etc.	Distance hardware component needs to travel through to activate device.	Use various materials with different rigidity for adaptive customisation. (Work = Force X Distance)	Joystick knobs of different lengths; longer lever requires great ROM but less force. Use forms that require different distances for activation.	Touchpad! or switch Use different base devices for collaborative customisation that require either a small ROM (touch-pad) or a large ROM (selection of switches).	Use an easily manoeuvrable mount that can position the ATCID at various distances from the individual.	
Question 4: These issues relate to service-user needs regarding ATCID use and training.			**Ways to enrich the product package**				
Correct positioning and mounting of the ATCID.	Mount and mount-interface	How the therapist arranges the ATCID in proximity to the user.	Obviate need for mount - user wears ATCID.	Provide an easily adjustable & re-adjustable mount. Use quick release levers and colour/number coded shafts.	Use shape memory alloys for mount material.		
Question 5: These issues relate to desirable traits of an ATCID.			**Ways to enrich the product package**				
A good match between service-user's goals and ATCID solution.	Whole product package	How well the ATCID satisfies the user's goals.	Make the device adaptable and customisable.	Find out goals and provide solution using observation and team participation.	Use list of questions/types of tests to determine best ATCID - MPT questionnaire (69).	Allow trialling period for new ATCIDs.	Facilitate follow-up sessions and on-line feedback forums.
Question 6: These issues relate to your frustrations associated with ATCIDs.			**Ways to reduce or negate the frustration**				
High cost of ATCIDs and access to funding for purchasing	Whole product package	Monetary cost of the ATCID.	Increase lifetime of product, i.e. build in the ability for the ATCID to adapt with users changing requirements.	Use off the shelf parts; examine other devices for component lists.	Increase market share by mass customisation or universal design.	Reduce overall cost of AT to the user by reducing abandonment.	Implement Design For Manufacture and Assembly guidelines (DFMA).

Table 13 Adapted Morphological Matrix

4.3 Phase II: Participatory design workshops with AT users with disabilities

4.3.1 Participatory design workshop results

The Participatory Design (PD) workshops were about empathising with ATCID users' and understanding their experiences and needs, in order to develop design criteria and concepts for customisable ATCIDs. A concurrent aim was to refine techniques for PD workshops involving individuals with motor and communication related disabilities. The four workshops and device development between these sessions took place across a two year period between 2012 and 2014.

Data came from the following five tools used during the workshops: Warm Up, Discussion, Design Dishes, Prototypes and Evaluation. Since the workshops were designed to be flexible and exploratory, data was also produced from participant-led discussion. Though discussion touched on broader ideas and perspectives about living with a disability, these were not included in the final results because they sit outside the remit of the design framework and don't serve to inform a design direction for the customisable ATCID or workshop format. The discussion also illuminated some ideas about the psychological relationships participants have with AT; these are included because they were deemed to be relevant to the investigation. Though five tools were used, the results were synthesised in a joint thematic analysis because ultimately, participants broached new ideas in an ad-hoc manner at different times, when different tools were in use.

For example, in the design dish exercise, participants recalled experiences about their past technology usage when engaging with the stimulus artefacts, but they also related things about past technology usage during the discussion and prototype exercises. The Design Dish Tool was useful in its own right too, but the main result was that no agreement existed between different AT users with regard to favoured aesthetics. Some participants selected different combinations of soft, hard, rough, smooth, brightly coloured and mutedly coloured options, while some participants had no preferences in relation to visual aesthetics. In practice, the stimulus materials were less about putting together the constituents of a satisfactory ATCID, and more about encouraging and fuelling further discussion.

Thematic analysis requires a researcher to identify themes that unify patterns in data. However, at the same time, the overarching research questions and aims also drive the analysis. In this instance, the aims were to develop criteria for customisable ATCIDs and to develop ATCID product concepts that are sensitive to user needs. With this in mind, the final thematic framework structures ideas about participants' ATCID experiences under these two headings: frustrations and workarounds.

Frustrations are essentially 'problems-to-solve' in disguise, and problems are stimulus for solution generation. In the workshops, a participant's frustration was couched - or framed - in some type of anecdote. The whole anecdote was important because the frame provided insight into what the user's problem was and consequently, how it may best be solved. When frustrations were hidden more deeply in an anecdote, they highlighted latent needs [222], which are underlying

problems that a person unknowingly articulates. Latent needs appeared in complaints people made about a technology or activity, and they were identified by critically looking at statements made by participants and asking, 'what problem/issue is this person really talking about; what is the root problem here?'.

Typically, it is difficult for people to envision solutions or scenarios that are unfamiliar or not clearly analogous to a related context, but by discussing experience rather than projected desires, frustrations and latent needs became apparent. Latent needs emerged in sentiments about reasons for AT abandonment, frustrations incurred by AT use, and also in workarounds participants had employed when their technology was inadequate.

Koopman and Hoffman describe a workaround as an 'alternate path' as follows: 'when a path to a goal is blocked, people use their knowledge to create and execute an alternate path to that goal' [223] (p. 71). A workaround bypasses as blockage or problem, but it does not eradicate it. Workarounds can be arduously and purposefully devised, but they can also be intuited and go unnoticed by a user. They exist in different contexts, from human-computer interaction, to cooking and other acts of daily living. An example is the idea of putting uncooked rice in a salt cellar to absorb moisture and stop salt grains sticking together, so the salt can flow out smoothly. One way of looking at this workaround involves seeing the root problem as salt grains sticking together when they encounter moisture in the air. A product solution might be a salt cellar design that contains a non-toxic moisture absorber, or a cellar that grinds the salt as it comes out. Workarounds are useful for a designer to understand because a workaround devised by one user, may

never occur to another - and if many people experience the root problem, then it may be worth redesigning a product to more clearly solve it. A workaround that a user has constructed is not necessarily the design answer because they can be time-consuming or clunky, but the problem that it solves is useful to note for conceptualising new designs.

The two concepts of frustrations and workarounds constitute the highest-level themes in the framework analysis for the PD workshops. However, as the results were refined, frustrations were segmented as personal frustrations and ATCID related frustrations, as shown in Figure 19.

A proviso for these results is that they are not presented as relevant for all participants. Unlike the Delphi study, reaching consensus was not the aim of the workshops. Individuals' experiences and anecdotes provided distinct perspectives of AT use, and together they create a profile of multiple end-user issues. Also, the first workshop's initial framework analysis process produced themes that were more generic than intended, for example, 'ATCIDs should be convenient' and 'ATCIDs should be discreet'. These reflected older studies [25, 46, 224] and lacked instruction for how they should be applied in a design process so, as the workshops continued, more detail was incorporated in the thematic labels in an attempt to make them more clearly actionable to a design process. Another qualification is that the final themes become more useful as design stimulus when appreciated as an element of the participant anecdotes, examples of which are given in the next section. This comes back to the idea of framing, whereby a

problem with contextual information offers a richer starting point for solution generation.
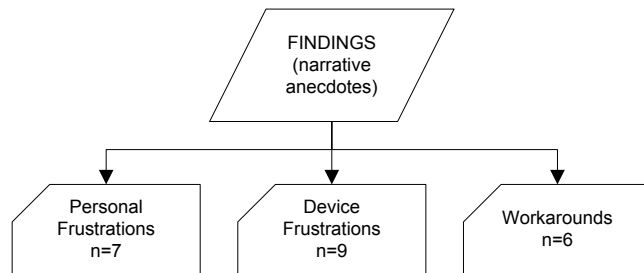
Figure 19 Participatory Design Workshop Results

4.3.1.1 Personal frustrations

Table 14 shows the seven themes related to personal frustrations that participants felt about their AT. These are more intrinsically associated than the technology frustration themes outlined in the next section. These personal frustrations portray a broader view of AT in general, but each one relates to ATCIDs too.

Personal frustrations that ATCID users experience

1) Dependence on AT and anxiety about what that means for the future
2) Inefficient task completion leads to AT dissatisfaction and frustration
3) If a disabling condition degenerates, the AT user's motivation can decrease
4) AT companies don't modify their products & obstruct users from making modifications
5) AT users tolerate pain in order to continue an activity
6) Expectations and attitudes towards AT vary - and this effects levels of satisfaction
7) Needs change over time as a person's condition worsens or improves

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Table 14 Workshop results 1: Personal frustrations

- <u>Dependence on AT and anxiety about what that means for the future</u>

All participants perceived AT and ATCIDs as important but AT and ATCIDs are not the main concern of users. AT is perceived only as a means to completing tasks and engaging in activities. The tasks and activities that ATCIDs facilitate were wide-

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ranging. They use computers and the internet for social activities, including e-mail, and social media sites, and for education, exams, and 'giving presentations' (P7). Participants also engaged in hobbies like listening to music, playing computer games and following sport leagues. Others used their ATCIDs to occupy themselves with creative pursuits like 'writing poetry' (P7), 'editing video... and researching stuff - like how to get to Ibiza!' (P8).

Computers have opened a world to people with motor and communication disabilities because they lessen the gap in apparent ability; once a person can control a computer, they can communicate in the same way as those without disabilities. They play a large part of occupational therapy programmes too, but this dependence on technology and ATCIDs can cause anxiety for those with degenerating conditions.

> A worry that has been playing on my mind is what will I do if I can't use a computer anymore, what will keep me entertained? I've been thinking this... as I've been losing some ability. There's nothing else to do. I use it to socialise, for entertainment. Those are the key factors... That's the main problem: finding something to do, boredom would lead to insanity... At the end of the day, it's about giving you something to do and a way to do it.

> [Workshop 2, P3]

This equalising power of ATCIDs also means more social inclusivity, both online and offline, in the real world.

> I really enjoy Airsoft. It's fun and when I play it, I feel equal. It's team-based and everyone's doing the same thing-equally. That's very important to me. It's great to be depended on in a competitive manner. I play with friends but with others too and there's always the same attitude-everyone's the same, everyone's just playing something.

> [Workshop 2, P3]

AT was seen to facilitate independence, but all participants desired more independence.

> I'd like to be able to do more stuff on my own. Just do anything I'd like to do.

> [Workshop 3, P4]

- <u>Inefficient task completion leads to AT dissatisfaction and frustration</u>

Participants often brought up issues related to speed and control during the workshops. These two themes are combined and referred to as efficiency here because in human-computer interaction usability studies, efficiency is defined as the relationship between a) the accuracy and completeness with which users achieve certain goals and b) the resources expended in achieving them [225].

In the first workshop, P1 commented about the speed of her power chair, envisioning 'a faster wheelchair' in the future. She also referred to the speed of computer access saying, 'If you slow them [joysticks and scanning software] down, they have to be really slow.' In the same workshop, P2 stated that 'when doing your work it takes too long - even with this new joystick. Both the hardware and the software cause this.' P2 also expressed control problems with his ATCID, stating that 'it could make [him] tired and frustrated.'

Participants blamed their own abilities, software and hardware for inefficiency. However they were also concerned with improving their own abilities to increase their efficiency. P2 revealed this by saying,

> When doing your work, things take too long… (I have to) use the dwell (function) to open a program… And it slows me down… I hope to get faster at working my new computer. I can imagine that soon it will be

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able to help me type quicker, and then I can be much happier doing my
day to day activities.

[Workshop 1, P2]

These issues around speed and control support the idea that efficiency is a key to

ATCID satisfaction.

In the future, I'd like to be able to just use my voice for everything. Just
say something and have it happen.

[Workshop 4, P8]

Efficiency was also a factor when people learn to use new devices. P3 said that

'things are not designed for what [he] needs so it takes a while to learn how to use

them' while P7 said, 'using the phone is hard, but I'm learning'.

- If a disabling condition degenerates, motivation can decrease

Motivation to learn and use AT is an important factor in successful and satisfying

AT adoption, but motivation is delicate and it can be affected by the support a

person receives, their past experiences and the state of their disability.

I was given a computer in school but at that stage I just didn't want any
help, I was stubborn at that time. I didn't want to be different. In the last
year and a half of school I lost all strength so I was in hell. I just didn't
want any help... I'm not typing a lot anymore as I've become weaker.

[Workshop 2, P3]

Experiencing a degenerating condition can itself effect a person's optimism and

motivation to continue with their routines. A person's motivation can also

decrease with the news that they need to restart the learning and training process

with a new AT device that fits their new needs.

Ultimately, human support networks are paramount. These networks inspire psychological drivers like motivation and confidence and work with users to create occupational therapy plans, prescribe and train them in AT use, and provide emotional care. Participants spoke highly about the people that help them, with P4 saying, 'The people at Seat Tech[6] are great - where would I be without them?!' Participants trust the clinicians and carers that work with them too and appreciate the extra lengths they go to in order to help them receive appropriate solutions.

> OT's or other people have (prescribed) my AT. I trust them to know what I need.

> [Workshop 4, P8]

- <u>AT companies don't modify their products and obstruct users from making modifications.</u>

Participants mentioned how product warranties can become void if one attempts to make modifications. They were frustrated by the fact that they would have to risk breaking their device and incurring a monetary loss in order to have a chance at getting a device that suited them.

> You know, a big issue I've had is with the people who make these chairs. The people who make (my joystick) don't communicate with (my chair manufacturer). They'll build things but they won't look at making alterations that you might need. Some things are not compatible and then it's tricky to do mods (modifications)… My dad has done loads but it's a real obstacle, with rules and that.

> [Workshop 2, P3]

P3 spoke a lot about the challenges involved in adapting technology to meet his needs. Referring to 'illegally' modifying off-the-shelf AT, he said that, 'there are

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[6] Seat Tech is a branch of Enable Ireland that provides posture positioning and seated mobility solutions.

good hearts doing good work here (in the Central Remedial Clinic), work that maybe they're not supposed to do'.

- AT users tolerate pain in order to continue an activity

Discomfort is part of daily life for many of the participants. Though participants often spoke highly of their AT and what it allowed them to do, they also spoke about how ATCIDs contribute to experiences of pain and strain. The size and layout were to features specifically mentioned.

> I'll be in agony after a short time always. My hands, wrists and palms. Yeah, you'd be in agony but it's either that or stop doing what you're doing so I just keep going... [My gamer mouse] is like this big bashable thing – you place your hand on a big saddle and it can be a bit strenuous.
>
> [Workshop 2, P3]

> There are buttons on (my joystick), but they are hard to press because they are in the middle. It can make me tired and frustrated.
>
> [Workshop 1, P2]

- Expectations and attitudes towards AT vary - and this effects level of satisfaction

As is to be expected from a group, some individuals were more positive about their experiences and some were more negative. This is likely down to general attitude as well as a result of the suitability of their technology. Some participants were consistently very positive about their ATCIDs. In the first workshop, P1 expressed great positivity towards her ATCID even though problems with it transpired during the session. She also seemed content to accept that she can't use a computer due to her tremor. Along with some others, this participant didn't speak about her ATCID as a piece of technology in its own right; for her, the ATCID and power chair

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were one unit. Positive features that she noted were the fact that this unit was 'easy to learn' and that she 'doesn't need to charge it every night… [She] charges it when it's almost flat-once a week… which is fantastic considering the amount of use it gets'. Others were less positive, communicating more negatively biased sentiments about their AT overall, talking about pain, inappropriate technology and cost.

- <u>Needs change over time as a person's condition worsens or improves</u>

    I've tried loads of different (ATCIDs) but eventually I couldn't use them, even the best ones. I used to use the Xbox for gaming, I used the generic controller. I can't anymore…

    [Workshop 2, P3]

Ability to carry out tasks and activities change as disabilities change. P3 explained that, 'I'm not typing a lot anymore as I've become weaker'. Along with this, AT abandonment can come about. All participants had tried, used and abandoned other ATCIDs before being prescribed with their present devices. P2 used a roller ball before but finds 'the joystick is easier now'.

The next section concentrates on the second group of frustrations, which all specifically relate to ATCIDs.

4.3.1.2 ATCID related frustrations

Table 15 shows the frustrations participants have about ATCIDs. These frustrations are more extrinsic to the user than the personal frustrations reported in the previous section; these relate directly to the technology, and less to the intrinsic effects they have on the user.

Frustrations that users experience in relation to ATCIDS

1) ATCIDs are not adaptable
2) Appropriate ATCIDs are not available
3) Users have different sensitivity requirements for ATCIDs
4) Users have different size and layout requirements for ATCIDs
5) Users have different visual and tactile aesthetic desires for ATCIDs
6) ATCIDs malfunction and break; they are not robust
7) The expense can be prohibitive/inhibiting.
8) Cables are a nuisance
9) Power/battery information is not communicated

Table 15 Workshop results 2: ATCID related frustrations

- <u>ATCIDs are not adaptable</u>

As mentioned, AT users abandon AT because of changes in both product availability and changes to their needs. Participants had all used a range of ATCIDs prior to their present devices. Some participants had, with their support networks, tried to make modifications to their own ATCIDs.

> My dad ripped (my joystick) all apart and clipped the springs inside so it wasn't so hard to move.

> [Workshop 2, P3]

Another participant had experienced increased product satisfaction when her joystick was customised with a cork stuck on the lever.

> I find the cork easier to control; the black knob is too short. (I've been) using it for two months. The cork has a nicer texture on my fingers. Before (I) just used the black knob. It feels more solid.

> [Workshop 1, P1]

Participants also complained that AT manufacturers 'build things, but they won't look at making alterations that you might need' (P3). Interactional adaptability, which relates to how a user physically controls the ATCID, was desired, along with functional adaptability, which relates to what the ATCID can do. Some ATCIDs were useful, but could not be used with certain software or electronic AT systems.

> It would help if I could use my joystick to play games.
>
> [Workshop 1, P2]

With this being said, one participant communicated the benefits of his adaptable ATCID.

> I can use my head switch to change my computer controller from a writer (for AAC) to the scanning joystick (for mobility).
>
> [Workshop 3, P5]

- Appropriate ATCIDs are not available

Participants had different levels of success with ATCIDs, due to tremor, high muscle tone, muscle weakness and other motor impairments. Comments pointed to frustration with ATCIDs regarding physical control issues.

> I've tried using a computer, but using a mouse with my shake is very, very difficult. I find them all - joysticks, scanning software - very sensitive. If you slow them down they have to be really slow.
>
> [Workshop 1, P1]

> I used hand switches on a tray for driving (my wheelchair) but it was temperamental.
>
> [Workshop 3, P4]

Rather than interacting with a computer directly with an ATCID, some participants preferred to use their Voice Output Communication Aid (VOCA) to dictate commands to their personal assistant who could then input those into a computer.

There was also a sense that there is not enough variety of ATCIDs available, with P3 saying that 'really you're dealing with the same equipment all the time'. When the mainstream computer input device stimulus was introduced during the design dish exercise, P2 pointed out that there were good features in lots of the devices but that none on their own would be right for him.

> If a few of these (mainstream joysticks) were joined together to make them better that would be good.

> [Workshop 1, P2]

- <u>Users have different sensitivity requirements for ATCIDs</u>

Participants had various opinions relating to the amount of force required to activate and control their ATCIDs. During the design dish exercise, when the ATCID stimulus was presented, P1 explained that her tremor made it difficult to use ATCIDs.

> I didn't like any of (these). I've tried them all before and none can compete with my shake. ...using a mouse with my shake is very, very difficult. I find them all - joysticks, scanning software - too sensitive.

> [Workshop 1, P1]

P3, who has muscular dystrophy, spoke a lot about device sensitivity. His muscles are getting weaker over time, so his needs are constantly changing too.

> The buttons (on my old mini keyboard) became too hard to press - and there are too many keys... the worst AT is bulky with no sensitivity

adjustment. All the AT I've used has been bad! It could be done a lot
better.

[Workshop 2, P3]

P3 had received help to put a small sensitive joystick on an imported all-terrain

chair he had purchased from Germany for using in Airsoft games.

The chair wouldn't respond to (the old joystick) - it wobbled like hell. So
now my special chair is very sensitive-I needed a way to turn down the
sensitivity - but that's not easy. I like (the new joystick) because it's so
sensitive-not like a big JCB one. It's nimble and small and easy to move…
touch it and it will wobble! …Using the (new joystick) in the last while, I
felt like the world opened up as I had always used the other clunky one.

[Workshop 2, P3]

The environmental context of use was also relevant. P3 explained that using an

ATCID outside in the cold could be more difficult.

I always need someone to press the buttons on my joystick. It's okay for
indoors but challenging outside. It's just hard and big and tough - that's
fine in a warm environment but it not so easy when it's cold. I have to
adjust it all the time if it's on different terrain and it locks up in the cold...
I need to reduce the amount of strength you need to move the controls.

[Workshop 2, P3]

- <u>Users have different size and layout requirements for ATCIDs</u>

The form of an ATCID was perceived as important. In relation to a device's layout,

P2 expressed problems posed by the layout of his ATCID; 'There are buttons on it,

but they are hard to press because they are in the middle.' P3 stated that 'there are

too many keys' on his old mini keyboard, whereas P8 liked the Gewa Prog, a

programmable 18 switch device, and P7 liked to use a compact keyboard for

writing poetry.

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In relation to a device's size, P3 liked that his joystick was 'tiny' but complained that 'there's just a little stick with a ball on the top... there's nothing to grasp and it's driven by your thumb'. P1 had a larger joystick lever than P3, but even that had been too small for her. She improved it with her therapist by attaching a cork to the top. On seeing the stimulus images of other ATCIDs, P3 commented they were all too large, saying:

> They have big buttons. I never know why everything has to be so big! It doesn't have to be like that. A really small trackball or switch is fine! It's better... Anything smaller and more confined is better for me... I don't like clunkiness...

> [Workshop 2, P3]

- <u>Users have different visual and tactile aesthetic desires for ATCIDs</u>

Participants had different opinions about how a device should look. Generally speaking, before being presented with alternatives, participants said they preferred plain black devices, but when shown the stimulus in the design dish activity, they changed their minds and responded enthusiastically to the idea of brightness and colour. This reflects the idea that people tend to make suggestions for new designs that are wholly based on their past experiences. The participants generally used plain black plastic ATCIDS so this was the point of reference. For example, in the first workshop, P1 commented that 'black is very neutral-anything else might draw unwanted attention to you and your chair.' However, during the design dish activity, P2 selected a bright red plastic mouse, a popular mainstream mobile phone and a game pad saying, 'they look nice... they look up to date... I want my technology to be up to date' and 'I would like hints of bright colour'. P1 chose similar images saying, 'I like the look of these'. P1 chose no AT stimulus stating, 'I

didn't like any of them'. This trend continued and in the end, all eight participants chose popular mainstream devices from the selection of stimuli, and no AT devices. The AT that was available was said to be 'big and clunky... analogue... old-fashioned' (P3). P8 said that 'the AT is boring and depressing-they look medically and rotten!'

P3 provided more evidence of this initially saying;

> I don't care how technology looks as long as it does the job. Saying that, I've used something like a plastic stick with a cork on top-so I have an issue with that type of look...I usually like greys and black-it's very boring isn't it?! I wouldn't like anything too bright or eye-catching. I wouldn't want to attract too much attention to it when somebody was saying hello to me! Yeah, grey or black.

> [Workshop 2, P3]

However, when the stimulus was presented he said that 'the colours are actually sort of bright and enthusiastic. These are just more appealing'.

Largely, participants wanted devices that are similar to mainstream technologies, but P2 suggested that personalisation of a device's aesthetic would be favourable.

> I might want to show my personality through my AT.

> [Workshop 1, P2]

In the third workshop, a participant who uses a head pointer added to this idea when she said spontaneously;

> I really like my pink cover (on my iPad). I chose it myself.

> [Worksop 3, P6]

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Participants also chose different textures and forms from the stimuli, though most preferred the softer textures.

> I like these (selecting the rubber, embossed card and green felt over wire texture swatches) I like how they feel on your hands.

> [Workshop 1, P2]

> It's definitely better to have something soft. There's a fabric layer over (my joystick). It's not great. I'd feel discomfort if I had something uncomfortable like this (pointing to a texture swatch with embossed pattern). But then, I have a mobile phone and it slips out of my hand a lot because it's too smooth… I had a felt backing on a phone and I liked it for grip.

> [Workshop 2, P3]

To support the finding that participants had different visual and tactile preferences for ATCIDs, Figure 20 shows examples of the stimuli that participants selected during the workshops.

Figure 20 Examples of participants' design dishes

- ATCIDs malfunction and break; they are not robust

Participants criticised the fragility of their ATCIDs. P7 complained that her 'key-guard used to come off' her keyboard before she got an on-screen keyboard and P3 was irritated by the fact that his joystick tended to 'lock up in the cold'. Participants also objected to the model for device repair, because they have to wait for the broken AT to be sent away, fixed and then sent back.

> The problem with my (various ATCIDs) is that they break a lot, especially my (portable communication device). Why do they have to go to England to get fixed? It's the same with hoists. There are different (components) coming from everywhere. The Irish have no brain when it comes to disability!
>
> [Workshop 1, P1]

Waterproofing was another concern for P1 since she had experienced problems with rain, food and drink affecting her ATCIDs.

> Mine aren't waterproof. I messed up my controller with rain. The rubber came off another one. So when it's raining you can't use them. I need a case. Drinks and coffee and food are other problems.
>
> [Workshop 1, P1]

- The expense can be prohibitive/inhibiting.

Though certain devices are prescribed and paid for by the state or the AT service-providers, others are not. P3 needed expensive technology to enable him to engage in his hobby stating, 'I also had to personally buy the off-road chair'. He also stated that he had 'used a mount, but it was out of [his] own pocket'.

- Cables are a nuisance

Cables caused the most prevalent issues, according to the stakeholders who took part in the Delphi study. They were also discussed in the workshops. P2

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complained that 'setting up all the wires and cables for [his] different devices is annoying'.

- <u>Power/battery information is not communicated</u>

Participants talked about their batteries running out of power, but the frustration related to the lack of notification devices provide.

> I would like a warning light for when your batteries were going to run out before it turns off. Or a voice to tell you that it was going to turn off.

> [Workshop 3, P7]

The next section reports on the workarounds that users employ to get around problems they encounter with their ATCIDs.

4.3.1.3   Workarounds

Table 16 shows the six workarounds identified during the workshops.

<u>Ways AT users bypass problems that relate to their ATCIDs</u>

1) Users employ mainstream computer input devices in their own way
2) Users retrofit ATCIDs with new parts to adapt the interaction style
3) Users modify the mechanical constitution of an ATCID to adapt the sensitivity
4) Users employ different ATCIDs for different tasks
5) Users change ATCIDs as their condition degenerates (or as the user rehabilitates)
6) Users find different physical positions that are most comfortable for different ATCIDs

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Table 16 Workshop results 3: Workarounds

- <u>Users employ mainstream computer input devices in their own way</u>

Mainstream technology is easier to acquire, since anyone can purchase it off-the-shelf in a store or online, and it is, generally speaking, less expensive than comparable AT. Participants mentioned quite a lot of mainstream technology in

their repertoires of technology, including iPads, smart-phones, and gaming computer input devices like the Nintendo Nunchuk, xBox and Playstation controllers. Participants spoke about how they had found their own way to interact with these mainstream devices to make them work for them. Speaking about 'the normal games controller' that P2 used to control his Playstation, he said;

> I use it on the floor - it works for me that way - with one hand and my knee.

> [Workshop 1, P2]

However, he also stated that one of the best things about his new ATCID is the fact that it is integrated, meaning it works with his power chair and his personal computer, because this means that he can access his computer while staying in his chair. P3 spoke about he uses a number of computer input devices to interact with his PC.

> I use the Mini Mouse with my right hand and the Razer Nostromo games controller with my left, while leaning forward on the table.

> [Workshop 2, P3]

P6 demonstrated her workaround with mainstream technology by using her head pointer to control an iPad mounted on her power chair. She also curved her body down to the tray mounted in front of her to control the touchscreen on her phone.

> I use my nose with my iPhone. People think I'm doing cocaine! I send texts with my nose with the phone angled up.

> [Workshop 3, P6]

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P4 pointed out a drawback that he perceived about using mainstream technology when he stated that 'it's very hard to hold onto [his] device because [his] sister takes it!'

- Users retrofit ATCIDs with new parts to adapt the interaction style

P1 had worked with a therapist to improvise a customised solution to her control issues by attaching a cork to the knob of her joystick. She commented that she 'finds the cork easier to control; the black knob is too short... It feels more solid now'. During the workshop, it emerged that she had tried other ATCIDs previously but 'didn't like any of them' because 'none can compete with [her] shake.' P1 has some hypertension and tremor issues, so the sturdy, stiff and large cork, shown in Figure 21, suits her needs. A number of times during the design dish activity, P1 expressed a liking for a texture, colour or device but would immediately state that it 'is not as good as [her] cork'. It was evident that she felt a strong bond with her device and expressed ownership regularly throughout the day referring to 'my cork'. P1's defence and feeling of ownership for her customised ATCID supports the idea that personal AT customisation has benefits.

Figure 21 Participant using her customised ATCID during the first workshop

- <u>Users modify the mechanical constitution of an ATCID to adapt the sensitivity</u>

Beyond adding components to the hardware, P3 had experience trying to modify the mechanics and electronics within his ATCIDs.

> My dad ripped (my joystick) all apart and clipped the springs inside so it wasn't so hard to move[7].

> [Workshop 2, P3]

During the design dish exercise, the mainstream computer input device stimulus reminded P3 of another modification he and his dad had attempted;

> It's really funny; I actually bought those two (gaming joysticks) before. We ripped the insides out of them to try to get them to work for me. It didn't work so well. They just didn't respond well.

> [Workshop 2, P3]

P3's hobby motivated a lot of computer input device modification. He and his dad had spent five years on a project to make an Airsoft gun rig for his power chair. He used 'an Arduino chip, relay switches… and also tried to use a Nintendo Nunchuk'. With help from his service providers, he had also modified how his power chair was controlled.

> Someone put (a more sensitive joystick) on my (privately imported) chair off the record. The person who was making the mod had never done this before… Basically, I needed the better controller on my hobby chair. It was so difficult to re-wire and change it.

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[7] Most joysticks employ a compression spring to automatically reset the shaft to neutral. Thicker or larger springs make the joystick harder to move and the automatic return to the neutral is faster and more powerful. In contrast, smaller springs make the joystick easier to move.

He pointed out the issues with this type of unregulated and improvised customisation, referring to warranty and safety issues.

> There are good hearts doing good work here, that maybe they're not supposed to (referring to modifications). I suppose for a company making stuff, it's a safety thing (referring to the fact that making modifications voids the warranty]. They're afraid of errors. If something is too powerful, and then if a control gets hit... I definitely have been worried before with my little niece. If I just touched off the control and knocked into her...

> [Workshop 2, P3]

- <u>Users employ different ATCIDs for different tasks</u>

All participants used multiple ATCIDs because they found that different ATCIDs were more or less appropriate, depending on the electronic AT devices or software programmes they were interacting with.

> The trackball is good for clicking around small areas but the track-pad is good when windows (on the computer screen) are bigger.

> [Workshop 4, P8]

P2 supposed that he 'would like to control all the software with the joystick'. He had to use buttons alongside his joystick to control certain functions but said 'they are hard to press because they are in the middle' and that made him 'tired and frustrated'.

P6 sends texts using her nose to control her iPhone; accesses Facebook using her head pointer control her iPad; communicates using her elbow to select letters on her alphabet sheet; and gets around using her elbow to move the joystick on her power chair.

- Users change ATCIDs as their condition degenerates (or as the user rehabilitates)

Participants' conditions were dynamic, with many of the cohort experiencing degeneration in their ability. P3 said that he has 'become weaker' as his muscular dystrophy continues to affect him.

> I've tried loads of different things but eventually I couldn't use them, even the best ones. I bought and threw away so many… I used to use the xBox for gaming and I used the generic controller. I can't anymore. You had to use that - only now are they beginning to make gadgets and devices to plug into the console, you can plug in a mouse and keyboard… but the PC works so well that I don't bother with the Xbox anymore. It's a better alternative for me. So I use the Razer Nostromo and the Mini Mouse.
>
> [Workshop 3, P7]

P7 found she was now less able to operate ATCIDs with precision.

> I used to have a roller-ball (mouse). When I couldn't use that anymore, I started using a joystick. Now I use a Cherry keyboard.
>
> [Workshop 3, P7]

- Users find different physical positions that are most comfortable for different ATCIDs.

There are a number of elements in a human-computer interaction system including the person, the input device, the processor and the output device, and the arrangement of each affects the system. Therefore, changing the type or placement of the input device will influence the efficiency of the system, as will changing the positioning of the person. Participants were familiar with this idea and demonstrated it in the ways they used their devices.

It used to be centre mounted on a tray in front of me but it's on the arm now. I got it changed to get more freedom in front of me.

[Workshop 4, P8]

I'll be in agony after a short time always. My hands, wrists and palms… I'll reposition myself and try moving around. When I'm learning to use something new, it's really just trial and error. I find out what I need to do and try different things, maybe it's me; I need to move an arm or something. Things are not designed for what I need so it takes a while. I might try with a pillow under my arm for comfort or something.

[Workshop 2, P3]

These three sets of results, personal frustrations, ATCID related frustrations, and workarounds all provide stimulus for solution generation. Before reporting on how the workshop results were used in the prototype development process, participant feedback about the workshops is described below.

4.3.1.4 Evaluation of the workshops by participants

Participants gave feedback on their experiences after each workshop. Everyone who took part was very positive, with the exception of those in the third workshop. P4 found the workshop 'a bit boring' and that the prototype concept didn't interest him. Participants agreed that the third workshop was slow. Other participants (P1, P2, P3 and P8) were generally mostly positive about how 'enjoyable' the day was and P3, P5 and P8 were particularly positive about the fact they felt they contributed. The same three individuals also commented that they felt they had learned new things during the workshop.

4.4   Prototype development and design

Once the Delphi Study was completed, the first design objective for the customisable ATCID was to specify the core technology that would translate the human interaction to a useful signal for the electronic AT. This core technology was to be the product platform, which is the universal element of the product that is used in all configurations or customisations of the ATCID. The Delphi study results largely influenced the universal product platform design since the Delphi study provided consensus on ATCID issues. The PD workshops provided information about individual's interaction issues, so those results largely drove the design process of the customised configurations.

Though the Delphi study results were used to generate different types of design solutions [See Appendix 6], the first job was to investigate and evaluate existing input device technologies for the product platforms in terms of those Delphi results. Technologies under consideration included; various single and multiple mechanical switches, including plate, lever and string switches; pneumatic sip and puff switches; proximity and acoustic sensor switches; optical mouse sensors; potentiometer and digital joysticks; and various touch panel technology. The Delphi study results were grouped into the following eight categories for the purpose of evaluating these technologies: robustness; cleaning and decontamination; customisability or the ability to be tailored in terms of sensitivity, size, modality, complexity and aesthetics; cost; software; positioning and mounts and; cables and batteries and; service package. Appendix 7 contains the full table of results labelled with their categories.

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Five of the six Delphi questions resulted in responses about robustness. Delicate components or assembly mechanisms were cited as failing, along with ATCIDs breaking without a clear cause. Cleaning and contamination issues were cited by the Delphi study participants.

Cost issues emerged throughout the six questions, and this was already a known issue with AT provision. Mass customisation is one way of reducing the cost of devices, because it increases the consumer base and therefore products can benefit from improved economy of scale. DFMA principles can also reduce the cost of products. Asides from these two theories, the technologies within the ATCID were preferable if they could deliver the best value to the device, by balancing effectiveness with price.

Customisability was highlighted across the questions as participants emphasised the need for devices that can be tailored to an individual's needs. Five traits relate to this category. First, customisable *sensitivity* is about tailoring the force required to activate the device. Customisable *size* refers to the size of the interaction elements and the distance that a user's body-part needs to travel in order to displace a joystick lever or activate a switch. Customisable *complexity* is about the number of different functions facilitated by the device and how that could be changed. For example, a single switch is a less complex ATCID than a joystick or a mini-keyboard with 10 switches, but if complexity is customisable, the ATCID should be able to facilitate different users' needs. Customisable *modality* is about how the device could be used in different ATCID modes, for example. as a joystick,

a single switch, a mini-keyboard or a touch panel. Finally, customisable *aesthetics* refers to the visual and tactile look and feel of the device.

Robustness, cost, cleaning and decontamination and customisability were used to evaluate the technologies. Software, positioning and mounts, cables and batteries and service package were all discounted because they were deemed beyond the scope of the design project. As mentioned in the literature review, devices used to access personal computers and other electronic AT can be divided into three categories: input devices, output devices and software [25] This design work focused on tangible input device hardware, so optimising software and driver design, though important features of an ATCID, were out of scope for this project. Though the device was designed to demonstrate its functionality, optimising the software was set aside for future work. Positioning mounts were also set aside for future work as these are different devices and therefore part of a different product domain. Given the results of the Delphi study, positioning mounts would appear to benefit from a redesign.

Cables for electrical power and for transmitting signal between the device and the electronic AT are an element of all ATCIDs, apart from those that operate wirelessly. Contemporary wirelessly operated input devices, such as the Logitech Wireless Solar Keyboard K750[8], utilise infrared transmitters and receivers and rechargeable batteries or solar power. No matter the technology within a given computer input device, wireless operation can be integrated into the design, so this too was omitted from the evaluation criteria for the product platform technologies.

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[8] Available from http://www.logitech.com, last checked August 2015

Another category deemed out of scope - though rich for directing future work - was service package. This includes how devices are prescribed and attained, and how use and maintenance is learned and practiced.

Ultimately, touch panel technology was selected as it best fit the above four criteria. First, in terms of customisability; where mechanical contact switches are defined in terms of their location and size on a device, a touch panel effectively presents a compact matrix structure of thousands of tiny switches that are defined by their coordinates. As a reminder from the literature review in this thesis, resistive touch panels are two, thin glass or acrylic panels coated with an electrically conductive, resistive material. One panel carries an X-axis and the other carries a Y-axis, and when the two layers are sandwiched together, it creates a single switch that is activated no matter where the panel is touched. A micro-controller can be programmed to detect the location, or x and y coordinates of the touch, based on the voltage drop sensed in each layer at the point where they make contact. A touch panel's make-up is such that it has the facility to perform as plate, or touch switches, and therefore a hypothesis was formed that a touch panel could also perform as a digital joystick, since these are also based on switches. None of the other technologies under consideration could perform as a touch panel, and contained many more sub-assemblies and parts to function. Starting with fewer parts also adhered better to the principles of DFMA, so the other technologies, which all contained many more parts and subassemblies, were less attractive for the product platform.

Touch panels also perform well in the areas of cleaning and decontamination, since they can be wiped down and do not contain different moving parts or small areas that can get contaminated. A touch panel appears as a single part, where other switches tend to be composed of multiple parts. This feature is also useful in terms of assembly and disassembly.

Touch panels also come with the benefits of being a popular mainstream technology. This means that they are low in cost and can be bought off-the-shelf, and don't single AT users out. Resistive touch panels were used for protyping. These are lower in cost than other types and can be activated with light pressure. Capacitive touch panels are more robust, but they must be controlled with another capacitive surface, like skin or metal. Touch panels as a standalone item are not more robust than a joystick or keyboard, but the intention at this point was that the customisable ATCID's housing would be designed to protect the internal technology.

At this early stage in the design process, the primary focus was on technical function while consideration for user interaction was secondary. The design aim was to make one device work with a personal computer as the following:

- a relative pointing aid, like a touch panel mouse on a laptop

- an absolute pointing aid, like that on a touch screen phone

- multiple switches, like a keyboard

- a single switch

The Arduino Uno microcontroller and off-the-shelf circuit boards were used to make initial prototypes. After initial investigation, the laptop style touch panel

pointing function was omitted from the prototype's development because the Arduino did not facilitate the necessary complex programming at the computer operating system's kernel level. This meant the focus was only about absolute readings of the the x and y voltage drop values across the touch panel. Cabling was soldered to the touch panel and connected to the Arduino. Smaller (approximately 40cm²) and larger (approximately 100cm²) touch panels were trialled, and although compactness was an important criteria, a larger one was selected because more, and larger, switches could be developed as custom modules.

Figure 22 shows the touch panel wired to the Arduino Uno. A programme was written to make the touch panel communicate with a desktop computer and enable it to act as one large single switch, so no matter where the panel was touched, the same function resulted. To do this, first a program was written in C to find the X and Y minimum and maximum values on the touch panel, which are depicted in Figure 23, and then a second program was written to print a word when the computer received the signal that the panel had been touched within its coordinates.
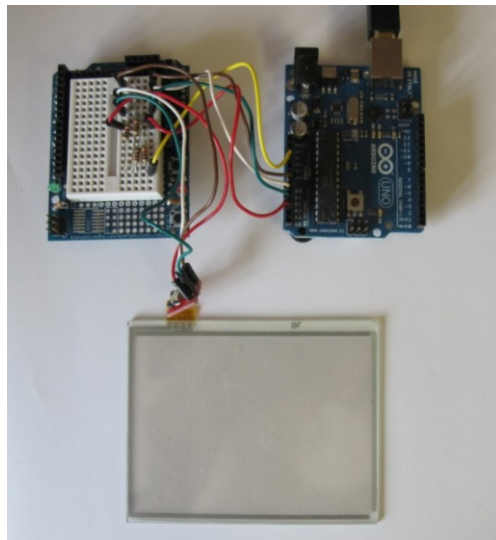
Figure 22 Arduino Uno microcontroller with resistive touch panel

Figure 23 Touch panel coordinates

To make the device work as four switches, the range of coordinates for quadrants was calculated and defined. A programme was then written and tested so if the device sensed pressure in one of the four quadrants, the programme printed a different word to signify which quadrant, or switch, had been activated. The

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sequence diagram for this is shown in Figure 24, and the C code for the programme can be found in Appendix 8. This served as proof of concept for the universal product platform.
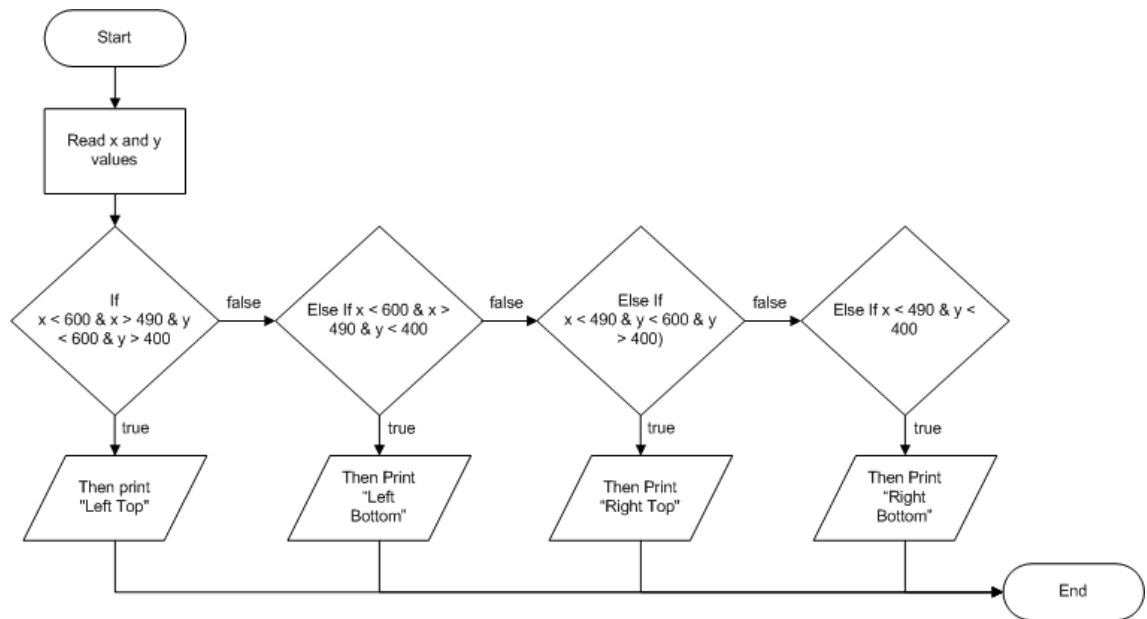

Figure 24 Sequence diagram for touch panel in 4-switch configuration

It was around this point when the data the workshops began and those results began influencing the design. Although the PD workshops contributed problems to solve, many of these had already emerged through the Delphi study. However, they were sense-checking milestones along the design process journey, providing navigation when design decisions and trade-offs had to be made.

The workshops produced qualitative data in a similar way to a focus group. Focus group data traditionally needs to be assessed, judged and analysed from the perspective that different types of social phenomena are likely to emerge. However, the purpose of the PD framework for customisable AT developed through this research, and the workshops therein, was not primarily to understand

social phenomena, but rather to conceptualise a product solution that satisfies user needs. That being said, discussion wasn't dogmatically focused on technology and products, and latent needs were often hidden in indirect discussion and personal stories. A problem-framing model, shown in Figure 25, was devised to translate the workshop data into statements that help generate design solutions.
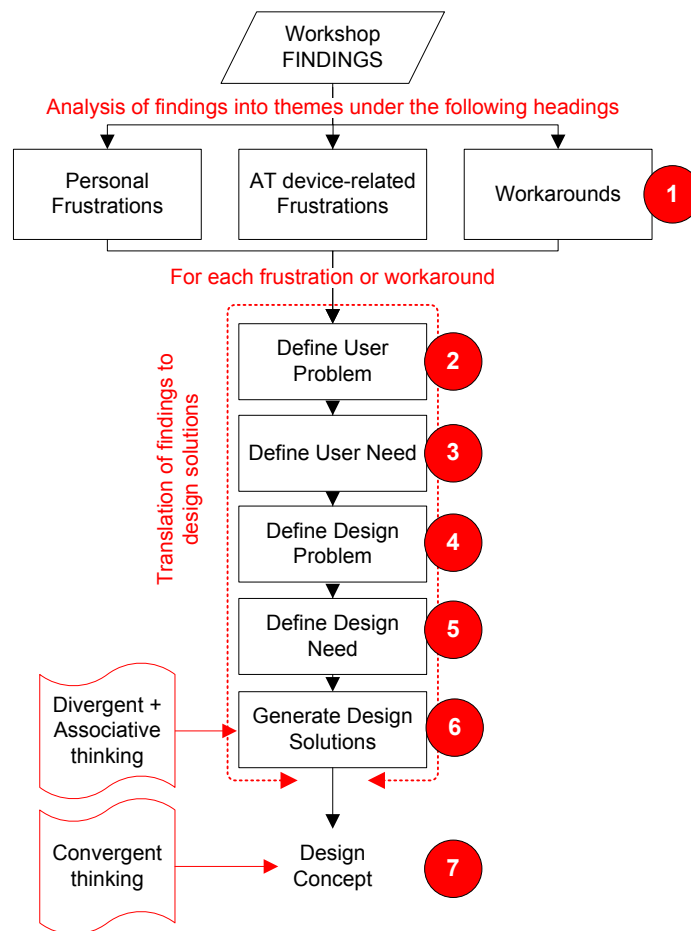

Figure 25 Problem-framing model for the analysis/translation of PD workshop data

First, participants' anecdotes and workshop contributions were collected and analysed through thematic analysis to produce personal and ATCID related frustrations and workarounds (labelled 1). Then, each frustration and workaround was redefined as a user problem (labelled 2). The user problem was then reframed

as a user need (labelled 3). This was then translated to a design problem, and then to a design need (labelled 4 and 5). That design need was used to stimulate solution generation with divergent thinking (labelled 6), before convergent thinking was used to define a design concept. The model is generic, and so transferable to product domains other than ATCIDs. An example of this model in use is shown below in Figure 26.
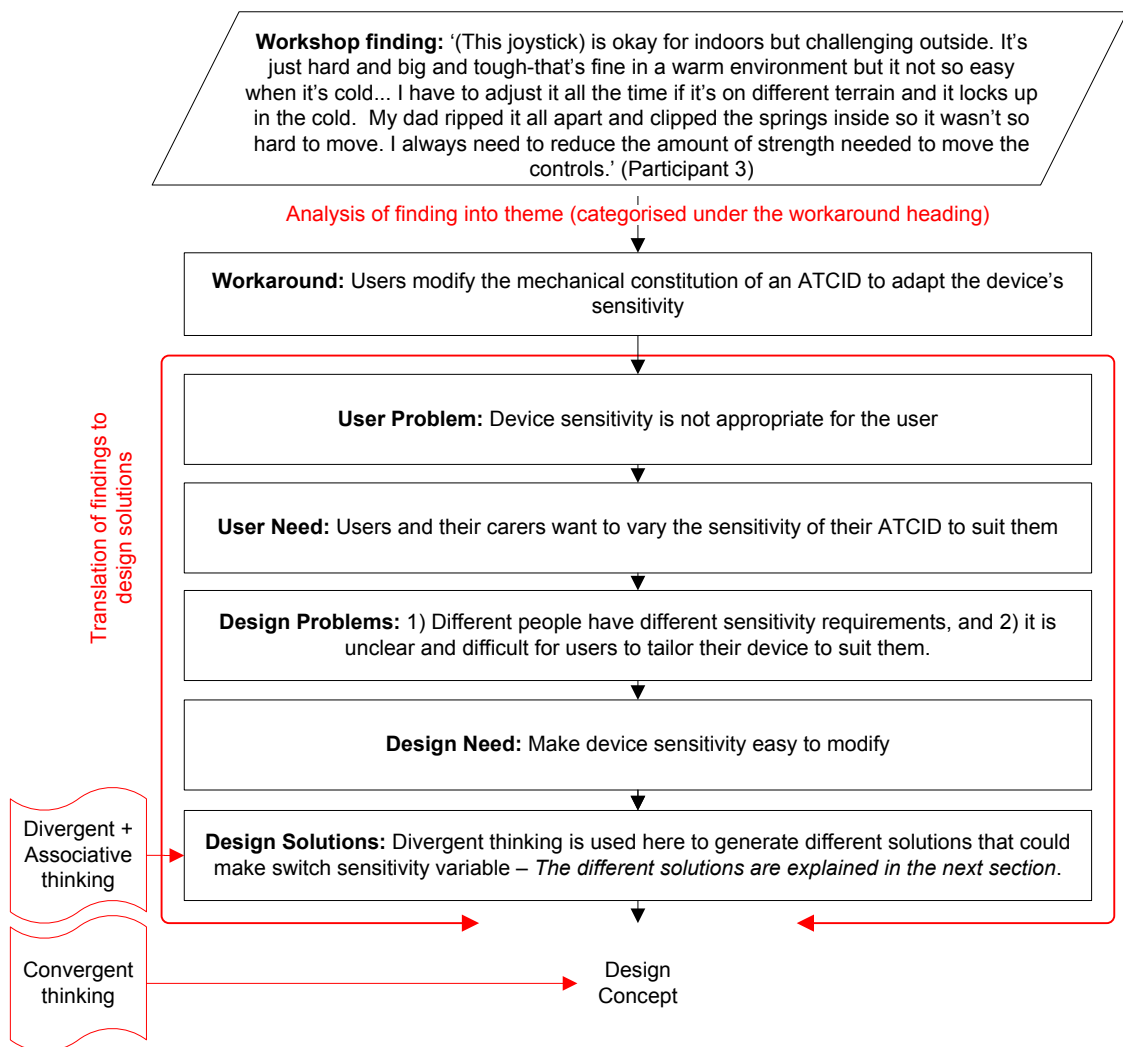

Figure 26 Example of using the problem-framing model for PD workshop data

Figure 26 depicts the process for a workshop finding that related to solving difficulties operating joysticks in cold weather by changing the mechanical hardware to make them more sensitive. This was categorised as a workaround, and then translated into a user problem related to inappropriate device sensitivity. The design problems were defined as follows: 1) Different people have different sensitivity requirements, and 2) it is unclear and difficult for users to tailor their device to suit their needs. These problems were translated to a design need to make device sensitivity easy to modify. Design solutions related to devices whereby the sensitivity could be modified. This example demonstrates how the outputs of the PD workshops can reflect and support the Delphi study results.

The problem framing model's purpose is to maximise the application of the findings to create design solutions. In this study, where ATCIDs were the subject of redesign, most of the PD workshop results simply supported the Delphi study results, however this may not be the case with other AT product domains. Some new results, which did not emerge in the Delphi study, included the need for customisable layouts on ATCIDs, and users' desires to have a signal on the device to show when the battery was running out. Another new idea was that users retrofit ATCID joysticks with their own objects to suit their interaction needs, so a customisable ATCID should facilitate this as well as offer an array of standard joystick levers.

In practice, the next design steps focused on the product elements that a user would directly interact with. The touch panel was now the core universal product platform and functioned as a configurable switch surface, but it did not satisfy the

need for feedback. Switch feedback can be audible, visual or tactile and tells a user that they have activated a switch. Additionally, highly sensitive switches that require light pressure suit some users, such as those with muscular dystrophy, but the participatory research showed that some users, like those with hypertonia due to cerebral palsy, need less sensitive ATCIDs. Also, a touch panel is not usually used in joystick design. A mechanical spring system is necessary to bring the lever of a joystick back to neutral after a person pushes it in a given direction. Essentially, spring systems are the foundation of switches and digital joysticks that give the user some sort of feed back during use, so that was the next element to look at. At this point, additional design aims were confirmed as follows:

- Design the device to work as a joystick (as well as the previously mentioned relative pointing aid, absolute pointing aid, multiple switches and single switch).
- Provide feedback to the user so they can sense that they have activated the device.
- Design the device so that the force required to activate the device can be varied/customised, i.e. so that the sensitivity of the device could be modified.

Below are images of rough sketch prototypes made to test different spring system solution concepts that had been generated via the morphological matrix and the PD workshops. One idea involved using a membrane skin mounted on a frame some distance above the touch panel. Increasing the distance between the

membrane and the touch panel increased the amount of force required to create a contact.
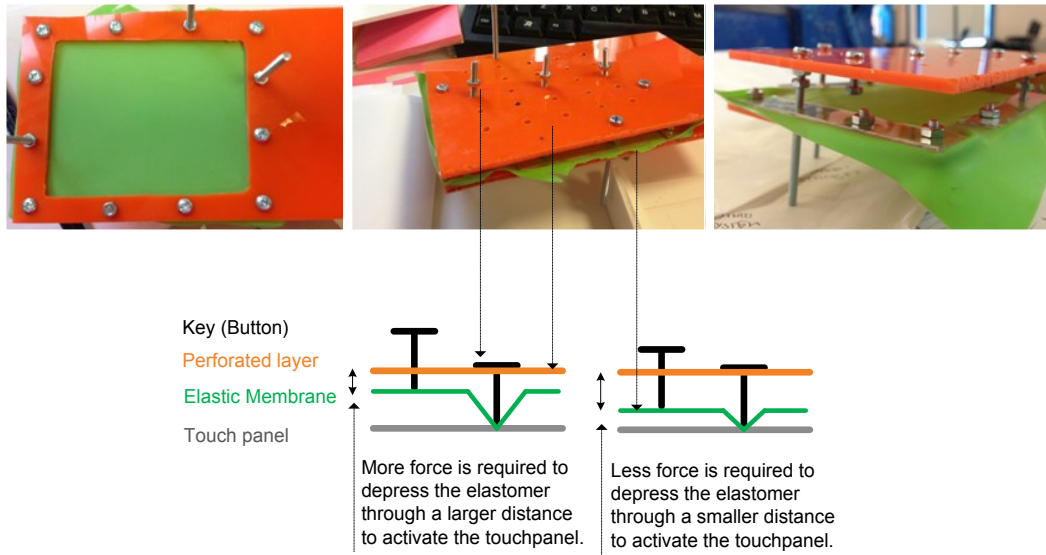

Figure 27 Alternative switch mechanism prototype

Another idea involved using two perforated surfaces, with one laying over the other. As one moves across the other, the net space that exists between the perforations increases or decreases. Small plastic clips were then placed in the space created, and these were pushed through the spaces to make contact with the touch panel beneath. The larger the space, the less force was required to push the clip through.

The final concept involved sheet material with a high ultimate tensile strength, such as spring steel or, in this case, acetal plastic. Prototyping lead to two parts being designed, cut, bent and laid over each other to create a matrix of cantilever

springs[9], as shown in . A third part acted as an axis for the fixed end of the cantilever and sits beneath the spring matrix. This can be directed so the axis is closer or further from the force that acts down on the cantilever when a switch is activated. The axis is directed by means of a screw system at the side of the device. Since the length of an end-loaded cantilever beam is inversely proportional to the applied force, users can customise the force required to deflect the beam and activate the touch panel by varying that distance between the applied force and beam axis. The longer the distance, the less force is required. The acetal was cut so that acrylic 'keys' slot onto the spring system. A frame of 20 switches was designed for proof of concept based on the fact that other mini keyboards had similar numbers of switches, and the size of the touch panel provided space for 20 standard keyboard-sized keys. The equation on the next page [226] (p. 262) demonstrates how a beam that is fixed at one end and loaded at the other end requires increased load in order to deflect to the same degree, as the distance is decreased between the fixed end of the beam and the load. This is the theory underpinning how the force required to activate a switch on the ATCID is increased or reduced by changing the distance between the fixed end and the loaded end of the cantilever beams that constitute each switch. A constant of one is used for elements of the equation that remain the same regardless of user interaction.

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[9] Solidworks®, Rhinocero® and CorelDRAW® were used to design and laser cut the prototype.
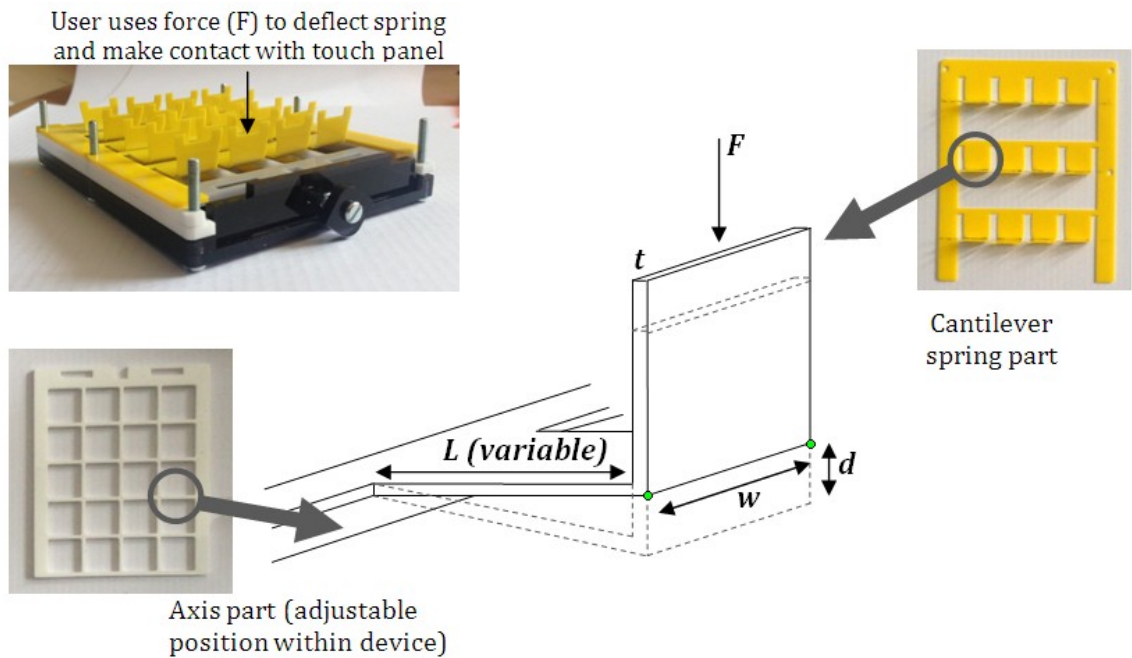
Figure 28 Cantilever Beam Switches

F = force applied to the switch (N) - which deflects the cantilever to make contact with the touch panel

E = elastic modulus of the cantilever spring material (N/m^2) *(constant)*

I = moment of inertia of the beam cross-section $(kg\ m^2)$ *(constant)*

L = length of the cantilever beam (m)

d = deflection distance (m) *(constant)*

w = width (m) *(constant)*

t = thickness (m) *(constant)*

$$F = \left[\frac{3EI}{L^3}\right]d$$

(226) (pg. 262)

Where,
$$I = \left[\frac{1}{12}\right]w.t^3$$

So,
$$F = \left[\frac{3E\left[\frac{1}{12}w.t^3\right]}{L^3}\right]d$$

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F_1= force applied to create deflection for a shorter beam length, where L=1

F_2= force applied to create deflection for a longer beam length, L=2,

So,
$$F_1 = \left[\frac{3E\left[\frac{1}{12}w.t^3\right]}{1}\right]d$$

And,
$$F_2 = \left[\frac{3E\left[\frac{1}{12}w.t^3\right]}{8}\right]d$$

So,
$$F_1 : F_2$$

As,
$$8 : 1$$

So, a longer beam requires less force to create the same deflection.

A force limiter grid was then designed to protect the touch panel from damage by limiting the amount of force acting on it when a user presses a switch or toggles a joystick. It also keeps the cantilever switches in place. These layers are shown on the left hand side of Figure 29. A digital joystick was designed to work with the cantilever spring assembly. Initially a ball and socket mechanism was prototyped, as were living hinge systems, but eventually, an elastomeric collar was fabricated to afford the lever enough flexibility, elasticity and tension to return to a neutral position after being displaced in any given direction. Other button/key configurations, sizes and layouts were created, and these are shown in Figure 30. These are examples of layouts that can be achieved, but not the only possibilities.

In parallel with these features, other design decisions had to be made. The principles of Design for Manufacture and Assembly (DFMA) and cost also provided direction. The number of parts was minimised, for example the acetal parts serve two functions; they are both cantilever spring beams, and provide a method of

attaching the acrylic keys to the springs, by means of a male-female mating system, as shown in Figure 29. Materials and fabrication processes were minimised by using laser cut acrylic and acetal sheet for all but the assembly nuts and bolts, the touch panel and Arduino controller, and the elastomeric joystick part. The disassembled customisable ATCID is shown on the right side Figure 29. The device was also designed with consideration to parts orientation, whereby all parts, except the axis grid slider sub-assembly, are assembled in the same direction, one on top of the other. This method of assembly, can be seen on the left hand side of Figure 29. In reality, this concept would be smaller and operate better using spring steel sheet in place of the acetal and polycarbonate sheet in place of the acrylic, but prototyping constraints led to the design shown in the figures. The red text in Figure 29 describes more ideal design specifications for the prototype. Future work would involve addressing these ideas and testing them in another prototype.

Figure 31 shows the modular component hierarchy in terms of how the different parts of the research informed the design of different parts of the prototype. The Delphi study results largely influenced the universal product platform, whereas the PD workshops results largely drove the design of the parts that allow the platform to be customised for different users and interaction styles.
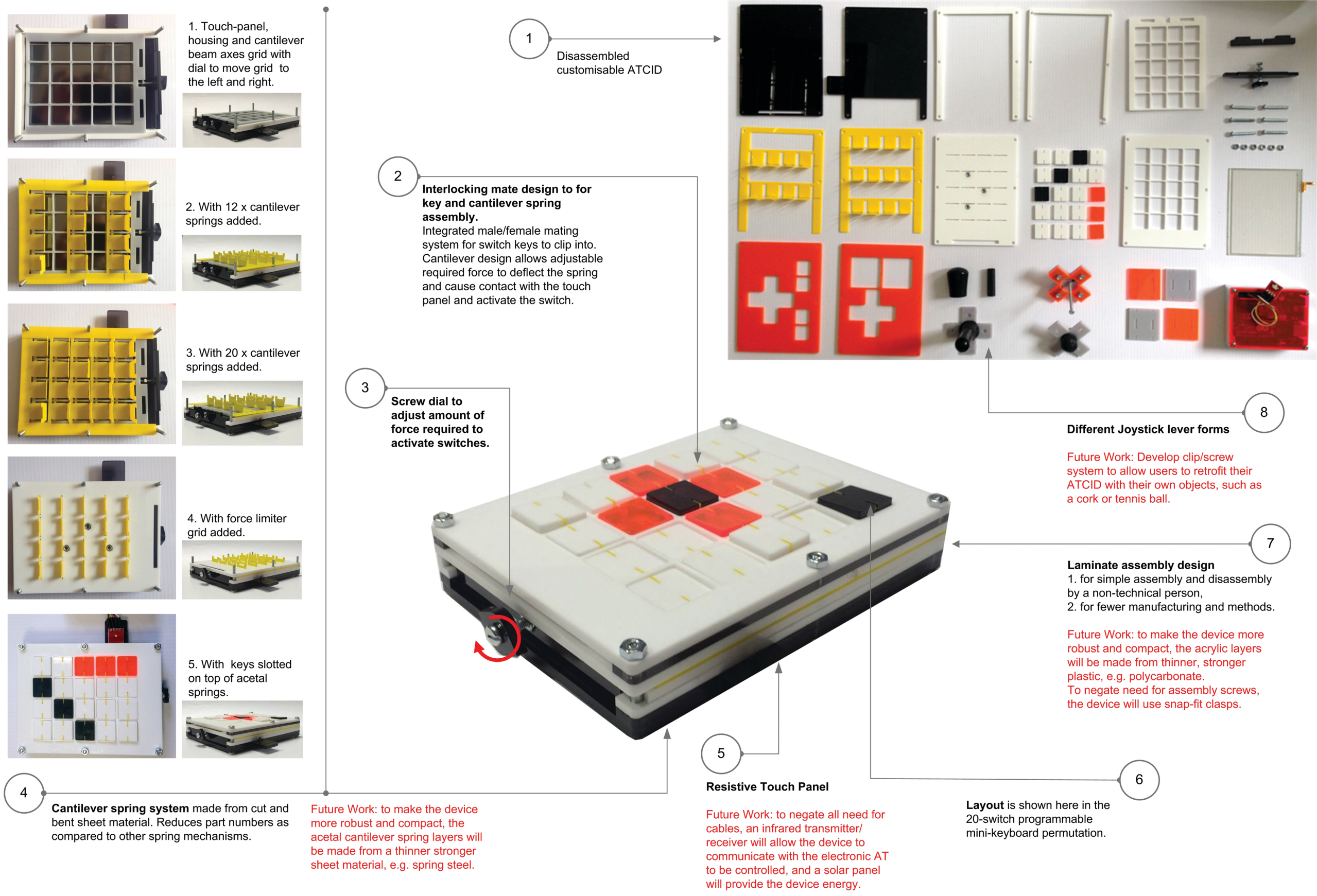
1. Touch-panel, housing and cantilever beam axes grid with dial to move grid to the left and right.

2. With 12 x cantilever springs added.

3. With 20 x cantilever springs added.

4. With force limiter grid added.

5. With keys slotted on top of acetal springs.

1 Disassembled customisable ATCID

2 **Interlocking mate design to for key and cantilever spring assembly.**
Integrated male/female mating system for switch keys to clip into. Cantilever design allows adjustable required force to deflect the spring and cause contact with the touch panel and activate the switch.

3 **Screw dial to adjust amount of force required to activate switches.**

8 **Different Joystick lever forms**

Future Work: Develop clip/screw system to allow users to retrofit their ATCID with their own objects, such as a cork or tennis ball.

7 **Laminate assembly design**
1. for simple assembly and disassembly by a non-technical person,
2. for fewer manufacturing and methods.

Future Work: to make the device more robust and compact, the acrylic layers will be made from thinner, stronger plastic, e.g. polycarbonate.
To negate need for assembly screws, the device will use snap-fit clasps.

5 **Resistive Touch Panel**

Future Work: to negate all need for cables, an infrared transmitter/receiver will allow the device to communicate with the electronic AT to be controlled, and a solar panel will provide the device energy.

6 **Layout** is shown here in the 20-switch programmable mini-keyboard permutation.

4 **Cantilever spring system** made from cut and bent sheet material. Reduces part numbers as compared to other spring mechanisms.

Future Work: to make the device more robust and compact, the acetal cantilever spring layers will be made from a thinner stronger sheet material, e.g. spring steel.

Figure 29 Customisable ATCID design features

Touch panel configuration. For use as a mouse pad - or as a single switch that requires the minimum force for activation.

For use as a multi-switch device, with a finger-guard, which requires minimum force for activation.

For use as a multi-switch interface. Layout, number of switches and force required for activation can be customised.

For use as a joystick with a short lever. Force required for activation can be customised.

For use as a joystick with a longer lever. Force required for activation can be customise.d

For use as a multi-switch device. Force required for activation can be customised.

All configurations of the device function based on a resistive touch panel and micro controller.

Scaled credit card – to convey size of the customisable ATCID.

Figure 30 Customisable ATCID configurations

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Secondary Module

Module

Module

Module

Primary Module

Module

Module

Universal Product Platform

1 2 3 4 5

1   2

1

SECONDARY CUSTOMISATION MODULES

Least universal, complex, expensive and functional.

(Design is driven individual end-user requirements, most acutely recognised in the workshops)

PRIMARY CUSTOMISATION MODULES

Somewhat universal, complex, expensive, functional.

(Design is driven by the coupling requirements to integrate the universal and customisation components)

UNIVERSAL PRODUCT PLATFORM

Most universal, complex, expensive, functional.

(A result of the Delphi Study, since commonality and consensus are key to a useful universal design)

Figure 31 Customisable ATCID - component hierarchy

4.5   Participatory design framework for customisable AT

On the next page, Figure 32 shows the final, transferable participatory design framework for customisable AT. This is a roadmap for future customisable AT design and it depicts how data is generated and fed into subsequent stages of the design process.

Product design is a problem solving process, and the conceptualisation of design solutions involves sketching and model-making. During this research, a spectrum of techniques were useful. The written word was used more at the beginning of the design process, when generating solutions to the issues found in the Delphi study. This was basically the divergent thinking, 'what is the solution?' phase. Sketching was required more as the project progressed because it is difficult to resolve how something might function with words alone. This stage was about answering 'how does the solution do its job?' Finally, the tangible prototyping phase was about testing, presenting and developing an idea further, responding to the question 'does this solution work?' Physical prototyping takes longer than sketching, and sketching takes longer than writing, so it makes sense to save the time consuming conceptualisation techniques until ideas are a little more defined. These three media phases are shown at the top Figure 32.

Main media used for concept generation, development and problem solving

Verbal
Primarily Written Word
"what is the solution?"
(ideate quickly)

Visual
Primarily Sketching
"how does the solution work"
(developing how solutions work)

Tangible
Primarily Prototyping
"does this work"
(testIng solutions)

Time

Literature Review

Themes for questions

Delphi Study

Participatory Design Workshops

Criteria for the design of other customisable AT devices

Customisable AT device prototype

FINDINGS (Gaps in the literature)

FINDINGS (Survey Results)

Workshop 1 – using abstract stimulus

Divergent + Associative thinking

Workshop 2 – using abstract stimulus

Divergent + Associative thinking

Workshop 3 – using prototype stimulus

Divergent + Associative thinking

Workshop 4 – using prototype stimulus

Need for actionable design criteria for AT

Need to involve users in the design process of AT

Implement idea of mass customisation in AT design

Prevalent parts of the 'X' AT device that malfunction

Solution Starters

Reasons the 'X' AT device malfunctions or fails.

Solution Starters

Characteristics of a service-user associated with selecting an 'X' AT device.

What's Customisable?

Service-user needs regarding 'X' product use and training.

Holistic Solution Starters

Desirable traits of an 'X' AT product.

General Criteria

Clinical stakeholders' frustrations associated with 'X' AT devices.

Contextual issues

Translation of findings to design solutions

Morphological Chart

Define each Issue

Define elements of device product which relate to issue.

Generate solutions (explore mainstream products, new materials/ technologies and other adjustments)

Divergent + Associative thinking

Convergent thinking

Concept for product platform

Workshop FINDINGS

Personal Frustrations

AT device-related Frustrations

Workarounds

For each frustration or workaround

Translation of findings to design solutions

Define User Problem

Define User Need

Define Design Problem

Define Design Need

Generate Design Solutions

Divergent + Associative thinking

Convergent thinking

Design Concept

SECONDARY CUSTOMISATION MODULES
Least universal, complex, expensive and functional.

PRIMARY CUSTOMISATION MODULES
Somewhat universal, complex, expensive, functional.

UNIVERSAL PRODUCT PLATFORM
Most universal, complex, expensive, functional.

Module Module Module Module

Module Module Module

Universal Product Platform

Figure 32 Participatory Design Framework for Customisable Assistive Technology

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Chapter 5

Discussion and Conclusion

5.1 Introduction

This research aimed to develop and demonstrate a participatory design framework for customisable AT, which addresses the need for low-cost AT products that satisfy a broad range of consumers' needs. The work aimed to address a gap in the literature pertaining to design research involving adults with communication and mobility related disabilities. Also, since the literature identifies customisation as a promising idea in AT [49-51], but does not propose ways to achieve such product designs, the research aimed to aid the design of customisable, modular AT. Additionally, as the Participatory Design (PD) literature was heavily biased toward software development, this research addressed the design of tangible products. A gap in the literature was also found at the data translation stage between 'gathering and analysing user data' and 'solution conceptualisation and design action'. Therefore, this research aimed to develop insight and understanding into how that translation stage might be better practiced.

The practical development of an AT computer input device (ATCID) acted as a vehicle to generate and evaluate a participatory design framework for customisable AT and, as a result, objectives for ATCID design eventuated too. The PD framework was used to determine problems that users experience with

ATCIDs, generate design criteria for ATCIDs, translate those criteria to product solution concepts, and develop a prototype of an input device concept.

This chapter discusses the main original outputs as follows:

1. A participatory design framework for customisable AT; arguments are presented to build confidence in the reliability and rigour of how the framework was developed, and in its usefulness as a transferable tool.

2. A revised product solution for customisable ATCIDs; the new conceptual ATCID is shown as an example of how the transferable PD framework can operate to produce new customisable product solutions.

3. Recommendations for future PD workshops involving individuals with communication and motor impairments.

4. Contributions to future ATCID design.

Finally, the chapter presents recommendations for future work and the thesis conclusions.

5.2   A participatory design framework for customisable AT

The main aim of this research was to contribute to the advancement of PD for AT, through the development of a transferable design method for various new customisable products. The PD framework for customisable AT was shown at the end of Chapter 4, and is now discussed in terms of its usefulness with respect to its purpose. Some of this section reflects issues raised in the methods chapter

(Chapter 3), but since the final framework was developed *through* the practical research phases, and informed by the results, it is only on reflection of the whole process that these methodological issues can be dealt with comprehensively.

Reliability, validity and rigour are three important concepts in qualitative research [227] that help to build confidence in the quality of that research. Reliability is about how replicable a study is in terms of getting similar findings again and again, and validity is about the correctness, credibility and transferability of research. These two concepts originated in the natural sciences, and since qualitative research has different epistemological foundations, there is uncertainty about whether these concepts are useful in determining the quality of qualitative research [217], including qualitative design research. The reliability of the results of this research is a somewhat redundant concept, since qualitative research is about people and their perceptions, and social phenomena such as issues that people find relevant about technology are dynamic evolving entities that change over time depending on cultural, economic, political, and environmental context. The traditional concept of validity is not relevant either, since both the participants and the researchers/designers influence results with their own world outlook, or 'weltanschauung' [84, 87, 88], and this means that it's unlikely the exact same results would come from a repeat of this research process. Rigour *is* typically associated with qualitative research; this relates to the thoroughness and precision of the research.

To address this issue of justifying quality in design research, Pedersen *et al.* [228] propose that validating a design method is a process of demonstrating usefulness

with respect to a purpose. The term 'validation' here refers to relativist validation, which is a conversational process of building confidence in the usefulness of the new knowledge with respect to a purpose [228], as opposed to empiricist validation, which is a numerical process whereby new knowledge is deemed either true of false. Empiricist validation is about formal accuracy where a problem is either right or wrong, more than practical application [228]. Relativist validation leans towards holism, where systems are viewed and examined as wholes because the functioning of individual components in a system does not explain the larger system. Relativist validation is concerned with the *context* of the new knowledge, not just the new knowledge alone. Pedersen *et al.* [228] (p. 4) say that relativist validation is appropriate for 'open problems, where new knowledge is associated with heuristics and non-precise representations'. Their definition of open problems match the definition of wicked problems [86, 87] in design, in that neither of these types of problems have right or wrong answers.

Pedersen *et al.* devised a model called the validation square [228], which has been adapted for this thesis [See Figure 33] and used below to argue relativist validation for the Participatory Design Framework for Customisable AT. The validation model involves five steps, each of which are labelled 1-5 in Figure 33. First, the purpose of the framework is defined and shown to be useful in terms of the literature (labelled 1). The framework is then determined to be *effective* in its ability to provide design solutions correctly by showing that the research methods are consistent and rigorous (labelled 2) and by justifying that ATCIDs were an appropriate domain to use as a sample case for the framework (labelled 3).
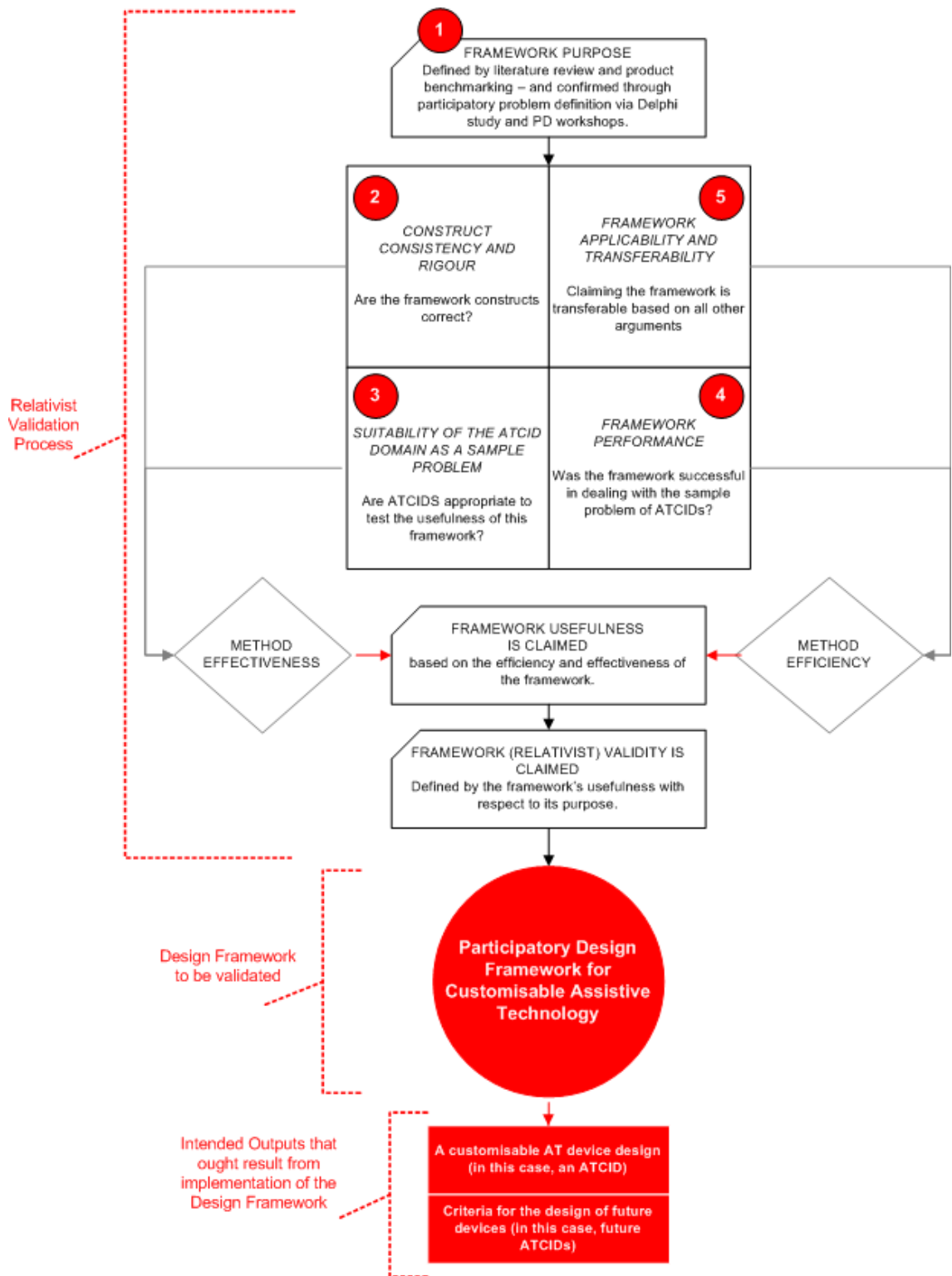
Figure 33 Validation Model adapted from Pedersen et al.

Then, the framework is determined to be *efficient* in its ability to provide correct design solutions by explaining how the framework addressed the ATCID domain sample problem (labelled 4) and by arguing that the framework is appropriate [223] for broader classes of problems and applications (labelled 5). Pedersen *et al.* propose that once these arguments are made, a design framework is deemed useful with respect to its intended purpose. At the bottom of the model in , the PD framework for customisable AT is depicted in the circle, and its intended outputs are listed below that. The next five short sections explain the PD framework in terms of these five labelled steps.

5.2.1 Framework Purpose

Before arguing for the consistency and rigour of the method constructs within the PD framework for customisable AT, its overall purpose (labelled 1 in Figure 33). is defined below in terms of what it is supposed to help create (product requirements), and how it is supposed to do that (process requirements). These criteria mirror the original aims and objectives of the thesis, First, the following product requirements describe the characteristics of all products that the framework is intended to help to conceptualise and create.

1. A tangible AT device

2. Which satisfies a specific, task-related need

3. Where there are currently a number of AT solutions available that attempt to fulfil that need, but due to the different characteristics of disabled users, different features are required

   OR

Where AT solutions are not currently available to fulfil that need, and due to the different characteristics of disabled users, different features are likely to be required

4. Whereby a non-technical person may customise the new AT tangible to suit a specific need profile

Next, process requirements characterise *how* the design framework generates the product type described above. These are phrased below as operational criteria that the framework satisfies, and are based on the methodological philosophy of the thesis. The design framework should;

5. Be participatory; the process should be driven by AT users

6. Be beneficent; all parties involved in the process should benefit in some way from it

7. Assist in translating the research data to design solutions

8. Facilitate consideration of Design for Manufacturing and Assembly (DFMA) in order to increase likelihood of low-cost products

These eight requirements are used in the subsequent relativist validation stages. As a result, the research is in part validated by itself, and this is a limitation. Self-referential, circular argumentation weakens the argument for rigour. This does not conclusively mean that the framework validity is weak, but the argument for its validity is weakened. One rationalisation for why circular argumentation is inevitable - and correct - for this framework, is based on the underpinnings of participatory research. PD is integrally exploratory and led by everyone involved; so the research questions and results develop on an ongoing basis. In this way,

participatory research can be only partly validated by the literature because validity becomes about how well the outcomes satisfy the issues that emerge during the research process.

Next, the need for a participatory design framework for customisable AT is established by evaluating existing design methods against the framework's eight intent requirements for outcome and process. Table 17 compares benchmark literature that are closest to the design framework developed through this research. The shaded areas show the literature gaps in relation to this research's intent. The table is not a full evaluation of the benchmarks; each has its own aims and intentions, and these are critiqued in their own right in the literature review.

		PD for Customised AT [142]	UserFIT Meta Toolkit for PD [57]	Framework for medical device development [139]	Involving children in AT design [137]	Living Labs Framework based on partnership & principles [141]	USAP framework for PD [143]	PD for people in marginalised communities [131]	**PD for Customisable AT** (as described in this thesis)
	Framework Requirements								
	1	An new AT tangible concept	Not specified	Not specified	Not specified	✓	Not specified	Not specified	✓	✓
Outcome Requirements	2	Which satisfies a specific, task-related need	✓	✓	✓	✓	✓	✓	✓	✓
	3	Where there are a number of AT solutions available that attempt to fulfil that need, but due to the different characteristics of disabled users, different features are required, **OR**	✓	x	x	x	x	x	✓	✓
		Where AT solutions are not currently available to fulfil that need, and due to the different characteristics of disabled users, different features are likely to be required	✓	x	x	x	x	x	x	✓
	4	Whereby a non-technical person may customise the new AT tangible.	x	x	x	x	x	x	x	✓
Process Requirements	5	Be participatory; the process should be led by people who use AT.	✓	✓	✓	✓	✓	✓	✓	✓
	6	Be beneficent; All parties involved in the design process should benefit in some way from the process.	Not specified	✓	Not specified	Not specified	✓	✓	✓	✓
	7	Assist in translating the research data to design solutions	x	x	x	x	x	✓	x	✓
	8	Facilitate consideration of Design for Manufacturing and Assembly (DFMA) in order to increase likelihood of low-cost products.	x	x	x	x	x	x	x	✓

Table 17 Relevant existing design methods evaluated against the 'Participatory Design Framework for AT' Requirements

The table provides evidence that the literature lacks methods for the participatory design of tangible AT devices, and customisable AT devices, and that methods have previously not considered DFMA guidelines. This combination of gaps is not surprising, given that DFMA is related to customisability; when products are easier to disassemble and reassemble – they are easier to customise. Beneficence is not always an aim in the PD literature either. On a macro level, the references in the table aim to help create new AT and medical devices, and that's beneficial – but on a micro level, the omni-directional learning aspect of PD is often forgotten. Some methods are more focused on the information or data flow from participant to researcher, but this research supports the idea that PD researchers have a responsibility to return the favour, and offer knowledge both during the process, and afterwards through dissemination.

5.2.2 Consistency and rigour

Consistency relates to logical sense, coherence and rigour. This section (labelled 2 in Figure 33). establishes the appropriateness of the following three pre-existing constructs that make up the framework: the Delphi study, the morphological matrix and PD workshops. The inclusion of the constructs is substantiated with evidence of their precedent applications and accepted domains of application.

The Delphi Study was deemed to be the correct construct for the framework because it is participatory and recognises the knowledge of experts working in the field. It generates a consensus among experts on specific design issues. It

suits a geographically disparate, time-constrained sample, since they never need to meet and participants can complete the questionnaires at a time that suits them. Delphi studies have been previously used with healthcare professionals to develop various criteria in relation to AT [25, 46, 224]. Semantic clarity was a limitation with the Delphi study used in this research, since definitions of the design issues, which participants were asked to rank, were not provided in the second questionnaire. Accordingly, participants may have interpreted the meaning of the design issues differently.

The morphological matrix is argued to be the right construct for the task of translating the Delphi Study results to design solutions concepts as it provides a structure for the Delphi study results to be framed as problems, and a structure for the conceptualisation of solutions to these problems. Additionally, morphological matrices were originally devised and have been used in the past to ideate and conceptualise different ways of solving problems [193, 229].

The PD workshop format involving users with disabilities is argued to be the correct construct for the task because it is participatory and recognises the knowledge of people that use AT. It promotes empathic design; the researcher/designer is part of face-to-face discussion with AT users to gather personal narrative anecdotes, understand their experiences, and ultimately identify real needs. It is a flexible construct; the format allows the investigator to tailor questions to the project goals, and also modify the approach according to how a session plays out. Finally, workshops have been previously used to develop AT concepts [131, 143].

5.2.3 Suitability of the ATCID domain as the sample problem

This stage demonstrates why the sample problem of ATCIDs was appropriate for exploring and generating the design framework (labelled 3 in Figure 33). These arguments specifically investigate the ATCID design, rather than the resulting transferable theory. Table 18 uses the literature to show evidence of the framework constructs being used to solve similar case problems to the ATCID 'problem'.

	Construct	Evidence in the literature	Author and Reference
1	Delphi Study	Elements for the assessment of persons with severe neurological impairments for computer access utilising assistive technology devices	Hoppestad [25]
		Consumer-based criteria for the evaluation of assistive devices	Batavia and Hammer[46]
		An ontology for physically controllable pointing devices.	Danial-Saad [224]
2	Morphological Matrix	AT device conceptualisation	Poulson [57]
		General Product Design Usage	Otto [230]
3	Participatory design workshops	Involving children in the design of AT	Allsop [137]
		PD for customised AT	Borges [142]
		Usability, Safety, Attractiveness Participatory design model	Demirbilek and Demirkan [144]
		PD of prosthetics with marginalised people	Hussein[131]

Table 18 Evidence to show the PD framework constructs are appropriate

Additionally, the ATCID domain is proposed as an appropriate sample problem for the PD framework because it matches the design framework's intention for 'product requirements'. First, the ATCIDs are tangible; a user physically interacts with the product. Second, ATCIDs satisfy a need; individuals with disabilities interact with computers and electronic AT via ATCIDs to

communicate, work, play, learn and control their environment. Third, there are currently a large number and variety of ATCIDs available that attempt to fulfil the same end-need, i.e. to control a computer or other electronic AT, but due to the different characteristics of disabled users, different features are required. Fourth, a non-technical person can customise the new ATCID. The new design concept is modular, and can be reconfigured without tools to act as a touch panel, a joystick, a switch or multiple switches.

5.2.4 Performance of the framework in solving the ATCID sample problem

This stage (labelled in Figure 33) builds confidence in the usefulness of the framework with respect to how well it solved the ATCID sample problem. Usefulness is substantiated in terms of how the new product concept satisfies the user needs and solves the experienced problems that were identified through the Delphi study and the PD workshops.

The research produced evidence that clinicians, therapists and AT end-users with disabilities called for computer input devices that could be adapted to an individual's needs in terms of interaction style, functionality and aesthetics. The customisable ATCID developed via the framework involves a new method to utilise touch panel technology as the basis for a customisable computer input device, whereby; it can act as a touch panel, a switch, multiple switches or a joystick with switches. This means that both the aesthetics and functionality can be customised in a variety of ways to suit a user's needs, and adapted as their needs change or if one position of use becomes strenuous over time.

The research found that different users have different needs when it comes to the sensitivity of devices. To meet this requirement, the new ATCID was designed so that the force required to activate the device is adjustable. The mechanical switch interface utilises cut and bent sheet material, which has a high ultimate tensile strength, to create a matrix of cantilever beam springs. These springs sit on a grid, which acts as the fixed beam axes for the cantilevers. The user can increase or reduce the beam length by means of a rotational dial, whereby changing this length works to increase or reduce the force required to displace the springs downwards to make contact with the touch panel, activating the device.

Both the Delphi study and workshops found that devices should be easily customised by non-technical people. The research called for devices that can be cleaned easily, and do not break when contaminated with dirt or spills. To meet these needs, the device was designed so that it can be disassembled and reassembled easily, facilitating easy customisation. Also, the touch panel can be removed and wiped down, and all other parts can be wiped or washed, unlike standard electro-mechanical switches.

Participants said that existing ATCIDs were too expensive. The new ATCID addressed this need for low cost[10] AT by utilising off-the-shelf electronic components. The conceptual ATCID design uses mass customisation principles, which serves to reduce manufacturing costs and the price to the consumer. The adaptability of the ATCID concept aims to reduce abandonment and resulting

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[10] The final prototype cost approximately €12 to make, excluding the Arduino controller and overheads.

wasted resources, since a user can change the interface style or sensitivity of the device when their needs change, rather than purchasing an entirely new ATCID.

Although not implemented in the prototype, the conceptual design intends to address the need for cable-free devices. Solar powered keyboards are already available, as are wireless computer input devices that communicate via infrared transmitters and receivers. These technologies are intended as a next step in the development of the concept.

5.2.5 Limitations and Strengths; Applicability of the framework beyond the sample problem

Pedersen et al. [228] (p. 8) state that "the purpose of going through the Validation Square is to present circumstantial evidence to facilitate a leap of faith, i.e. to produce belief in a general usefulness of the method with respect to an articulated purpose". This section (labelled 5 in Figure 33) declares the limitations of the research, explains its strengths and argues for the framework's transferability based on the previous relativist validation steps described in Figure 33.

One limitation is that commercial stakeholders are not involved. Although technology transfer is a key factor in measuring the success of a new product, this research advocated that the front end of the design process should primarily be user-centred. As a result, the framework purposefully does not suggest that AT manufacturers or commercial organisations be involved. Although they are stakeholders in the AT domain, they are not technically users

of AT. As such, it was deemed that commercial biases related to cost, precedent products and perceived feasibility could impact negatively on the user-centred research outcomes.

Furthermore, the principal author of this thesis, rather than independent designers in an industrial context carried out the framework application to the ATCID domain sample problem. Concepts generated in the morphological matrix and through the PD workshop process are inherently a product of both the study findings and their interpretation by the researcher. Bearing this in mind, the ATCID sample problem must be viewed only as a demonstration of how the framework can be applied, rather than a verifiable test of the process' efficacy.

Circular argumentation is a limitation of this relativist validation process – and Pedersen et al.'s [228] validation square, given that it make rationalisations about this research, that are based on this research. Future work described towards the end of this Discussion chapter proposes further evaluation work that could be carried out to strengthen and develop the framework further.

Having declared these limitation, inductive reasoning is used to argue that the design framework is useful for applications beyond the problem case of ATCIDs. Generality is based on the substantiated arguments already made. First, the individual constructs within the framework i.e. the Delphi study, morphological matrix, and PD workshops were demonstrated to be acceptable in terms of the overall framework intention. Second, The ATCID domain was justified as an appropriate sample problem for the framework because it matched the

frameworks intention in terms of 'product requirements'. Finally, The usefulness of the framework for the sample problem was demonstrated by the novelty of the ATCID concept, and how its features meet user's needs.

Strengths of this research also lie in its contributions to interdisciplinary research. The framework - and ATCID solution developed through the use of the framework - demonstrate how product design and social science practices can be integrated to devise new ways of working and creating things. An example of this is the integration of a Delphi study, which is typically a method used in social science research, and the morphological matrix, which is a tool for design engineers to generate product feature and function concepts.

So, based on these arguments, the design framework is presented as useful for other domains of AT, beyond the tested sample problem of ATCIDs.

The next section discusses the PD workshops with individuals with motor and communication disabilities. The literature contained little information about the practice of facilitating such workshops, so this contribution provides directional recommendations – and flags possible pitfalls - for future PD research.

5.3 Participatory design practice

This research suggests that openness and flexibility is paramount in both PD workshop planning and practice. A good relationship with interested gatekeepers in the organisations was useful, and networking played a part in this. The researcher knew the gatekeeper in Enable Ireland through previous unrelated projects. That gatekeeper not only opened communication avenues with service users from her organisation, but she also introduced the

researcher to the gatekeeper in the Central Remedial Clinic. E-mails were regularly exchanged during the set-up of the workshops since the gatekeepers' expertise and knowledge about their service users informed the inclusion criteria, and they also advised on and booked suitable spaces for the workshop locations within the organisations' headquarters. Internal gatekeepers are important also because they provide a level of comfort to those invited to take part. Although ethical approval committees theoretically give the green light to research, gatekeepers vouching for a project is very helpful.

Major issues during the research related to participant recruitment and attrition. Attrition should be anticipated, though it is unpredictable. Even though reminders were transmitted and participants confirmed their attendance in the run up to the PD workshops, other commitments and illnesses were common. Although absenteeism occurred, it was useful to have different numbers of participants in different workshops because the dynamics varied and could be compared for the purpose of defining an optimal number participating. It's difficult to dictate a number that is sure to work, given that other variables like personality and communication style and ability also affected the flow and dynamic in the workshops, so the solution is ultimately about flexibility. Workshops should be designed to function whether one or multiple participants attend. From this research, workshops with one or two participants, where those individuals may have communication impairments, are suggested as optimal. Fewer participants means less time waiting for others to respond, and more time to follow the participants' leads.

The preparation and use of engaging stimulus also helped the flexibility of the workshops. If one activity wasn't working well, or if there was a dip in energy, another activity could be rolled out. Stimulus acted as a springboard for discussion and a way to look at ATCIDs from different perspectives, whether that was functional, visual, textural or shape-related.

A watch-out for PD workshop practice relates to 'tunnel vision' [231]. This is the idea that users will only create ideas directly related to the patterns of activity which they are already accustomed to. To exemplify this, during the workshops, participants considered their hopes for the future regarding the way that they control their computers, wheelchairs and communication devices. Although the participants had responded generously with information about themselves and their technology, they engaged less in dialogue about concepts or ideas that were not linked with their current AT. Tunnel vision is dangerous because it can drive a designer towards a solution to a *perceived problem*, rather than an *existing problem*. Tunnel vision also manifests when users defend their devices even though they are clearly experiencing problems with them. To exemplify this, in the first workshop, one participant (P1) was consistently very positive about her computer input device, saying 'Mine is delicious! ... It's perfect!' However, as the workshop progressed, it transpired that her joystick lever had recently been modified with a cork to make it more comfortable because, previously, the joystick lever was too short. Later, it emerged that P1 can't use her ATCID, or any other ATCID she's tried, to access a computer due to her 'shake', or tremor. The participants' devices may be the best they have tried, and so therefore the best they can logically envision. This is one reason why

observation and discussion allowed by a workshop setting is useful; there is more than one chance to get to the truth. The insight about a topic might come later, when the participant is speaking about something different.

Although finding 'problems-to-solve' was an aim of the PD workshops, it was important not to point out problems about the ATCIDs in use, that go unnoticed by participants. It is the researcher's responsibility to protect participants from becoming disenfranchised by their AT, but also to endeavour to see all faults with the AT and note them down as latent needs.

A final recommendation for useful PD workshops relates to objectivity. The design researcher may need to deal with criticism when working with prototypes or materials that they have developed, so they must be objective about the feedback and probe participant further for specific flaws in order to generate constructive criticism for the development of the designs.

The next section discusses the results of the Delphi study and PD workshops These are specific to ATCIDs, so not determined to be transferable to other product domains. They are, however, transferable to future ATCID related research and design.

5.4   ATCID design and development

In the Delphi study, clinicians highlighted problematic elements of current ATCIDs. The most highly ranked results were mechanical and related to robustness. This suggests that more robust alternatives to parts or components prone to malfunction are required. The AT literature does not provide contemporary information about problematic elements of ATCIDs, so solutions

have not been published. However, design engineering literature reflects a number of the issues and offers possible solutions. For example, Design for Manufacturing and Assembly (DFMA) techniques could solve the problem of small parts getting lost by proposing multi-functional part design and minimised part numbers.

Participants proposed reasons for the failure and malfunction ATCIDs. Again, devices were found to lack robustness. Another interesting issue related to dirt build-up, which causes keys and buttons to get stuck. Participants noted a lack of instructions around decontamination procedures for ATCIDs and difficulties with infection control when devices are shared. These issues provide a strong case for ATCIDs that can be more easily cleaned or are more resistant to dirt. Here, solution generation led to devices that are dishwasher safe, employ hydrophobic or oleophobic coatings, or are encased in a membrane which can be easily disinfected. Like the first question, there is little evidence of this type of data in the literature.

The Delphi study generated a list of service-user characteristics associated with ATCID selection. Each characteristic highlights one or more functional elements of an ATCID that should be customisable. The large number of results suggests that in order to design an appropriate device for a range of users, features should primarily be inclusively or universally designed and only when this is not possible should they be customisable. The characteristics can be broadly categorised into physiological, emotional, and contextual. Range of motion, muscle tone, tremor, fine motor control, strength and vision, along with

cognitive ability and the presence of pain all relate to physiological function. Motivation and level of interest and stamina are emotional issues. Contextual issues relate to the type of activity facilitated by the ATCID, the environment of use, and the support which the user has.

The list of characteristics produced by the Delphi study are supported by Hoppestad's [25] Delphi study, which provided a list of elements for computer use assessment and Danial-Saad *et al.*'s [224] Delphi study, which presented an ontology for physically controllable pointing devices. The intention for the results of these previous studies was different in that they aimed to support assessment and prescription of devices, rather than the design of new devices. However, by using this type of information during the development of customisable AT, a designer can attempt to create AT solutions which allow use by individuals with various levels of muscle strength, visual acuity or range of motion. Though measurement range data is not available for many user characteristics, awareness of the characteristic variables during concept generation helps to inform the development of adaptable solutions that are useful for a greater number of people.

Satisfactory device adoption requires a holistic approach that considers the user's physical, emotional and environmental factors. The results of the Delphi study suggest that the provision of instructional information, peer and emotional support and access to a device trialling period would make product use and training more efficient and satisfactory. Conceptual solutions include the provision of demonstration videos about how to assemble, use, modify and

clean customisable ATCIDs, and the establishment of specialised online peer networks for sharing ATCID information.

Clinicians were also asked to list and rank what they perceived to be desirable traits of ATCIDs. The results reflected Batavia and Hammer's [46] seminal study in 1990, which used focus groups with people with disabilities to generate a list of consumer based criteria for the evaluation of assistive devices. Batavia and Hammer acknowledged that the study was preliminary in nature due to the small sample (n=12) that was not necessarily representative of the population, and that the criteria were not tested for validity and reliability. Still, their study is cited regularly in the literature and has been used as part of an AT framework to conceptualisation and measure AT usability [232]. The sample described in this paper is not considerably larger but as it was composed of professional users rather than end-users, the similarity between the results helps to validate both pieces of research.

Scherer and Lane [233] produced categories for assessing consumer profiles of ideal AT. These all echo Batavia and Hammer's results as well as those generated in this research. Arthanat *et al.*'s [232] Usability Scale for AT (USAT), Hoppestad's Delphi study, as described above, and Danial-Saad *et al.*'s [224] list of device features also support the results of the Delphi study. One point about these previous studies is that, although the criteria are useful in a broad sense, instructions on how to apply them in a clinical or real-life setting is less clear. Batavia and Hammer [46] noted that studies in the past had resulted in issues about how AT was regarded by users and why AT was purchased and

abandoned, but not on how they should be designed, manufactured and selected. The studies mentioned above succeeded in generating and collating this type of information, but they did not then propose a way of applying the criteria in the design process of new devices.

The Delphi study highlighted 13 new desirable ATCID traits not evident in previous studies about computer input devices. These tended to relate to modern technology trends such as the desire for wireless operation, universal connections and batteries that can be easily recharged. Certain desirable traits proposed by participants match results about user characteristics that were also generated in the Delphi study. For example, appropriate sensitivity and appropriate size resulted as two desirable ATCID traits. This matches the idea that devices with different sensitivities and sizes suit different users, because users have different levels of muscle strength, movement control and range of motion. To exemplify this, a person with advanced muscular dystrophy may require a smaller, lighter, more sensitive switch than someone with hypertonia or cerebral palsy. These ideas consequently lead concepts whereby the sensitivity and size of the device can be easily adapted. The participants with disabilities provided data during the workshops that reflected these traits. In describing how ATCIDs do not meet their specific needs, sensitivity, size, layout and aesthetics all emerged as key variables that define the appropriateness of an ATCID.

Participants shared their frustrations with ATCIDs during the research. These results shed light on real-life use contexts and the associated issues.

Frustrations highlighted that AT devices are part of larger systems where other devices, systems, environments and the user influence each other. The frustrations about the high cost of ATCIDs, access to funding, the cost of repair and short warranties all reflect the need for low cost AT. Frustrations, and user workarounds, largely related to difficulties with tailoring devices to individuals' needs, and adapting devices when user requirements change. These issues support the need for mass customisation in ATCID design.

5.5   Future work

Although this research focused on ATCIDs, the methods of collecting, analysing and using information generated by AT-users are intended for application to other tangible AT product domains. Future work involves using the framework to solve a different AT domain sample problem. Postural support, mobility aids, feeding apparatus and musical instruments are examples of device domains which would be appropriate. This step could provide insight into how the framework should be developed and strengthen the claim that the framework is transferable and applicable beyond the ATCID sample problem.

Another step that would help evaluate the framework would be to recruit other designers to assess it. As a lighter touch piece of research, this might involve a survey or interviews with designers to gather their opinions on it. A more robust approach would involve facilitating designers in developing a product concept with the framework, and asking them for feedback on the experience. It would also be useful to benchmark these experiences against those had by designers tasked with tackling the same product domain design problem,

without the use of the framework. In this case, the designers not using the framework would have to document their process so that the different design *methods* could be compared, and not just the final design *outcomes*. Implicit knowledge will always be a variable in the design process, or in solving a wicked problem, so this evaluation cannot be scientifically robust, but it could serve as a useful step in arguing for or against the usefulness of the framework with respect to its intended purpose.

Along with the design framework itself, the customisable ATCID developed through this research would also benefit from future work. The spring design should be optimised, alternative materials should be tested to reduce the size and weight of the device, programming needs to be taken beyond a test programme, and drivers are needed to integrate the device as a functional controller for computers, power mobility aids, environmental controls and communication devices. Future work for the device would also address the need for device use and training aids. It would be advisable to explore an on-line service model, where users could select the most suitable configuration of the customisable ATCID, based on their particular needs, and then receive it for a trialling period. Device usage, customisation and maintenance videos, and a peer support network could be a useful method of addressing the needs for product demonstrations, reviews and support. Mounting and positioning issues were cited in the Delphi study, and this would be another useful product domain on which to apply the PD framework, in order to develop a customisable assistive mounting system. Cables were cited as being

problematic, so future work should also include developing the device to operate wirelessly.

The results of the Delphi study were disseminated among those who participated in that research phase, but to close the loop for all participants, dissemination by means of a presentation of the findings has been proposed in Enable Ireland in late 2015.

Finally, Hersh [104] highlighted that an assistive product is more likely to develop a large market sector if it has additional applications for people without disabilities, so another piece of work would involve investigating the need for customisable computer input devices for mainstream usage. Regularly changing an individual's routine patterns of human-computer interaction could theoretically help to reduce the problems associated with repetitive strain injury.

5.6   Conclusion

The aim of this research was to make a contribution towards improving AT experiences for people with disabilities. The key outcome of this research is a design framework underpinned by the social model of disability, which supports a participatory approach to designing customisable AT devices. This research builds on literature about desirable criteria for AT and provides instructions about how to generate, translate and apply the outcomes of user involvement to the conceptualisation of a new product.

This interdisciplinary research called upon both design engineering and health related literature and methods. Two phases of PD research were tailored to suit the overall aim. First, a questionnaire-based Delphi study facilitated the involvement of professionals working with individuals who have disabilities, and second, a series of PD workshops involved AT users with disabilities.

Assistive Technology Computer Input Devices (ATCIDs) were selected as a sample domain to act as a vehicle to develop and demonstrate the framework. The research produced an array of design issues with current ATCIDs including; mechanical issues; contextual difficulties related to funding, support and information; frustrations about the lack of adaptability; and poor aesthetics.

Various user characteristics and needs that are relevant to ATCIDs were also identified, including range of motion, muscle tone, tremor, dexterity and cognitive ability. This information was useful to highlight certain elements of a new ATCID that need to be either inclusively designed or customisable.

To the best of the author's knowledge, a Delphi study has not previously been used to generate design issues and stimulate product solution conceptualisation. The workshops then served as a useful means to frame these problems in an end-user's reality, while supporting empathic design. The findings from the Delphi study and the PD workshops were translated into design solution concepts via an adapted morphological matrix and a problem framing model. The final product developed through the exploration and application of the framework was a customisable ATCID prototype, whereby a touch panel product platform can be reconfigured to also act as a switch, multiple switches or a joystick, and whereby the force required to activate the controls is variable, by means of a novel mechanical switch interface made from sheet material.

This research addressed a methodological gap in the PD and AT literature. There was evidence of PD research tools that help generate and capture data, as well as examples of product design concepts that were produced through participatory projects. However, it was unclear as to how participants' data was – or should be - translated into product solutions. This gap is not discussed in PD or AT literature, but the topic has long been debated in product design discourse [234]. Recognising and tracing the paths between the discovered needs and the design solution is paramount to ensuring PD efforts are not tokenistic. This requirement to document the links between data and results reflects Ritchie and Lewis' [217] hallmarks of interrogative qualitative data analysis. They proposed that synthesis should be captured so that resulting concepts are traceable, and that the process should be documented and

transparent in case the work is to be re-visited or continued. The design framework developed in this thesis does not propose that there are defined steps that will lead to a successful product solution; however, it does aim to contribute a more structured means to conceptualising solutions that satisfy problems experienced by a target population, and a means to help capture the translation of research data to design solution.

The Chilean architect, Alejandro Aravena, argues that participatory design 'is not a hippie, romantic, let's-all-drink-together-about-the-future kind of thing', nor is it about 'trying to find the right answer' with participants. Rather, PD is about 'trying to identify with precision what is the right question, because answering the wrong question well, is still wrong' [235]. This quote summarises the process very well. The participatory design framework for customisable AT is not an algorithm that provides a precise answer to problems within a given AT product domain, but it is a tool to encourage, guide, stimulate and trace the development of technology solutions that meet user-defined problems.

The framework supports design thinking and wicked problem-solving, in that, although there is some structure to define and solve an AT product domain shortcoming, the outcome is not determinably correct. The design team, including the research participants invariably affect the results. The team's collective 'weltanschauung' [84, 87, 88], or worldview, colours the associative creative thinking process. Acknowledging this indeterminability is an important part of embracing participatory product design.

Technology, medical interventions, and the socio-cultural context and physical environment will all continue to evolve and change over time, and it's not possible to know now what activities and tasks a person with disabilities may wish or need to do in 20 years time – or exactly what AT they will need. However, regular AT product investigation and assessment, along with need-finding research like that described in this these, may help inform the designs of the future. Problem framing, problem solving and participatory design practices are applicable to the development of more than products; they are also practices for the design of services and systems. This research is intended as one small contribution towards a more inclusive and well-designed infrastructure, where health and education services, technology and the built environment, and the societal systems we use and participate in, are designed to be more accessible, useful and appropriate for more people.

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Appendices

Appendix 1: Ethical approval letters

RE: Dublin Institute of Technology Application for ethical clearance Ref. 46/11
Sent: Thu 14/07/2011

Hi Pearl,
Your response was reviewed by the Research Ethics Committee and ethical approval
has been granted to your research.
Kind regards
Raffaella

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RE: Dublin Institute of Technology Application for ethical clearance Ref. 46/11bis
Sent: Tue 21/02/2012

Dear Pearl,

Thank you for your clarification. Your research is granted ethical clearance by the
Research Ethics Committee by Chair's action.
It is recommended that you remove Appendix 3. The Committee will note in its
records that this was not considered appropriate in light of the participants being
cognitively able.
On behalf of the Committee, I wish to thank you for your attention to detail and for
engaging with the process of ethics review in such a positive way.

Kind regards
Raffaella

Raffaella Salvante
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Dublin Institute of Technology
143-9 Rathmines Road, Dublin 6, Ireland
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EnableIreland

Enable Ireland Research, Ethics and Quality Committee
Research Proposal Approval Form

Date: 14 September 2011

Reference Number: Q75

Applicant Name: Pearl O'Rourke

Proposal Title: The generation of a framework for user-centred assistive technology (AT) hardware design through the development of a computer input device

---

REQC Feedback

Approved:
You may proceed with the research as outlined in the research proposal submitted to the REQC. The REQC Co-ordinator will contact you for an Interim Progress Report which you must complete at a later date. A final copy of the study must be submitted to the REQC Co-ordinator after completion to the following address:
Kate Kearney
HR & Corporate Affairs
Enable Ireland
8 Russet Court
Churchyard Lane
Ballintemple
Cork

Kate Kearney
Enable Ireland Research Ethics & Quality Committee Co-ordinator

Enable Ireland Research, Ethics and Quality Committee

Enable Ireland Research, Ethics and Quality Committee
Research Proposal Approval Form

Date: 21 February 2012

Reference Number: Q75

Applicant Name: Pearl O'Rourke Phase 2

Proposal Title: The generation of a framework for user-centred assistive technology (AT) hardware design through the development of a computer input device

REQC Feedback

Approved:
You may proceed with the research as outlined in the research proposal and subsequent amendments submitted to the REQC. A final copy of the study must be submitted to the REQC Co-ordinator after completion to the following address:
Kate Kearney
HR & Corporate Affairs
Enable Ireland
8 Russet Court
Churchyard Lane
Ballintemple
Cork

Kate Kearney
Enable Ireland Research Ethics & Quality Committee Co-ordinator

Enable Ireland Research, Ethics and Quality Committee

Appendix 2: Info pack sent to Delphi study participants

E-mail for assistive technology technicians, information technology trainers, physiotherapists, occupational therapists, carers, speech & language therapists and rehab engineer

Dear Sir/Madam,

A study is currently being undertaken in The Dublin Institute of Technology. The research aims to develop a framework for user-centred assistive technology (AT) design through the development of a new computer input device. Based on your experience working with AT for service-users with motor/communicative disabilities, it would be greatly appreciated if you would consider taking part in the study.

The research is concerned with AT input devices used to access computers; this includes joysticks, switches, trackballs or other products which support a client with motor disabilities in accessing an AAC device, power mobility aid, environmental control or PC.

The research method used here will be the Delphi method, a technique to formulate group consensus from an expert panel. It will be composed of two questionnaires and will call for a combined time commitment of up to one and a half hours. After analysis of the first questionnaires, you will be contacted to complete the second, which will be developed from the results of the first.

A gatekeeper in your organisation has proposed you as a valuable participant to represent your field of work. You are now asked to nominate three other people from within your organisation, who share your profession to also consider taking part. For example, if you are the representative OT, please nominate three other OTs in your organisation who you believe to have experience in assistive technology computer input devices.

Please find more information in the attached document. If you agree to partake, please complete and return the consent form and the questionnaire to the address below. A hard copy of this letter and the attachments has also been sent to you your place of work with a stamped address envelope so you may post either a printed copy of this soft version or the hard copy sent to you.

If you would prefer to complete the questionnaire over the phone, please call the number below to make arrangements.

Yours Sincerely

_____

Pearl O'Rourke

School of Mechanical and Design Engineering,
Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland.

Phone: 087 966 5866, E-mail: pearl.orourke@dit.ie

Code_____

CONSENT FORM

You have been selected to participate in a research study investigating better assistive technology design practice. Please complete this form after reading the information sheet provided. Once completed, please return to the researcher at the address below.

Researcher:	Ms. Pearl O'Rourke, under the supervision of Dr. Ray Ekins, Dr. Eugene Coyle, Dr. Fiona Timmins, Mr. Bernard Timmins and Ms. Siobhan Long.
Contact Details:	Pearl O'Rourke School of Mechanical and Design Engineering D.I.T. Bolton Street, Dublin 1 E-mail: pearl.orourke@dit.ie Phone: 087 966 5866
Organisation undertaking research:	Dept. of Applied Technology, School of Mechanical and Design Engineering, Dublin Institute of Technology.
Title of study:	A Delphi Study; the first step towards the generation of a framework for user-centred assistive technology (AT) design through the development of a computer input device.

To be completed by the participant:	Yes	No
Have you read the provided information sheet and been fully informed about this study?		
Have you had an opportunity to ask questions and discuss this study?		
Have you received satisfactory answers to all your questions?		
Have you received enough information about this study?		
Do you understand that you are free to withdraw from this study at any time, without giving a reason for withdrawing?		
Do you agree to take part in this study, the results of which are likely to be published?		
Have you been informed that this consent form shall be kept in the confidence of the researcher?		

Signed:	Date:
Name in block capitals:	
Signature of Researcher:	Date:

Information Sheet

What's this all about?

You are invited to take part in a research study due to your professional experience and interaction with people who have motor/communicative impairments.

Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information. It is up to you to decide whether or not to take part.

Title of study

The generation of a framework for user-centred assistive technology (AT) design through the development of a computer input device.

Objectives

To inform a set of actionable design criteria for the development of computer input devices for individuals with motor/communicative impairments.

You
Service-users
Design
Technology

A bit of background

For people with severe motor and communication impairments, computer technologies can offer access to mainstream society, improve independence and increase the capacity to engage fully in daily activities and academic or vocational options. AT such as augmentative and alternative communication aids, power wheelchairs, personal computers and environmental controls are examples of such computers.

For individuals who cannot use a standard keyboard and mouse, scanning software may be accessed via AT devices such as switches, joysticks, trackballs and head-pointers. The design and functionality of these items vary vastly as different devices aim to satisfy different needs. Products target relatively small, niche markets and this leads to high costs being placed on the funding body or, increasingly, the disabled client. Additionally, the outdated culture of obtrusive, cold and clinical aesthetics has been found to inflict a stigmatising effect on the service-user. Subsequently there is a high rate of abandonment associated with generic products on the market.
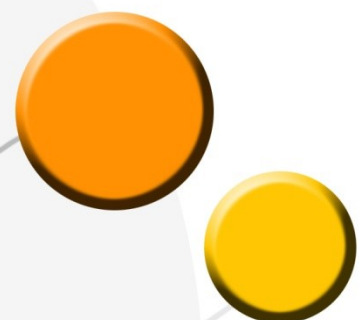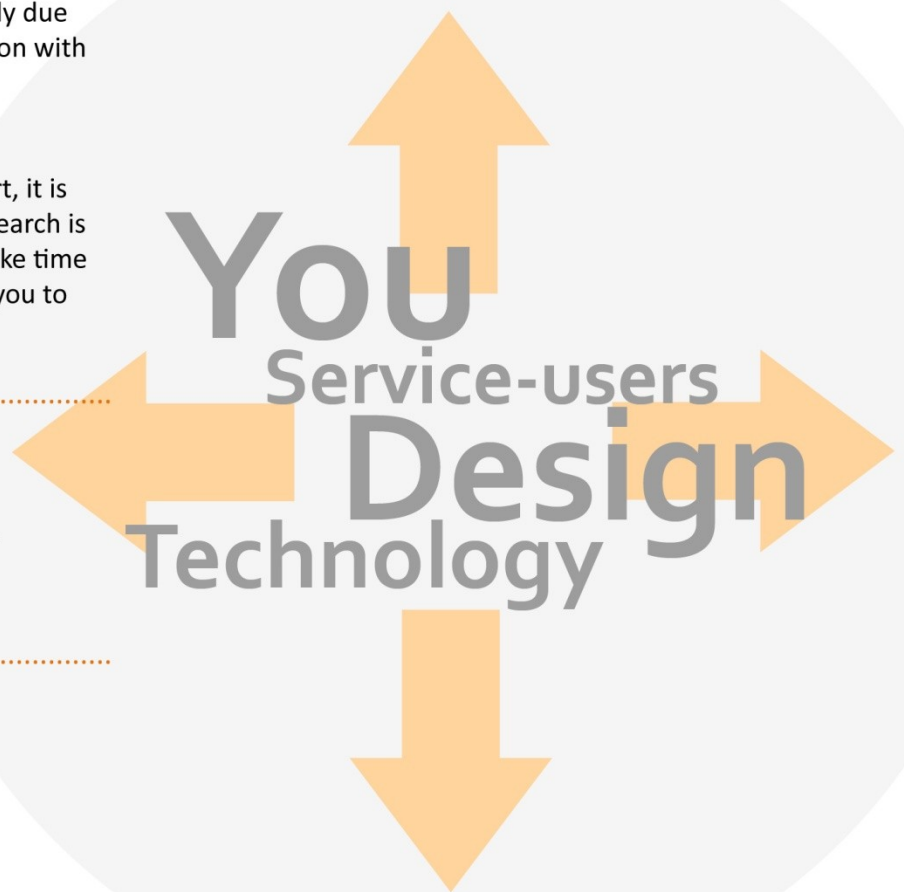
The large and varied array of people involved in the provision and use of AT products further makes it difficult to get the balance of design solution correct. Stakeholders may include the service-user and their carer, a rehabilitation engineer, an occupational therapist, a speech therapist, a physiotherapist and a doctor. Others who may contribute include psychologists, educationalists and, perhaps, fund-holders.

User-centred design aims to create products that fit well with the user instead of forcing them to change the way they act in order to utilize the product. The approach involves users in the whole design process in order to match the product to the requirements and to increase practical use. This initial questionnaire based study aims to reach a consensus on professional opinion about the important qualities of assistive technology computer input devices. Subsequently, a device will be prototyped and a piece of research involving service-users will take place.

How you can help

The research method used here will be the Delphi method, a technique used to formulate group consensus from an expert panel. It will be composed of two questionnaires and will call for a combined time commitment of up to one and a half hours. The first should take about 45 minutes to complete. You will be asked seven short questions related to you and your experience and six longer questions about certain aspects of AT. You will be contacted in five to six weeks to complete the second questionnaire, which will be developed from the results of the first.

If you take part, you will;
- contribute to a new body of important and applicable information on AT in Ireland,
- help identify key criteria for AT computer input devices,
- aid in the design of a new, low-cost computer input device for individuals with motor and communicative impairments, and
- upon completion of the study, receive a summary of the findings.

Extra Information

Due to the nature of the Delphi method, your responses will be anonymous and of equal value to other participants'. A code will be assigned to you for the purpose of tracking received questionnaires and will be used in subsequent mailings. The code list linking your name to your code will be secured in an encrypted file and a hard copy will be stored in a secure locker. Your name will be deleted from the code list when your final questionnaire is received or if you decide to withdraw from the study. At such point, all information provided will become anonymous.

Should you require any further information on the study or your participation, please do not hesitate to contact the researcher. Details are on the consent form. This study is funded by the Irish Research Council for Science and Technology.

Thank you for your time and consideration.

References

1. Bradley N, Poppen W. Assistive technology, computers and internet may decrease sense of isolation for homebound elderly and disabled persons. Technology and Disability. 2003;15(1):19-25.
2. Houlihan BV, Drainoni ML, Warner G, Nesathurai S, Wierbicky J, Williams S. The impact of internet access for people with spinal cord injuries: A descriptive analysis of a pilot study. Disability and Rehabilitation. 2003;25(8):422-31.
3. Brodwin MG, Star T, Cardoso E. Computer assistive technology for people who have disabilities: Computer adaptations and modifications. Journal of Rehabilitation. 2004;70(3):28-33.
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Appendix 3: Delphi study questionnaires

QUESTIONNAIRE 1

The Generation of a Framework for User-Centred Assistive Technology (AT) Research and Development through the Design of a Universal Computer Input Device for Individuals with Severe Physical/ Communicative Disabilities

Delphi Questionnaire: Round 1 of 2

Participants: Professionals with assistive technology experience

Thank you for agreeing to participate in this study; your contribution is greatly appreciated.

This research is concerned with **Assistive Technology Computer Input Devices** (ATCIDs). An ATCID is defined as any piece of hardware used to control electronic AT by a service-user with a motor impairment. This excludes service-users who are able to use keyboards and mice. Essentially, the term refers to **joysticks, switches, trackballs and touchpads**, along with their **mounts**, which are used to access one or more computerised device, for example, a power mobility aid, communication device, personal computer or environmental controls unit.

During this survey, you will first be asked seven short questions about you and your professional role. After this, six questions about your experience with ATCIDs will be posed. Please feel free to contact the researcher at any time if you have queries or comments about the questionnaire. The results of this study are completely anonymous as your answers will be linked only to a code. Access to names will be wholly restricted to the primary researcher working on this project.

A gatekeeper in your organisation has proposed you as a valuable participant to represent your field of work. You are first asked to **nominate three other people** from within your organisation, who share your profession, who you believe to have some experience of ATCIDs. For example, if you are the representative OT, please nominate three other OTs.

 1.
 2.
 3.

Please tick this box if you would like a hard copy of the second and final questionnaire sent to you with a stamped addressed envelope. If you do not mark this box, you will only be sent a soft copy, which you can then return by e mail.

Demographic Information

1   Gender

i.   Male ☐

ii.   Female ☐

2   What is your current job title?

i.   Occupational Therapist ☐

ii.   AT training provider ☐

iii.   AT/IT technician ☐

iv.   IT training provider ☐

v.   Physiotherapist ☐

vi.   Academic ☐

vii.   Rehabilitation engineer ☐

viii.   Other, please specify ☐

_____

3   What is your main clinical setting?

i.   Service-user's home ☐

ii.   Clinic/AT service ☐

iii.   Other, please specify

_____

4   Where is your client base located?

i.   Dublin region ☐

ii.   ROI, excluding Dublin ☐

iii.   NI ☐

5 What qualifications do you hold relevant to your field of work?

(Please specify type of qualification, e.g. BSc, and area, e.g. Physio.)

6 How many years of experience (relevant to your work) do you have?

i.	<1 year	
ii.	1-5 years	
iii.	5-10 years	
iv.	10-15 years	
v.	15-20 years	
vi.	>20 years	

7 Do you currently work with any clients who require or use assistive technology computer access peripherals, e.g. switches, joysticks, trackballs?

i.	Yes	
ii.	No	

Device Research and Development Information

For the purpose of this study, an assistive technology computer input device (ATCID) is defined as any piece of hardware used to control electronic AT by a service-user with a motor impairment. This excludes service-users who are able to use keyboards and mice. Essentially, the term refers to joysticks, switches, trackballs and touchpads, along with their mounts, which are used to access one or more computerised device, for example, a power mobility aid, communication device, personal computer or environmental controls unit.

Broad criteria have been developed for the selection of AT and a number of factors have been found to impact positively on AT devices. You are now asked to answer the following six questions to contribute to a set of actionable design criteria for satisfactory ATCIDs. Please attempt to provide **four or five** items for each question. If you cannot answer a question, please write N/A in the box. The questions are categorised according to the Human Activity Assistive Technology (HAAT) model. Information on the formulation of the study can be acquired from the researcher.

The answer boxes will enlarge as you type. If you are filling this out on a hard copy and need more room, please write on the back of the sheet.

1 Assistive Technology

Durability, dependability and repair-ability are traits that relate to the longevity and functionality of a device. When an assistive technology computer input device (ATCID) breaks or stops working, it can have a negative effect on a service-user's relationship with their technology.

1A If you have witnessed ATCID failure, or have had to request or carry out maintenance on such a device, please list the most prevalent parts of the input device that require attention, e.g. cabling is torn. You may also mention parts specific to a particular type of ATCID, e.g. a switch.

1B If you are aware of reasons that have caused an ATCID to fail, please list these reasons.

Flexibility and customisation are ideas which attempt to accommodate the changing needs of a service user by reducing the need for device replacement. Customisation also allows for fitting the device to a user's specific needs.

1C   Please list the key characteristics/variables you associate with a service-user's abilities and an ATCID, e.g. range of movement. These may be the variables you look at if you carry out AT or disability assessments.

2   **Activity**

Simplicity, learnability and operability (satisfactory device activation) are terms which relate to the need for a service-user to receive training. Simple, successful operation of an ATCID is paramount to user satisfaction, but training, whether ongoing or at device introduction, is often required.

2A   What are the requests/needs which you are asked to facilitate with regard to ATCID use and training?

3 Human

Effectiveness (the extent to which an AT device enhances functional capability or independence) and personal comfort are traits of AT that impact upon service-user preference and acceptability.

3A Please list what you perceive to be desirable traits of an assistive technology computer input device (ATCID) in relation to user preference. Please be as specific as possible.

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3B If you, in your personal, professional capacity, experience any frustration with ATCIDs (when selecting, assessing, training, affixing, removing, cleaning and so on), please list what frustrates you.

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Many thanks for participating in this study; your contribution is most valuable. You will be contacted in the coming weeks with regard to the second and final part of the survey. If you have any questions or concerns, please do not hesitate to contact me.

Yours Sincerely

Pearl O'Rourke

_____

School of Mechanical and Design Engineering

Dublin Institute of Technology

Bolton Street, Dublin 1, Ireland.

Phone: 087 966 5866

E-mail: pearl.orourke@dit.ie

Delphi Questionnaire: 2

Participants: Professionals with assistive technology experience

Thank you so much for your continued participation. The results of this second and final questionnaire will contribute valuable information to a larger research study concerned with user-centred assistive technology (AT) design. This study is focused on AT computer input device (ATCID) development. ATCIDs include joysticks, switches, trackballs, track-pads and other products which support a service-user with motor disabilities in accessing a PC, communication device, power mobility aid or environmental control.

To complete this questionnaire, please read the statement (numbered 1-6) and then indicate what you believe to be the importance of each issue in relation to that statement using the scale below.

I believe the issue is;

1	2	3	4	5
not important at all	not so important	something I feel neutral about	important	very important

For example, in statement *1*, if you believe the issue of *USB ports breaking* is *important* in relation to *malfunctioning ATCIDs*, please click on box *4*, like this;

	1	2	3	4	5
USB and other ports break/fail	☐	☐	☐	☒	☐

---

1. These issues relate to the **most prevalent parts of an ATCID which malfunction.**

	1	2	3	4	5
USB and other ports break/fail	☐	☐	☐	☐	☐
Connections between cable and ATCID wear/break	☐	☐	☐	☐	☐
De-soldered joints break	☐	☐	☐	☐	☐
Touch screens stop being responsive	☐	☐	☐	☐	☐
Screens break/crack	☐	☐	☐	☐	☐
Cables wear/break/twist/fray/tear	☐	☐	☐	☐	☐
Internal electrical switch contacts wear and break	☐	☐	☐	☐	☐
Sensors fail	☐	☐	☐	☐	☐
Fuses have defects	☐	☐	☐	☐	☐
Memory boards fail	☐	☐	☐	☐	☐
Devices have false calibrations	☐	☐	☐	☐	☐
Conflicts between computer and ATCID driver exist	☐	☐	☐	☐	☐
Software becomes corrupted (e.g. Curser moves without deflection of joystick)	☐	☐	☐	☐	☐

	1	2	3	4	5
Movement of ATCID becomes restricted due to dirt build up	☐	☐	☐	☐	☐
Keys/buttons lift away from ATCID	☐	☐	☐	☐	☐
Switches stick in a closed/open position	☐	☐	☐	☐	☐
Small parts get lost (e.g. Clamping screws)	☐	☐	☐	☐	☐
Plugs break	☐	☐	☐	☐	☐
Joysticks becomes loose	☐	☐	☐	☐	☐
Unexplained/Unclear reasons for device failure	☐	☐	☐	☐	☐
Magnetic devices interfere with controls	☐	☐	☐	☐	☐
Batteries fail	☐	☐	☐	☐	☐
Mounts loosen at joints	☐	☐	☐	☐	☐

2. These issues relate to the **reasons ATCIDs malfunction or fail.**

	1	2	3	4	5
No articulating joint on USB connections	☐	☐	☐	☐	☐
Weak joints from cable to device	☐	☐	☐	☐	☐
Poor ergonomic design	☐	☐	☐	☐	☐
Battery charge is insufficient	☐	☐	☐	☐	☐
Software updates conflict with device drivers	☐	☐	☐	☐	☐
Electrical short circuits	☐	☐	☐	☐	☐
Device falling/being knocked/banged	☐	☐	☐	☐	☐
Inappropriate/rough use and over use of device	☐	☐	☐	☐	☐
General wear and tear	☐	☐	☐	☐	☐
Cables getting caught or being pulled roughly from ports	☐	☐	☐	☐	☐
Constant activation of a device with force	☐	☐	☐	☐	☐
Stress on the device due to user's movement	☐	☐	☐	☐	☐
Mounts loosen due to movement of the client	☐	☐	☐	☐	☐
Lack of policy in relation to regular service of atcids	☐	☐	☐	☐	☐
Poor maintenance of device	☐	☐	☐	☐	☐
Poor care of device when not in use, e.g. During transport	☐	☐	☐	☐	☐
Poor battery conditioning practice	☐	☐	☐	☐	☐
Incorrect device set-up by carers	☐	☐	☐	☐	☐
Poor routing of cable exposing it to damage	☐	☐	☐	☐	☐
Dirt, spills and dust contamination	☐	☐	☐	☐	☐

3. These issues relate to the **characteristics of a service-user** associated with selecting an ATCID.

	1	2	3	4	5
Range of movement of the anatomy which could control an ATCID, e.g. Head, neck, limbs,	☐	☐	☐	☐	☐
Spasticity/muscle tone	☐	☐	☐	☐	☐
Tremor	☐	☐	☐	☐	☐
Speed of movement	☐	☐	☐	☐	☐
Control of movement/ preciseness	☐	☐	☐	☐	☐

	1	2	3	4	5
Physical stamina	☐	☐	☐	☐	☐
Posture/positioning	☐	☐	☐	☐	☐
Ability to repeat a movement wthout strain	☐	☐	☐	☐	☐
MACS level	☐	☐	☐	☐	☐
Muscle strength	☐	☐	☐	☐	☐
Grasp	☐	☐	☐	☐	☐
Wrist/finger function (dexterity/sensory perception/proprioception)	☐	☐	☐	☐	☐
Cognitive ability	☐	☐	☐	☐	☐
Experience with computers	☐	☐	☐	☐	☐
Motivation/Level of interest	☐	☐	☐	☐	☐
Concentration /attention	☐	☐	☐	☐	☐
Hearing	☐	☐	☐	☐	☐
Vision	☐	☐	☐	☐	☐
Presence of pain	☐	☐	☐	☐	☐
Verbal ability	☐	☐	☐	☐	☐
Environment of use	☐	☐	☐	☐	☐
Activity to be done	☐	☐	☐	☐	☐
Access to technical support	☐	☐	☐	☐	☐
Funding situation	☐	☐	☐	☐	☐
Service user's level of Independance	☐	☐	☐	☐	☐
Service user's social network and their familiarity with the technology	☐	☐	☐	☐	☐
Type of wheelchair being used, if used	☐	☐	☐	☐	
What the ATCID will be mounted on (requirement for clamps and mounts)	☐	☐	☐	☐	☐
Presence of epilepsy	☐	☐	☐	☐	☐
Condition progresssion (rehabilitation/degeneration)	☐	☐	☐	☐	☐

4. These issues relate to **user needs** regarding **ATCID use and training.**

	1	2	3	4	5
How to adapt functionality for the service user's changing needs	☐	☐	☐	☐	☐
Maintenance and care instructions	☐	☐	☐	☐	☐
Simple written instructions for ATCID set-up and use	☐	☐	☐	☐	☐
Pictorial instructions for ATCID set-up and use	☐	☐	☐	☐	☐
List of common trouble-shooting/faqs	☐	☐	☐	☐	☐
Contact details of supplier and technical support (in case trainer is not available)	☐	☐	☐	☐	☐
Recommendations for use in educational settings for school staff and boards	☐	☐	☐	☐	☐
Instilling confidence	☐	☐	☐	☐	☐
Instilling motivation to practice, explore and use	☐	☐	☐	☐	☐
Introduce service-user to other clients who have experience of the device	☐	☐	☐	☐	☐

Inclusion of service user's social network in training (family/carers/teachers)	☐	☐	☐	☐	☐
Access to device for trial period	☐	☐	☐	☐	☐
Correct positioning and mounting	☐	☐	☐	☐	☐
Set-up of regular meetings	☐	☐	☐	☐	☐
Review of equipment	☐	☐	☐	☐	☐
Demonstrations	☐	☐	☐	☐	☐
Specific training around a task or feature	☐	☐	☐	☐	☐
Basic IT training	☐	☐	☐	☐	☐

5. These issues relate to **desirable traits of an ATCID.**

	1	2	3	4	5
Attractive aesthetics	☐	☐	☐	☐	☐
Size	☐	☐	☐	☐	☐
Weight	☐	☐	☐	☐	☐
Shape	☐	☐	☐	☐	☐
Colour	☐	☐	☐	☐	☐
Design based on mainstream devices	☐	☐	☐	☐	☐
Social acceptibility; a design which doesn't make the user stand out	☐	☐	☐	☐	☐
A good match between service-user's goals and ATCID solution	☐	☐	☐	☐	☐
Versatility/flexibility/capability to be multi-functional	☐	☐	☐	☐	☐
Does not impede movement of service-user	☐	☐	☐	☐	☐
Comfortable to use/does not cause strain	☐	☐	☐	☐	☐
Adaptable to service-user's specific needs	☐	☐	☐	☐	☐
Access to local providers who can give training, maintenance and repairs	☐	☐	☐	☐	☐
Portable	☐	☐	☐	☐	☐
Clear menus	☐	☐	☐	☐	☐
Clear instructions	☐	☐	☐	☐	☐
Easy to operate	☐	☐	☐	☐	☐
User-friendly	☐	☐	☐	☐	☐
Reliable	☐	☐	☐	☐	☐
Easy to maintain	☐	☐	☐	☐	☐
Durable/robust/sturdy	☐	☐	☐	☐	☐
Easy to set up and dismantle	☐	☐	☐	☐	☐
Quick to install	☐	☐	☐	☐	☐
Quick to turn on	☐	☐	☐	☐	☐
Easily positionable	☐	☐	☐	☐	☐
Re-adjustable	☐	☐	☐	☐	☐
Long battery life	☐	☐	☐	☐	☐
Easily rechargable battery	☐	☐	☐	☐	☐
Wireless	☐	☐	☐	☐	☐
Universal connection (USB)	☐	☐	☐	☐	☐

	1	2	3	4	5
Compatible with different operating systems	☐	☐	☐	☐	☐
Up-to-date	☐	☐	☐	☐	☐
Low cost	☐	☐	☐	☐	☐

6. These issues relate to **your frustrations associated with ATCIDs.**

	1	2	3	4	5
Fittings with screw holes snap when tightened	☐	☐	☐	☐	☐
Non articulating/non-extended USB connections	☐	☐	☐	☐	☐
Devices not being plug and play /drivers need to be loaded from cds	☐	☐	☐	☐	☐
Lack of instructions around correct decontamination procedures	☐	☐	☐	☐	☐
Infection control difficulties when devices are shared by different users	☐	☐	☐	☐	☐
Multiple parts need to be unscrewed and dismantled for decontamination	☐	☐	☐	☐	☐
Not being able to adapt the system for exact service-user needs	☐	☐	☐	☐	☐
Having to modify the device for changing service-user needs	☐	☐	☐	☐	☐
Positioning in multi care environment (Clamps and mounts need individual adjustment everytime; this is difficult to replicate)	☐	☐	☐	☐	☐
Limited access to customer support/technical assistance/repair assistance/product manufacturers	☐	☐	☐	☐	☐
Limited resources/devices available in clinical environment to use for assessment	☐	☐	☐	☐	☐
Lack of information on devices	☐	☐	☐	☐	☐
Information not shared between personnel	☐	☐	☐	☐	☐
Lack of follow through by families and schools	☐	☐	☐	☐	☐
People's lack of willingness of carers/professionals to be trained despite their roles indicating they should	☐	☐	☐	☐	☐
High cost and access to funding for purchasing device	☐	☐	☐	☐	☐
Cost of repair/Short warranties without additional payment	☐	☐	☐	☐	☐
Discrepancy of funding throughout the country	☐	☐	☐	☐	☐
Time to assess/train	☐	☐	☐	☐	☐
Time needed to repair device, leaving service-user with no ATCID	☐	☐	☐	☐	☐
Information not shared between personnel	☐	☐	☐	☐	☐
Lack of follow through by families and schools	☐	☐	☐	☐	☐
People's lack of willingness of carers/professionals to be trained despite their roles indicating they should	☐	☐	☐	☐	☐
High cost and access to funding for purchasing device	☐	☐	☐	☐	☐
Cost of repair/Short warranties without additional payment	☐	☐	☐	☐	☐
Discrepancy of funding throughout the country	☐	☐	☐	☐	☐
Time to assess/train	☐	☐	☐	☐	☐
Time needed to repair device, leaving service-user with no ATCID	☐	☐	☐	☐	☐

Appendix 4: Info pack sent to participatory design workshop

participants

Information Sheet

What's this all about?

You are invited to take part in a research study due to your knowledge and experience using assistive technology.

Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information. It is up to you to decide whether or not to take part.

Title of study

The generation of a framework for user-centred assistive technology hardware design through the development of a computer input device.

Objectives

To design a new assisstive technology computer input device through participatory design activites.

YOU Technology Design

A bit of background

Augmentative and alternative communication aids, power wheelchairs, personal computers (PC's) and environmental controls are computerised assistive technologies which help people access information, improve mobility and assist with communication. People use different tools to control these devices. Mice and keyboards are mainstream tools but joysticks, switches, trackballs and touch pads are also used. These are examples of Assistive Technology Computer Input Devices (ATCIDs). We believe that some improvements can be made to ATCIDs and we'd like you to be involved in deciding what these improvements should be.

Your knowledge and experience of using an ATCID is very valuable so we'd like to invite you to participate in a design workshop. At the workshop, there will be two or three participants who have experience using ATCIDs and a researcher will be there to facilitate the day. The workshops will start at 10am and finish at 4pm. There will be two shorter breaks and one longer break for lunch, which we'll provide.

How you can help

If you agree to take part in the workshop, you will be part of a design team. Other members of the design team are service-users of Enable Ireland and The Cedar Foundation. They are also taking part in design workshops. The researcher facilitating all the workshops will share the outcomes of the workshops with all participants as the project proceeds.

This is participatory research. During the workshop the researcher will introduce and explain the activities and design games throughout the day and then you'll work together on ideas. If you have an idea for a design activity, you can discuss that too. During the workshop, you will be accompanied by a personal assistant (PA). They will be there to provide you with support during the various activities.

If you take part, you will;
*help to design a new assistive technology computer input device (ATCID),
*help to develop recommendations for future workshops like these, and
*upon completion of the study, receive a booklet which will show the story of your design process, explain the results of the workshops and showcase the final design.

At the workhop, you'll start with some warm up games and then share views on ATCIDs. Before the workshop, you will receive a question guide which you can use to prepare some answers if you like, or you can just think about the questions and discuss them on the day. After this, you'll use different materials to explore ideas for a new ATCID. You'll also look at some ideas for the new design and discuss these.

After the workshop, the researcher will take the work back to the design studio. She will study what was done during the day and develop some prototypes from the ideas. Prototypes are models which will be used to test the ideas. She will also make a presentation of the what was done at the workshop. You'll receive a copy of this. The day will finish with a short evaluation where you will be asked some questions about what you thought of the workshop. At the end of the study, if you like, the researcher will return your work to you.

Extra Information

Photographs will be taken at the workshop and the activites will be videotaped. Details of this study and some of the images from the days may be published but published images will not show your face and your name will not be used. If you have any issues with being photographed or videotaped, that's not a problem, but please contact the researcher before the workshop.

Should you require any further information on the study or your participation, please do not hesitate to contact the researcher. Details are on the consent form. This study is funded by the Irish Research Council for Science and Technology.

Many thanks for your time and consideration.

What's this all about?

You are invited to take part in a research study due to your knowledge and experience using assistive technology.

Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information. It is up to you to decide whether or not to take part.

Title of study

The generation of a framework for user-centred assistive technology hardware design through the development of a computer input device.

Objectives

To design a new **Assisstive Technology Computer Input Device** through participatory design activites.

A bit of background

Augmentative and alternative communication aids, power wheelchairs, personal computers (PC's) and environmental controls are computerised assistive technologies which help people access information, improve mobility and assist with communication. People use different tools to control these devices. Mice and keyboards are mainstream tools but joysticks, switches, trackballs and touchpads are also used. These are examples of Assistive Technology Computer Input Devices (ATCIDs). We believe that some improvements can be made to ATCIDs and we'd like you to be involved in deciding what these improvements should be.

How you can help

If you agree to take part in the workshop, you will be part of a design team. Other members of the design team are service-users of Enable Ireland and The Cedar Foundation. They are also taking part in design workshops. The researcher facilitating all the workshops will share the outcomes of the workshops with all participants as the project proceeds. This is participatory research. During the workshop the researcher will introduce and explain the activities and design games throughout the day and then you'll work together

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If you take part, you will;
*help to design a new Assistive Technology Computer Input Device (ATCID),
*help to develop recommendations for future workshops like these, and
*upon completion of the study, receive a booklet which will show the story of your design process, explain the results of the workshops and showcase the final design.

At the workhop, you'll start with some warm up games and then share views on ATCIDs. Before the workshop, you will receive a question guide which you can use to prepare some answers if you like, or you can just think about the questions and discuss them on the day. After this, you'll use different materials to explore ideas for a new ATCID. You'll also look at some ideas for the new design and discuss these.

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Extra Information
Photographs will be taken at the workhop and the activites will be videotaped. Details of this study and some of the images from the days may be published but published images will not show your face and your name will not be used. If you have any issues with being photographed or videotaped, that's not a problem, but please contact the researcher before the workshop.
Should you require any further information on the study or your participation, please do not hesitate to contact the researcher. Details are on the consent form. This study is funded by the Irish Research Council for Science and Technology.

Many thanks for your time and consideration.

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Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland
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CONSENT FORM FOR PARTICIPANTS

You have been selected to participate in two design workshops. Please read the information sheet provided and, if you choose to participate, complete this form.

Researcher:	Ms. Pearl O'Rourke, under the supervision of Dr. Ray Ekins, Mr. Bernard Timmins, Prof. Fiona Timmins, Prof. Eugene Coyle and Ms. Siobhan Long.
Contact Details:	Ms. Pearl O'Rourke Post-Graduate Office, Top Floor, Lurgan St. Building, Dublin Institute of Technology, Bolton St., Dublin 1 E-mail: pearl.orourke@dit.ie Phone: 00353 (0)87 966 5866
Organisation undertaking research:	Dept. of Applied Technology, School of Mechanical and Design Engineering, Dublin Institute of Technology.
Title of study:	**The generation of a framework for user-centred assistive technology hardware design through the development of a computer input device.**

To be completed by the participant (Mark the box beside each statement if you agree)	**X**
I have read the provided information sheet and been fully informed about this study.	
I have had an opportunity to ask questions and discuss this study.	
I have received satisfactory answers to questions I have asked.	

I have received enough information about this study.	
I understand that I am free to withdraw from this study at any time, without giving a reason and that this will not affect my future relationship with DIT.	
I understand that these workshops will be video-taped and that recordings will not be made public.	
I understand that if images are used in published material, my confidentiality and anonymity will be maintained and images showing my face will not be used.	
I agree that this consent form shall be kept in the confidence of the researcher.	

Signed:	Date:
Name in block capitals:	
Signature of Researcher:	Date:

Please note that the information provided by participants will be held and processed by DIT in accordance with the provisions of the Data Protection Acts, 1988 and 2003.

CONSENT FORM FOR PARTICIPANTS

Researcher: Ms. Pearl O'Rourke, under the supervision of Dr. Ray Ekins, Mr. Bernard Timmins, Prof. Fiona Timmins, Prof. Eugene Coyle and Ms. Siobhan Long.

Contact Details: Ms. Pearl O'Rourke
Post-Graduate Office,
Top Floor, Lurgan St. Building,
Dublin Institute of Technology, Bolton St., Dublin 1
E-mail: pearl.orourke@dit.ie
Phone: 00353 (0)87 966 5866

Organisation undertaking research: Dept. of Applied Technology,
School of Mechanical and Design Engineering, Dublin Institute of Technology.

Title of study: The generation of a framework for user-centred assistive technology hardware design through the development of a computer input device.

To be completed by participant's PA (Mark the box beside each statement if you agree)	x
I have read the provided information sheet and been fully informed about this study.	
I have had an opportunity to ask questions and discuss this study.	
I have received satisfactory answers to questions I have asked.	
I have received enough information about this study.	
I understand that I am free to withdraw from this study at any time, without giving a reason for withdrawing.	
I understand that these workshops will be video-taped and that recordings will not be made public.	
I understand that if images are used in published material, my confidentiality and anonymity will be maintained and it will not be possible to identify me.	
I agree that this consent form shall be kept in the confidence of the researcher.	

Signed:	Date:
Name in block capitals:	
Signature of Researcher:	Date:

Please note that the information provided by participants will be held and processed by DIT in accordance with the provisions of the Data Protection Acts, 1988 and 2003.

CONFIDENTIALITY AGREEMENT FOR PARTICIPANTS

(Please turn over for information on data protection.)

I, _____ agree that;

- I will keep personal and sensitive information that is revealed during the workshop confidential.

- I will not share the specific contents of the workshop with anyone not involved in the workshop.

- I will not divulge any information that would allow someone who is not involved in the workshop to know who participated.

Signed:	Date:
Name in block capitals:	
Signature of Researcher:	Date:

DATA PROTECTION INFORMATION

Prior to the workshops, the researcher will assign a code to each participant for the purpose of tracking received questionnaires. These codes will be used to identify participants during data analysis, i.e. no names will be used in the analysis files. Any notes the researcher makes will use these codes as identifiers. The list linking the participant's name to their code will only be available to the researcher and will be secured in an encrypted file and a printed copy will be stored in a secure locker in DIT. When the final workshop is completed, the file will be deleted and the printed copy will be shredded by a professional confidential shredding company. At such point, all information provided will become anonymous. The anonymous data will be kept for at least six years.

Original soft data which associates participants to their contribution, i.e. video recordings and photographs, will be stored on a USB key in encrypted files. These files will be accessible by a password known only by the researcher. The USB key will be retained for six years, after which point it will be destroyed mechanically.

Sensitive data will not be discussed during the workshops. However, if a participant discloses any data of a sensitive nature, this will not be used in the analysis process. This confidentiality agreement is to be signed by all present at the workshops (PAs, participants, videographer, and researcher).

If you have any queries about the data protection procedures involved in this research, please contact the researcher (details as before).

Appendix 5: Participatory design workshop evaluation form

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Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland
t +353 1 402 3000   f +353 1 402 3999   ● www.dit.ie

Code_____

Participatory Design Workshop Evaluation 1

Thank you for taking part in the design process today. Your contribution is greatly appreciated. This questionnaire will help us to understand what you thought about the workshop and make improvements for the future.

The questionnaire is made up of nine questions and it will take about 20 minutes to complete.

Please state how much you agree with the statements in the first seven questions. There are five choices for each statement; strongly disagree, disagree, neutral, agree and strongly agree. Please mark the box above your answer.

The last two questions ask about what you liked and didn't like about the day.

The procedure today helped me to describe my views about assistive technology computer input devices (ATCIDs).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

1. **I believe that the group understood my ideas.**

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

2. **I felt free to express myself.**

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

3. **I am satisfied with this means of obtaining my ideas.**

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

4. The procedure was enjoyable.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. The procedure was valuable.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. I feel like I learnt something new today.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. What was the best thing about the workshop?
You can write more than one answer.

8. What did you not like about the workshop?
   You can write more than one answer.

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Many thanks for participating in this study; your contribution is most valuable. You will be contacted in the coming weeks with regard to your second and final workshop. If you have any questions or concerns, please do not hesitate to contact me.

Yours Sincerely

Pearl O'Rourke

_____

School of Mechanical and Design Engineering

Dublin Institute of Technology

Bolton Street, Dublin 1, Ireland.

Phone: 087 966 5866

E-mail: pearl.orourke@dit.ie

Appendix 6: Delphi study results stimulating design solution conceptualisation

(The results of Question 1 are provided here as an example, that is 'Issues that relate to prevalent parts of an ATCID which malfunction'.)

Issue	Solutions
Cables wear/break/twist/fray/tear	Take out cables (wireless), Use robust insulating materials, Make cables very rigid/ flexible, Make connections very rigid/flexible, Eliminate option of excess cable (retractable, wind/tuck into something...like Apple battery), Have purposeful breaking point which can reconnect (for varying lengths)
USB and other ports break	Articulating joints, Very rigid/flexible, Magnetic USB plug (like Apple)/magnetic 'glove', Make USB flush along port
Internal electrical switch contacts fail	Take out electrical switch contacts, Use robust casing / contacts, Protect with casing
Sensors fail	Take out sensors, Use robust sensors
Movement of ATCID becomes restricted due to dirt build up	Eliminate areas where dirt can accumulate, Make decontamination easy (dishwasher), Reduce parts, Make disassembly easy, Use easy to clean materials/forms
Keys/buttons lift away from ATCID	Reduce number of parts, Provide membrane cover, Use robust connections
Lightweight switches are continuously accidentally activated and break	Calibrate for forces used in order to pick correct switch for given force, Use robust switches
Connections between the cable and the ATCID wear	Use robust connection, Make connection very rigid/flexible, Use articulating connection, Secure connection flush with static object
Touch screens stop being responsive	Protect touch screens with cover, Eliminate touchscreen, Use different type of touch panel (more robust)
Monitors break/crack	Eliminate monitors, Protect monitors
Devices have calibration problems or are difficult to calibrate	Eliminate need to calibrate, Make callibration easy, Make callibration recordable/repeatable
Conflicts exist between the computer and ATCID driver	Use plug and play drivers, Make updates accessible online

Software becomes corrupted (e.g. curser on screen moves without deflection of joystick)	Simplify software, Debounce switch signals using pull down/ pull up resistors, Allow for recalibration/remind user to recalibration of devices
Small parts get lost (e.g. clamping screws)	Eliminate small parts, Use snap fits Use screw on parts (whole part screws on rather than is attached with many small screws, Use 'childlock' type screw on parts
Plugs break	Eliminate plugs, Use robust plugs, Use easily replaceable plugs
Unexplained/unclear reasons cause device failure	Provide FAQs, Use robust casing Layers of components 'slide' into robust casing.
Batteries fail	Eliminate batteries Use solar power Use hybrid power
Mounts become damaged	Eliminate mounts Make mounts very rigid/flexible
Mounts loosen	Eliminate mounts Use connections that will not loosen Standardise connection sizes
Switches stick in a closed/open position	Use unsticky materials (teflon) Eliminate areas where dirt could build up causing stickiness Use materials that will not change over time (springs/foams?)
De-soldered joints break	Do not use solder Use snap fits etc Reduce number of parts Use robust manufacturing methods
Joysticks becomes loose	Reduce number of parts Use material/fixings that will not change over time

Appendix 7: Delphi Study Results – categorised to determine the criteria for evaluating and selecting product platform technology

Issues relating to prevalent parts of an ATCID which malfunction	CATEGORY
1. Cables wear, break, twist, fray or tear.	Cables /batteries
2. Connections between the cable and the ATCID wear.	Cables /batteries
3. Touch screens stop being responsive.	Robustness
4. Devices have calibration problems or are difficult to calibrate.	Software
5. Conflicts exist between the computer and ATCID driver.	Software
6. Small parts get lost, e.g. clamping screws.	Customisable ATCID (DFMA principles)
7. Mounts loosen.	Positioning and mounts
8. USB and other ports break.	Robustness
9. Internal electrical switch contacts fail.	Robustness
10. Sensors fail.	Robustness
11. Movement of ATCID becomes restricted due to dirt build up.	Cleaning and decontamination
12. Keys/buttons lift away from ATCID.	Robustness
13. Lightweight switches are continuously accidentally activated and break.	Customisable sensitivity / robustness

Issues relating to the reasons ATCIDs malfunction or fail	
1. ATCID falls/is knocked or banged.	Robustness
2. Inappropriate, rough and over-use of device.	Robustness
3. Cables get caught or are pulled roughly from ports.	Cables /batteries
4. ATCID undergoes general wear and tear.	Robustness
5. ATCID is poorly maintained.	Robustness + Cleaning and decontamination
6. Battery conditioning practice is poor.	Cables /batteries
7. Weak joints connect cables to device.	Robustness
8. Battery life or charge is insufficient.	Cables /batteries
9. Batteries fail.	Cables /batteries
10. Software updates conflict with device drivers.	Software
11. Poorly routed cables are exposed to damage.	Cables /batteries
12. Dirt, spills and dust contaminate the ATCID.	Cleaning and decontamination
13. Movements of client cause mounts to loosen.	Robustness
14. ATCID is poorly cared for when not in use, e.g. during transport.	Robustness

Issues relating to the characteristics of a service-user associated with selecting an ATCID	
1. Range of motion of the anatomy which controls the ATCID	Customisable (tailored) size
2. Spasticity/muscle tone	Customisable (tailored) sensitivity
3. Tremor	Customisable (tailored) sensitivity

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4.	Control of movement, i.e. ability to make precise movements	Customisable (tailored) sensitivity
5.	Ability to repeat a movement without strain	Customisable (tailored) sensitivity / size
6.	Motivation and level of interest	Customisable (tailored) ATCID
7.	Posture and client's position	Customisable (tailored) ATCID + Positioning and Mounts
8.	Wrist and finger function, i.e. dexterity, sensory perception, proprioception	Customisable (tailored) sensitivity / size
9.	Physical stamina	Customisable (tailored) sensitivity / size
10.	Cognitive ability	Customisable (tailored) complexity
11.	Condition progression, i.e. improving or degenerating	Customisable (tailored) complexity
12.	Activity to be facilitated by the ATCID	Customisable (tailored) modality
13.	Environment the ATCID is used in	Robustness + Cleaning and decontamination
14.	Presence of pain	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
15.	Concentration and attention	Customisable (tailored) complexity
16.	Grasp	Customisable (tailored) size
17.	Speed of movement	Customisable (tailored) sensitivity
18.	Muscle strength	Customisable (tailored) sensitivity
19.	Access to technical support	Service package
20.	Funding constraints	Cost
21.	Vision	Customisable (tailored) size and aesthetics
22.	Service user's level of independence	Customisable (tailored) complexity
23.	Service user's social network and their familiarity with the technology	Service Package + Customisable (tailored) complexity
24.	Type of wheelchair being used, if one is used	Software Customisable (tailored) complexity
25.	What the ATCID will be mounted on and the requirements for clamps and mounts.	Positioning and Mounts

Issues relating to service-user needs regarding ATCID use and training		
1.	Correct positioning and mounting of the ATCID	Positioning and Mounts
2.	Access to ATCIDs for trial period	Service package
3.	Instilling the motivation to practice, explore and use the technology	Service package + Customisable (tailored) ATCID
4.	Simple, written instructions for ATCID set-up and use	Service package
5.	Pictorial instructions for ATCID set-up and use	Service package
6.	Maintenance and care instructions	Service package
7.	Information on how to adapt the ATCID for the service user's changing needs	Service package
8.	Contact details of supplier and technical support	Service package
9.	Instilling confidence in the service-user	Service package + Customisable (tailored) ATCID
10.	Involvement of the service user's social network in training procedures, e.g. family/carers/teachers	Service package
11.	Reviews of equipment	Service package
12.	Basic IT training	Service package
13.	Provision of demonstrations	Service package
14.	List of frequently asked questions for	Service package

	troubleshooting	
15.	Recommendations for use in educational settings (for school staff and boards)	Service package
16.	Introduction of the service-user to clients who have experience of the ATCID	Service package
17.	Specific training around a task or feature	Service package
18.	Regular meetings with the service-user	Service package

Issues relating to desirable traits of an ATCID

1.	A good match between service-user's goals and the ATCID solution	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
2.	Comfortable to use and does not cause strain	Customisable (tailored) sensitivity / size / complexity / modality + Positioning and Mounts
3.	Does not impede movement of service-user	Customisable (tailored) size + Positioning and Mounts
4.	Adaptable to service-user's specific needs	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
5.	User-friendly	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
6.	Reliable	Robustness
7.	Easy to set up and dismantle	Customisable ATCID (DFMA principles)
8.	Long battery life	Cables /batteries
9.	Easily rechargeable battery	Cables /batteries
10.	Easy to operate	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
11.	Re-adjustable	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
12.	Attractive aesthetics	Customisable (tailored) aesthetics (+overall non-medical device styling)
13.	Sensitivity	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
14.	Design is based on mainstream devices	Customisable (tailored) aesthetics (+overall non-medical device styling)
15.	Social acceptability, i.e. a design which doesn't make the user stand out	Customisable (tailored) aesthetics (+overall non-medical device styling)
16.	Versatility/flexibility/capability of the ATCID to be multi-functional	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
17.	ATCID is intuitive to use, e.g. software has clear menus)	Software
18.	Comes with clear instructions	Service package
19.	Easy to maintain	Robustness + Cleaning and decontamination
20.	Durable/robust/sturdy	Robustness
21.	Quick to turn on	Software
22.	Easy to position	Positioning and Mounts
23.	Has a universal connection, i.e. USB	All ATCIDS
24.	Appropriate weight	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
25.	Quick to install	Software
26.	Compatible with different operating systems	Software
27.	Up-to-date	Software
28.	ATCID provision is paired with access to local	Service package

provides who can supply training, maintenance and repairs	
29. Appropriate size	Customisable (tailored) size
30. Appropriate tactile characteristics	Customisable (tailored) sensitivity/ aesthetics
31. Low cost	Cost
32. Portable	Cables /batteries
33. Wireless operation	Cables /batteries

Issues relating to frustrations associated with ATCIDs		
1.	The high cost of ATCIDs and access to funding for purchasing	Cost
2.	Positioning in multi-care environment, i.e. clamps and mounts need individual adjustment every time; this is difficult to replicate	Positioning and Mounts
3.	Limited access to customer support/technical assistance/product manufacturers	Robustness + Cleaning and decontamination
4.	Cost of repair and short warranties without additional payment	Cost
5.	Discrepancy of funding throughout the country	Cost
6.	Time needed to repair devices, leaving service-users without ATCID	Robustness + service package
7.	Devices are not plug-and-play, e.g. drivers need to be loaded from CDs	Software
8.	The system is not easily adaptable for suiting exact service-user needs	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
9.	The ATCID needs to be modified for changing service-user needs	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics
10.	ATCID positioning	Positioning and Mounts
11.	Lack of follow through by families and schools	Service package
12.	Time needed to assess and train service-user	Service package
13.	Products are specialist or niche	Customisable (tailored) sensitivity / size / complexity / modality / aesthetics

Appendix 8: Code for Arduino programme for 4-switch configuration

```
int y1 = A0;
int x2 = A1;
int y2 = A2;
int x1 = A3;
void setup() {
  Serial.begin(9600);
}
int readX(){
 pinMode(y1, INPUT);
 pinMode(x2, OUTPUT);
 pinMode(y2, INPUT);
 pinMode(x1, OUTPUT);
 digitalWrite(x2, LOW);
 digitalWrite(x1, HIGH);
 delay(5); //pause to allow lines to power up
 return analogRead(y1);
}
int readY(){
 pinMode(y1, OUTPUT);
 pinMode(x2, INPUT);
 pinMode(y2, OUTPUT);
 pinMode(x1, INPUT);
 digitalWrite(y1, LOW);
 digitalWrite(y2, HIGH);
 delay(5); //pause to allow lines to power up
 return analogRead(x2);
}
void loop()
{
 int x = readX();
 int y = readY();
 if( x < 600 & x > 490 & y < 600 & y > 400)
  { Serial.println('Left Top');
 }
  if( x < 600 & x > 490 & y < 400)
  { Serial.println('Left Bottom');
 }
  if( x < 490 & y < 600 & y > 400)
  { Serial.println('Right Top');
 }
  if( x < 490 & y < 400)
  { Serial.println('Right Bottom');
  }
  delay(200);
}
```

Publications, Presentations and Awards

Journal Publications

O'Rourke, P., Ekins, R., Timmins, B., Timmins, F., Coyle, E. and Long, S. (2013) Crucial design issues for special access technology; a Delphi study, Disability and Rehabilitation: Assistive Technology.

Timmins, F., Timmins, B., **O'Rourke, P.,** Long, S., Ekins, R., & Coyle, E. (2014). Interdisciplinary doctorial supervision: Lessons for nurse education and practice. Nurse education today, 34(11), 1338-1342.

Award

National Winner of the Institute of Engineering and Technology (IET) Present Around the World Award (2013)

Conference Proceedings

Chance, S.M., & **O'Rourke, P.** (2014) Promoting 'Material Ethics' in the Digital Age of Engineering and Product Design. *E&PDE 2014, the 16th International Conference on Engineering and Product Design Education, Twente, The Netherlands.*

O'Rourke, P., Ekins, R., Timmins, B., Timmins, F., Coyle, E. and Long, S. (2013) Devising Participatory Design Workshops for Individuals with Diverse Disabilities, AAATE conference, Portugal.

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approach. In *DS 76: Proceedings of E&PDE 2013, the 15th International Conference on Engineering and Product Design Education, Dublin, Ireland, 05-06.09. 2013*.

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Presentations

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O'Rourke, P., Ekins, R., Timmins, B., Timmins, F., Coyle, E. and Long, S. (2011) The generation of a design method for customisable assistive technology, Enable Ireland National AT Seminar, 29th November 2011, Enable Ireland, Sandyford, Dublin.

O'Rourke, P., Timmins, B., Long, S., Ekins, R. Coyle, E. and Timmins, F. (2011) The generation of an assistive technology design framework through the development of a computer input device. Students learning with Communities Summer School, Thursday 23rd June 2011, Dublin Institute of Technology, Cathal Brugha Street, Dublin .

O'Rourke, P., Timmins, B., Long, S., Coyle, E. and Timmins, F. (2011) Maximising the role of the service user in the context of assistive technology hardware R&D. Irish Posture and Mobility Network (IPMN) Seminar, Monday 24th January 2011, Engineers Ireland, 2 Clyde Road, Ballsbridge, Dublin 4.