Chapter 2
Developing an Interactive TV for the Elderly and Impaired: An Inclusive Design Strategy

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Abstract Combining the development of multimodal technology with research exposes the weaknesses of conventional approaches when the target users are elderly or impaired. This chapter examines the antecedents, implementation and evaluation of a User Centered approach to the design of interactive technology such as iDTV and mobile devices that takes into account the variability and extraordinary capabilities of users and how to design for them. It describes the strengths and weaknesses of the new Inclusive Interaction Design approach and compares a usage case with another separate project with the same goals.

2.1 Why a User Centered Design Strategy? An Overview for Researchers or Practitioners

Why is it necessary to say more about User Centred Design in the context of inclusion? The answer is that Inclusive design strategy accommodates a greater range of users than normative usability or extreme accessibility approaches. Designing for this mid-range of capabilities extends design to mainstream groups who have been limited by the digital divide.

Inclusion refers to the quantitative relationship between the demand made by design features and the capability ranges of users who may be excluded from use of the product because of those features. By 2020, almost half the adult population in the UK will be over 50, with the over 1980s being the most rapidly growing sector. These "inclusive" populations contain a great variation in sensory, cognitive

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and physical user capabilities, particularly when non-age related impairments are taken into account. Establishing the requirement of end users is intrinsically linked to the User centered Design process. In particular, a requirements specification is an important part of defining and planning the variables to be varied and measured and the technology use cases to be addressed during the interactions during user trials. This chapter looks at the background and motivation for this approach, some methods and methodology and uses the GUIDE iDTV project (www.guide-project.eu) as a case study of operationalising the approach. Finally, a comparison is made with a related EU project, spring-boarding a discussion of key issues raised and future scope.

2.1.1 Relation to Inclusive Design

Rather than consider impairment as synonymous with a disability or medical condition, the casting of impairment as a set of interrelated functional capabilities is an approach that has been introduced in the context of designing information technology. The idea here is that dysfunction due to ageing and other causes can be divided, as part of an inclusive user-centred design process, into various qualitative types of capability and the quantitative ranges for them that can be found in the population [28].

Research in the field of Inclusive design has developed the theory and practice of calculation of exclusion for product design. This is based on the fundamental concept of the capability-demand relationship and aims to quantify the number of people in the disabled population who would be excluded from use of a product as a result of the functional demand made by the product interface interacting with their function capabilities [35, 47, 48]. Inclusive Design aims to make products and services accessible to the widest range of users possible irrespective of impairment, age or capability. To do this, a substantial research effort has been directed towards developing the underlying theory and practice of design analysis in order to develop and provide tools and guidance to designers and those commissioning designs that they can use to improve the inclusion of a resulting product [6, 22]. This approach may be contrasted with that of Universal Design or "Design for All" as a main distinctive feature is that it does not advocate producing single products that satisfy a range of impairments. Instead it proposes widening the scope of designs deliberately to include more people with marginal capabilities.

2.1.2 Relation to Accessibility

Accessibility interventions frequently address specific well established disabilities in society. Only in recent years has this included age related impairments. Not all functional disability results from ageing. Some common examples of non age-related impairment include specific conditions such as stroke and head injury, which may affect any or all of perception, memory and movement, depending on the location and extent of damage to the brain.

Other conditions are generally associated with movement impairment. For example, Parkinson's disease is a progressive loss of motor control causing weakness, tremor and physical atrophy; Cerebral palsy is a non-progressive condition causing effects such as spasms, dynamic coordination difficulties and language and speech production impairment. Of course, many other conditions such as Down's syndrome and multiple sclerosis (MS) may affect cognitive capability either directly, through language learning and use, or indirectly through its effects on hearing, speech production and writing.

Of all the sources of variations discussed, many differentially affect normal population ranges of capability. They may be rapidly changing and vary in intensity both within and between individuals, leading to a demanding design environment that requires close attention to conflicting user requirements and a better understanding of user capability. Again, this confirms that interaction design for future generations of products must be inclusive. The relationship between the user's capabilities and their environment has long been considered in the context of assistive technology [30]. Newell [30], for example, considers the equivalence of ordinary interactions impaired by extreme situations and impaired individuals in ordinary situations. Design should focus on the extra-ordinary or impaired first, accommodating mainstream design in the process [31].

2.1.3 Relation to Usability

Many products today are laden with a host of features which for the majority of users remain unused and often obscure the use of the simple features of use for which the product was devised. For example, since the target cognitive capabilities anticipated by the designers are often similar to their own demographic and largely not affected by age-related cognitive impairment, the cognitive demands made by such products are frequently high.

Since designers often anticipate that the cognitive capabilities of users will be similar to their own demographic and largely not affected by age-related cognitive impairment, and while the experimental literature seems to support this, the cognitive demand made by products is frequently high [21, 22]. Usability standards and methods [26] use statistical distribution assumptions to cater for the assumed "normal population". However, an alternative analysis of inclusive populations provided by Newell [28] discusses the normal distribution formed by the proportion of population with differing degrees of functionality [28]. Rehabilitation engineering, for a start, specifically works with extremely low ranges of functionality; while accessibility design involves accessibility innovations offered as options on standard design and cater for low functionality and low to medium functionality groups. Inclusive design is identified as addressing the mainstream and extending the scope of design to accommodate greater numbers of lower functionality users. The standard normative approach to usability prevalent at the present and ubiquitous in both standards and pedagogical material is therefore likely to be inadequate for informing design in the future, where wider capability ranges are anticipated, and would certainly be inadequate for informing inclusive design of the GUIDE iDTV user interfaces.

2.1.4 Background to Inclusive Design and Antecedent Work

Inclusive Design aims to make products and services accessible to the widest range of users possible irrespective of impairment, age or capability. To do this, a substantial research effort has been directed towards developing the underlying theory and practice of design analysis in order to develop and provide tools and guidance to designers that they can use to improve the inclusion of a resulting product [6]. This research has principally been motivated by changes in national and International demographics evident in recent years leading to increasing numbers of older and reduced numbers of younger product users. The problems that arise from this include increased prevalence of impairment, which has led to legislative requirements for greater inclusion at home, at leisure and in the workplace. For the purpose of the GUIDE project, with intended end users encompassing the elderly and the mild to moderate impairments, this is an advantageous approach.

2.1.5 Brief History of Inclusion Research

Inclusive design is a user-centered approach that examines designed product features with particular attention to the functional demands they make on the perceptual, thinking and physical capabilities of diverse users, particularly those with impairments and ageing. It is known, for example, that cognitive capabilities such as verbal and visuospatial IQ show gradually decreasing performance with aging. Attending to goal-relevant, task features and inhibiting irrelevant ones is important in product interaction and this is known to be affected by ageing. Attentional resources may also be reduced by ageing, such that more mistakes are made during divided attention, dual task situations [29, 32, 36, 39, 41].

The elements of the population that should be considered by research in inclusive design were addressed by Keates and Clarkson [18] who identified the loci of sub-populations within a theoretical space bounded by the severity of perceptual, cognitive and movement capability dimensions [18]. They illustrated the shortfalls apparent in usability approaches to design that propose normative methods that do not take into account sufficient variability across the population and hence cannot give rise to designs that are accessible and also cater for functional impairments at differing levels [26]. Keates et al. identified three sub-populations:

1. Special purpose design that caters for specialised products for specific impairment needs;
2. Modular or customisable designs where one product or multiple products can be configured to user needs and preferences; and
3. User aware design that aims to extend the design of mainstream products to accommodate as many users as possible.

Another related design approach that embraces social context, is that of universal design. This design approach advocates designing specific products so that they are usable for the widest possible range of capabilities. For example, buildings should be suitable for all possible end users regardless of functional capabilities, age, or social contexts [34]. Although illustrated by numerous architectural examples, this approach falls short of the detailed quantitative analysis required for interaction design. The rationale and underlying theory connecting the principles is not apparent. A further category is that of ordinary and extraordinary design that aims to improve design for older, impaired users of low functionality while at the same time enhancing design for the mainstream and ordinary users in extreme environments [29]. On this basis, design should focus on the extraordinary or impaired first, accommodating mainstream design in the process [31]. This issue has been pursued further in the context of understanding the properties of user populations from disability survey data [47, 48].

2.1.6 Why Do Trials or Experiments?

In Inclusive design, this sort of analytic approach to the evaluation of designs is intended to mitigate the need for extensive observational trials or experiments with products in use by selected samples of people. Instead, data about the prevalence of capability is used holistically in conjunction with a categorisation and task analysis of product properties and features, in order to quantify the numbers of users and sub-populations of users, who can use a design without mental or physical failure or difficulty. Such an inclusion task analysis requires:

1. A data set of the distribution of capability in the population, and
2. Methods for characterising and measuring the products' demands in different functional areas; sensory, cognitive and physical [35].

However, it is also clear that it must also take into account situational and cultural factors such as the social, physical and economic context of use. Importantly, this latter consideration is a novel research development related to design for all and universal design [43] that focuses on the exclusion of individuals from using products as a result of difficulties of use or failure of interaction resulting from the product's demands exceeding users' capability. The quantification of this capability-demand relationship is therefore referred to as a calculation of product inclusion.

Table 2.1 Gender balance for each of the age ranges and populations included for all impairments

Overall impairments (UK 1997)	Age range	Male (Pop size) [Exclusion]	Female (Pop size) [Exclusion]	Both (Pop size) [Exclusion]
	49–60	21.84 % [3.91 m]	19.51 % [3.97 m]	20.67 % [7.88 m]
	60–90	42.53 % [4.65 m]	41.39 % [5.89 m]	41.89 % [10.54 m]

2.1.7 Sampling Strategies: What Is a User?

In order to manifest this Inclusive design approach into the design and technical development of an interactive TV for older people such as the GUIDE system the GUIDE project pursued a user-centred design approach at the level of end-user interaction. A separate analysis was carried out for Developer interactions, assuming developers as users. This is described in GUIDE documentation. End user requirements for ageing and for those people with impairments were collected using a mixed methods approach based on the advantages of triangulation of data sources [9, 20]. In essence, this approach does not commit to a single source of data or a single data collection approach. The studies employed, contributed to the empirical triangulated approach that employed a range of methods that were capable of independent results. This allowed findings to be cross-checked against each other, helped to balance the advantages and disadvantages of the individual methods, and obtained a spectrum of views at different levels of objectivity [9, 20]. In the case of GUIDE, the framing of the project as a design problem for a set-top box prototype constrained the triangulation and assists it by directing the focus of comparison on the design of the final interactions between user, system, technology, and usage context.

Establishing the requirements of end users is intrinsically linked to the User Centred Design (UCD) process. In particular, requirements specification is an important part of defining and planning the variables to be varied and measured and the technology usage cases to be addressed during the interactions in the user trials.

For the purpose of devising a working sampling strategy for early pilot trials it was necessary to adopt a stratified sampling strategy, screening participants who took part in the GUIDE user Survey and allocating them to age and capability ranges of interest and that were required for analysis. GUIDE initially grouped participants into groups with respect to the severity of their perceptual, cognitive and motor capabilities [See section 3.5.4 of GUIDE D2.1, The screening criteria are exemplified for Gender in Table 10-3].

The relative proportions of participants in sampling categories were initially decided by opportunistic sampling but this process was informed by the Inclusion and disability analysis [Section 4.3.3, D2.1] based on the exclusion calculations of proportion of an exemplar EU population (UK GB) who might be expected to fall into the categories of high, medium and low impairment, and who consider themselves disabled in some capability area (Table 2.1).

For example, the gender balance for the population age ranges and proportion of individuals experiencing some impairment for each gender were also calculated using the exclusion estimation form the UK inclusive design exclusion calculator [47, 48]. Because the sampling strategy of older and impaired users in the age groups of interest was, by necessity opportunistic, these calculations were used as a broad indication of an estimate of the relative sizes of the samples required in each category. This meant, for example, that roughly twice as many individual would be sampled in the older age group compared with the younger age group and that the sample should be biased towards larger numbers of female rather than male participants. In the actual sampling these proportions were only partially achieved, the predominant population being older female, although the age group sampling was partially successful. The extent which this reflects the sample specific to Northern Spain is unknown but comparisons with other populations in the UK and Germany were carried out in the analysis of year 2 user trials. However, the resulting distribution was at this point only an approximation to the ideal. Although the distribution is biased to the older 60–90 age group, within that the impairments are concentrated on the low impairment groups with less in the medium and high impairment groups. This is the result of the opportunistic sampling but fortunately is broadly consistent with the proportions suggested by the estimates and also presents some face validity in that this is the distribution one would expect from daily experience of working with older populations. In the UK there are 0.76 Males to each female in the 65+ age group [11]. There was a strong bias towards female rather than male participants and this exceeds that which was estimated. The smaller number of participants in the 40–60 age groups reflects the lower generally lower frequencies of impairments in this age range. The concentration of high impairments in the age range may reflect small sample bias. The nature and definition of impairments however, is a matter of definition.

2.1.8 Models of Disability

Non-age-related impairment is frequently associated with disability, although a number of models of the notion of disability exist and different sectors, such as engineering or medicine may disagree as to which are more useful and appropriate. For example, the World Health Organization's International Classification of Impairment, Disability and Handicap [46], model provides a standardised language, but its framework is medical and categorises disability as the functional performance consequences of impairment, which in turn is caused by loss or abnormality of bodily structure or function. This categorisation is widely used in gerontology and assistive technology. The model mixes medical conditions, terminology and philosophy with objective performance. The revised ICIDH2 avoids some of the original negative connotations by terminological improvements, but the aim remains to support caregivers rather than designers [46]. Nevertheless, the ICIDH irretrievably confounds medical conditions, jargon and philosophy, with objective performance. Petrie, for example, notes this weakness and proposes a purely functionally based classification of disability as a basis for the design of ICT interfaces [36]. In contrast, socially-motivated models emphasise the role of society in classifying people as disabled and focus on its obligations in providing the resources and interventions to prevent exclusion of individuals from full participation in society [33]. A hybrid model, combining the biological and social models, emphasises the complexity of impairment in functional and social terms, and focuses on its variability over time and within the individual. This model of disability encompasses both the interactions between multiple functional impairments and the consequent effects when these in turn interact with the detailed social effects of impairment, such as lack of empathy or negative attitudes. This model is adopted by GUIDE and embraces social psychology, social-economic, psychiatric and statistical considerations, as well as being consistent with developing fields, such as well-being [2].

2.1.9 Development Versus Research

The GUIDE project requires the simultaneous development of a software system capable of running on a set-top box, and also the carrying out of User centered design of the interface features and designed adaptions. This is necessary to support the end-user: the elderly and mildly impaired iDTV user with appropriate and effective adaptions compensating for perceptual, cognitive and physical impairments. Both forms of development are required for successful software outcomes; however the effectiveness of the GUIDE interventions requires both processes concurrently. This leads to a design environment based on overlapping sets of requirements. Development is usually alternated in an iterative cycle with evaluation. Evaluation can be cast as formative or summative evaluation [42]. In the former evaluation of change proceeds during development, while in the latter an evaluation is made at the end of a development. For example, good software development uses user trials in a formative way to evaluate new development and modify the design iteratively as the design proceeds towards completion. On the other hand, user centered design requires intervals of stringent and summative experimental examinations of the proposed adaptions for their effectiveness at improving interaction with representative samples of impaired populations. These two processes are not necessarily conflicting but require different levels of standardisation and fidelity of conditions. Current practice in engineering software design is appropriate for development and formative evaluation but frequently lacks rigor and experimental power. In particular, usability approaches are inappropriate for UCD of elderly and impaired populations who may possess higher incidences and variability of impairments and this necessitates accurate stratified sampling for user trials. Conversely, high fidelity prototyping is required for effective testing of elderly peoples' responses to proposed adaptions, necessitating advanced development techniques.

2.1.10 Some Problems with Normative Methods and Usability

The goal of an inclusive design "exclusion" analysis is that a proposed product design is subjected to capability-demand analysis in order to identify whether it can be used by people with specific quantified impairments. In order to develop system and interface designs that improve general human performance it will also be necessary to go outside of the boundaries of "normative" human capability and deal with extra-ordinary human capability in ordinary settings. To date, research underlying CTA approaches has focused on ordinary users in extra-ordinary situations of workload or physical context, such as air traffic control, piloting modern aircraft, or medical diagnosis. However, as pointed out by Newell [30], individuals with capability impairments may be faced with the need to interact with designs intended for normal capabilities in everyday situations whilst possessing variable and unusual rages of capability [30, 31]. Hence, the user of a product may be excluded or disabled from effective use of it by poor design of its interface features, as for example when a key-pad is unusable in a low lighting situation.

On this basis, a novel and key requirement criterion of the framework GUIDE aims to develop is that it should be capable of accommodating an extra-ordinary range of capabilities, such as those presented by older and disabled people [30, 31]. However, these capabilities and their patterns of occurrence are not well understood, particularly for the engineering and technical backgrounds, so we turn next to summarise them for developers and non-practitioners.

2.1.11 The Elderly User

Age related impairments are associated with a variety of causes and conditions. For example, between the ages of 45 and 75 there may well be significant loss of static and dynamic visual acuity and contrast sensitivity, colour vision, focusing and adaptation to dark. Hearing loss increases with age, initially in the high, and later in the high to middle frequency ranges. Initial mild to moderate losses of strength and aerobic capability often progresses to slowing of movement and stiffness due to conditions such as arthritis. Movement and coordination are affected by ageing, particularly in the accuracy and speed of the dexterous movements required by mobile products and user interfaces. There are reductions of taste, smell and touch, and general health may be affected as a result of increased frequency of impairing chronic conditions such as hypertension, dementia and arthritis [7]. With respect to the interaction of product users with designed features, a number of mental or cognitive age-related variations have been clearly identified in the literature. There is a general slowing of cognition and response times. Attentional and split attention capability is reduced and automated responses may be slow to learn and more difficult to suppress. On the other hand, users maintain well-learned skills and abilities such as reasoning, well into old age [13]. This form of memory is stored for the long term and corresponds to so-called crystallized intelligence, whereas the immediate perceptual and instantaneous reasoning capability, identified as fluid intelligence, is more impaired with increasing age [29]. This is particularly true of memory for procedures and episodes or events but not for semantic memory regarding the meaning of objects. Fluid intelligence is strongly related to the functions and capacity of working memory and its related processes such as executive function, which are thought to simultaneously retrieve, hold and use short-term information during an interaction. These capabilities are likely to be heavily involved during novel or unfamiliar tasks, such as the first use of interactive products like GUIDE IDTV. Pre-dementia impairment is also distinguishable in itself and is compatible with normal ageing, identified as Age-related Memory Impairment (AAMI). Some specific conditions that are strongly associated with cognitive ageing are dementia and Alzheimer's disease. Although these conditions are increasingly prevalent with age, they also involve physical changes in brain structure than can affect perception, memory and movement. Dementia and Alzheimer's are associated with general degradation of short-term memory (STM), particularly memory for personal experience. Long-term memories may be unaffected but the ability to retrieve these and deal with them in the short term is impaired, particularly when a structured interaction such as a dialogue is required. Dementia also affects verbal and visual spatial abilities, such as the perception of coherence in pictorial layouts and icons, or in the appreciation of metaphorical meanings. The understanding and production of speech is often impaired through specific aphasias [5, 13, 29].

While acknowledging that individuals differ in their cognitive profile of capabilities, and despite considerable intra-personal and inter-personal variability, the general trend is for increasing impairment and increasing variation over age, with some notable exceptions relating to crystallized general intelligence [5, 29, 36, 39]. The GUIDE requirements analysis was configured for cognitive impairment as well as perceptual and physical impairment with data collected during rigorous trials with cognitively impaired users on standardised cognitive tests.

2.1.12 Disability and Mild to Moderate Impairment

Not all functional disability results from ageing. Some common examples of non age-related impairment include specific conditions such as stroke and head injury, which may affect any or all of perception, memory and movement, depending on the location and extent of damage to the brain. This impairment would impact such users' interactions with the GUIDE system.

Other conditions are generally associated with movement impairment and, for example might affect peoples' ability to hold and point a handheld controller or to gesture and point using GUIDE's Visual Human Sensing input mechanism. For example, Parkinson's disease is a progressive loss of motor control causing weakness, tremor and physical atrophy, while cerebral palsy is an early acquired but non-progressive condition resulting from brain damage causing effects such as spasms, dynamic coordination difficulties and language and speech production impairment. Autism and Asperger's Syndrome are associated with impairment in the development of social communications capabilities and interaction skills such as non-verbal communication. In autism, these social dysfunctions are also accompanied by other general effects of reduced cognition, while in Asperger's other functions are unaffected. Problems using GUIDE were anticipated in the case of these impairments through the introduction of an "Avatar" or Virtual human being as an output modality during use. Of course, many other conditions such as Down's syndrome and multiple sclerosis (MS) may affect cognitive capability either directly, through language learning and use, or indirectly through its effects on hearing, speech production and writing.

Of all the variations discussed, many differentially affect normal population ranges of capability. They may be rapidly changing and vary in intensity both within and between individuals, leading to a demanding design environment that requires close attention to conflicting user requirements and a better understanding of user capability. Again, not only does this confirm that interaction design for future generations of ICT products for ageing must be inclusive, but also that, as in the case of GUIDE, the difficulties of specifying requirements for multiple conflicting conditions must be mitigated by a risk reduction strategy. This involved reducing the range and intensity of impairments accommodated by GUIDE and a focus on user data generated by trials with the actual prototype interfaces as they were developed.

2.1.13 Inclusion from an Analytical Functional Perspective

An analytic approach to the evaluation of designs mitigates the need for observational trials with products by relating data about the prevalence of capability ranges in the population with an analysis of the demand made by product properties and features. This enables a quantification of the number of users who can use a specific design. To date, there has been some success in identifying data sets and appropriate impairment and capability models for perception and movement in this novel "inclusive" research context. However, previous attempts to do so for cognitive aspects of product feature interaction have encountered a lack of suitable data and models.

2.1.14 Measuring the Capability-Demand Relationship in Interaction

Inclusive design, as developed by this approach, examines designed product or interface features with particular attention to the functional demands they make on the perceptual, thinking and physical capabilities of diverse users [10, 18, 35, 45].

Other related approaches, for example, use a single comprehensive data set from 100 people containing anthropometric and behavioural data but omit cognitive information. This latter HADRIAN system allows designers to query the data base for numerical and personal information [37] and the SAMMIE development allows the data to be used in a task analysis with trials of fit between virtual human figures and interfaces [38].

Initial research has focused on the only known complete set of data on capability variation for the population publically available through the UK Office of National Statistics [18]. This representative national data was from a UK disability follow-up (DFS) survey of over 7,000 individuals carried out in 1997 and was intended to establish the prevalence and severity of quality of life problems arising from functional impairments [8]. It used a methodology devised for a number of partial surveys of Family resources and disability carried out by the UK Office of Population Censuses and Surveys [12]. The 1996–1997 survey used a self-report scaling approach, where respondents answered question items that were intended to locate their levels of functional impairment on a set of scales that were then used to calculate an overall index of severity of disability. The scales used included specific question items addressing functional capabilities, such as vision, hearing, dexterity, reaching and stretching, locomotion, intellectual function and communication. A number of less relevant scales related to areas such as continence, digestion and scarring were deemed more indirectly related to product interaction. Despite a mismatch between these disability-based scales and the requirements of functional capability analysis, recent research developments have successfully deconstructed this data set enabling derived values to be used in a psychological scaling approach to a product audit procedure. Hence, visual demand can be ascertained by asking designers to estimate the visual demand of the product feature on a visual scale with anchor points describing viewing text of different sizes [47]. Similarly, physical demand may be estimated by making comparison judgments with question items involving picking up pins or lifting objects and walking set distances. These judgments are indexed to the survey items of the original data set to yield estimates of numbers of individuals excluded at a given scale level [48]. In GUIDE these quantitative estimates have been used to estimate proportions of impairment as capability ranges in the older age groups.

However, despite their utility, the DFS survey scale items were compiled from sets of items devised by a chosen set of knowledgeable judges. One weakness of this approach, however, was the poor match of the Intellectual function survey items with cognitive capability. In particular, the survey scales were defined by judges who were practitioners and therapists, and focused on complex everyday tasks requiring intellect, rather than on current theories of cognitive function [24]. Furthermore, the resulting lack of correlation between items and scales and between individual judges led the survey designers to construct a scale that simply summed the numbers of intellectual problems selected form a undifferentiated list. An analysis of the requirements for analytical inclusive design scales carried out by Persad et al. highlighted this weaknesses of the survey scale functional assessment approach and discussed the requirements for improved capability measures [35]. For example, the survey's visual scale gave estimates of the individual's global level of visual functioning along a visual capability dimension. This was done by combining the responses to graded sets of items that addressed particular functions selected by practitioners, such as reading and person recognition. Persad hypothesised that a more accurate approach would be to use objective measures of low-level functional capability, in conjunction with a model relating these low-level capabilities and their combination. This would be used to predict high-level task performances, such as recognising a screen display setting, selecting a button or menu item.

An alternative approach would be to use psychological scaling as a method of obtaining precise estimates of visual and motor functional demand from specific product features. This has been investigated in more recent development of the inclusive design scales in order to quantify sensory and physical functions [48]. However, an further alternative, used in GUIDE core and framework, described in this book, takes a different starting point: namely, that of using accurately collected user data to developing a predictive model in the functional domain. The antecedents of this theoretical approach were outlined by Langdon et al. [22, 23], and are described elsewhere in the light of associated empirical findings.

2.2 User Models vs. Usability

A model can be defined as "a simplified representation of a system or phenomenon with any hypotheses required to describe the system or explain the phenomenon, often mathematically". The concept of modelling is widely used in different disciplines of science and engineering ranging from models of neurons or different brain regions in neurology to construction model in architecture or model of universe in theoretical physics. Modelling human or human systems is widely used in different branches of physiology, psychology and ergonomics. A few of these models are termed as user models when their purpose is to design better consumer products. By definition a user model is a representation of the knowledge and preferences of users [1].

There is therefore a case for the development of frameworks that synthesis theories, models and findings from other fields into integrated approaches. This is instead of local theories that tend to identify contradictory hypotheses in a constrained theoretical context and test for these in a specific experimental domain. The creation of such frameworks fall more naturally to engineering and clinical communities [40] and this is consistent with the trends in computer science of software development. Also, the accompanying hybrid methodologies that are developed combine rigorous observation, quantification and computational modelling, often drawing on techniques from natural observation and qualitative research.

A good example of this general approach is the earlier work of Jacko and Vitense [17] who justify the development of a novel conceptual framework directed towards user profile modelling that takes into account disability [17]. Taking the ability to access information as a fundamental requirement, they assembled a number of elements based on a comprehensive review of existing literature. Using this they then developed two classifications of functional ability and impairment in order to supplement conventional user profiles for the ultimate purpose of constructing a user model for accessible ICT design of handheld and wireless devices. Arguing that designers must have an understanding of impairments and associated functional abilities, the framework describes an approach based on the use, in the first instance, of impairment classification to drive an outline of capability with reference to specific cognitive, perceptual and physical abilities. This is accompanied by a mapping of functional abilities to current technologies with a focus on the cost-benefits analysis of whether specific technologies can benefit impaired users. Finally, they propose that this information is used to enhance conventional individual user profiles that may contain further rich information on needs, skills, preferences and habits and could be used adaptively in a user model. A case study example relates to a common impairment of vision, that of age-related degeneration of the retina. Since central vision loss is common in this case, they identify abilities such as near visual acuity, depth perception, night vision and colour discrimination that are likely to be degraded. A general user profile could be constructed from this information that may then be utilised by a user model. This, in turn, could make assumptions about the effects of degradation of these abilities in order to identify a number of adaptive configurations and styles. These would then impact GUI design variables, such as font size, colours and the use of speech input and output. This rationale is entirely consistent with the HCD development strategy of GUIDE.

However, one issue not completely addressed by this conceptual framework is the variability of pathology, impairment and abilities within the context of the unique individual. The authors proscribe adaption but the means for specifying the nature and configurations of adaption for success at the individual level are unclear. In particular, for example, the complexities of the interaction between perceptual, cognitive and movement cognition are not fully understood, as is exemplified by consideration of how learning takes place during the development of skills with newly experienced interfaces and how this relates to prior experience and performance.

Other researchers have attempted the rigorous modeling of inclusive human performance and tested this by using a detailed quantification of a range of human capabilities. Perhaps the best example is Kondraske's Elemental Resources Model (ERM) of human performance [19]. This is based on a calculation of compatibility by utilising resource-demand constructs such as visual acuity, contrast sensitivity, working memory capacity, force generation and movement capabilities, for a set of basic functions. Over a number of studies, Kondraske explored the relationships between high-level measurements of performance and low-level performance resources such as specific perceptual, cognitive and motor abilities. In conclusion, warning that correlations and regressions cannot capture the complexity of such relationships, he proposed a resource economic system performance model based on the likelihood of limitations in specific resource utilisations and the common non-linear thresholds that resulted from combining the measured variables [19].

The aim of such techniques has been to find the variables that have the highest correlations to higher level constructs. This is to say, which variables are mostly responsible for performance. This is a conventional approach in human factors and ergonomics for creating predictive models. However, its practice requires large enough numbers of cases to achieve statistical significance for multiple regressions [35]. Alternatively, as is described in more detail in Chap. 4, representative samples of specific impairment groups can be tested in capability tasks and the resulting values used to calibrate a user model capable of user simulation using hidden Markov algorithms and perceptual models. Such an approach was developed and implemented in the GUIDE framework as the GUIDE Simulator and User Model. This approach is dependent on validation using the statistical similarity of the model's performance and the originally sampled groups' capability performance.

2.2.1 How User Models Can Help

The GUIDE framework for adaption of its interface to specific users is based on user modelling. This is based on the principal that detailed interaction of demand with variable levels of reduced capability in extra-ordinary interactions [30] may be quantifiable using simplified approaches tested using user modeling techniques such as GOMS and ACT/R. This could give rise to a better understanding of the design principles applicable to designing interfaces for variable cognitive capability.

Models such as ACT-R will be essential to address the effectiveness of the proposed inclusive models for quantification as predictive tools for analytical exclusion auditing of alternative designs for inclusive populations. It is acknowledged that such an approach may not capture unique or idiosyncratic variation in capability due to other aspects of ageing or impairment. For example, as has been already mentioned that Newell et al. [27] argue that it may not be possible for modeling to distinguishing the relative effectiveness of two Augmented communication (AAC) input interfaces [27]. It may not be possible to operationalise all the user's responses during an interaction although modeling can be used to instantiate various alternatives. The value of the quantitative accuracy in cognitive modeling may lie in its generality. This is not conducive to modeling the high variability found in impairment in the wider population but models could be varied to characterise different types of user. Specific or extreme users may require specially structured models and these can be accommodated by the modeling approach. Complex architectures such as ACT-R are capable of modeling errors, parallel processing and ranges and clusters of performance capability [16]. On the other hand, insights from the validation of the modeling process may yield better models of impaired interaction, particularly if cognitive impairment is considered explicitly. It is unclear whether alternative approaches to theorising about individual capability and performance would be more accurate or successful. The unknown or additional unconsidered factors such as specific cognitive impairments, social and emotional factors or communication disorders may affect the ways in which demand from design features can exclude users. These are not predicted by conventional user models [27]. However, in principle, these factors would be made more salient by the qualitative and quantitative mismatch between the model set-up, the specific predictions made and the observed user behaviour during experimental product trials with ageing and impaired users. Insights gained from these mismatches would then be used to develop better models.

The principal difference between conventional user modeling and modeling for inclusive demand is the necessity to deal with extraordinary ranges of perceptual, cognitive and movement capability in the prediction of performance with product interfaces. An important consequence of successful development of the framework and development of interactive software based on the sort of cognitive model intended, will be that developers need not have a detailed understanding of impairment in order to find out where aspects of their designs may exclude users with a certain level of capability. Nor, it is intended, will it be necessary for them to carry out expensive and time-consuming user trials with numerous participants. However, the importance of also relating the model to the knowledge and information that comes from health practitioners, the clinical and therapeutic disciplines, and design practice, cannot be underestimated. These will need to be incorporated into any tools developed using analytical inclusive design. Hence, user information and indexed knowledge, in the form of personas, video and presentation of key design and user capability issues, should be provided in documentation to contextualise the development process. In particular, the importance of variability in capability, within individuals and within the population should be stressed, in order to capture the diversity of older and impaired populations. Information about the social and economic context of interaction should also be available and linked to the adaption analysis. Ultimately, the utility of the framework will be judged by the developers' experimental tests of the effectiveness of inclusion resulting from the system adaptions with users, and levels of user satisfaction.

2.3 Case Study: Interactive Digital TV

The GUIDE project pursued a user-centred design (UCD) approach on the level of end-user interaction. End user requirements for ageing and those people with impairments have been collected using a mixed methods approach based on the advantages of triangulation of data sources [9, 20]. In essence, this approach does not commit to a single source of data or a single data collection approach. Instead data is collected from multiple approaches, for example: literature review, quantitative data analysis of data from forums, user trials, user surveys, and questionnaires, qualitative analysis of observational data from user forums or interviews, video from user trials and usage ethnography. A triangulated approach then seeks to establish the predominant weight of evidence on the basis of agreement or

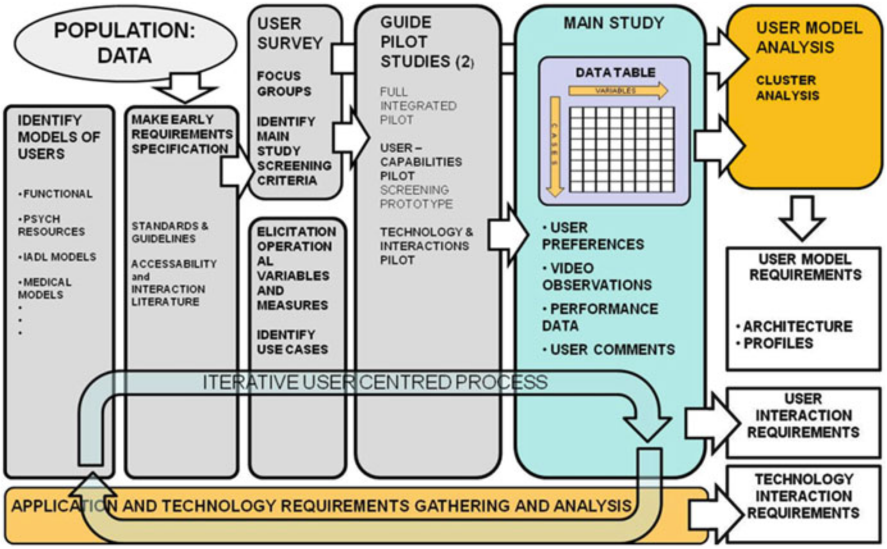

Fig. 2.1 The iterative basis of the User Centered Design process in GUIDE

disagreement between sources knowing the strengths and limitations of the methods and methodologies. The studies employed, contributed to the empirical triangulated approach, employing a range of methods that are capable of independent results. This allowed findings to be cross-checked against each other, helped to balance the advantages and disadvantages of the individual methods, and obtained a spectrum of views at different levels of objectivity [9, 20]. In the case of GUIDE the framing of the project as a design problem constrains the triangulation and assists it by directing the focus of comparison on the design of the final interactions between user, system, technology, and usage context.

An overview of the particular methods used is shown in Fig. 2.1. The sampling strategy employed was opportunistic, and stratified, choosing data sources according to convenience and resource limitations. In particular, much of the work took advantage of empirical and observational trials. However, the combination of multiple sources permits triangulation and thus increased validity and reliability of qualitative findings. In the case of GUIDE, the framing of the project as a design problem constrains the triangulation and assists it by directing the focus of comparison on the design of the final interactions between user, system, technology and usage context. Establishing the requirements of end users is intrinsically linked to the User Centred Design (UCD) process. In particular, requirements specification is an important part of defining and planning the variables to be varied and measured and the technology use cases to be addressed during the interactions in the user trials.

2.3.1 Engineering Design vs. Human Centered Design

There is a great deal of variation between design disciplines, particularly between the main disciplines: engineering, product and communications design. Engineering Design generally adopts a highly prescriptive sequence of stages including requirements analysis, now current in Standards such as those of the DIN or VDI. Modern rapid-prototyping approaches such as that adopted by GUIDE utilize a spiral iterative design stages rather than a waterfall or concurrent stage model. On this basis, stages of requirements gathering, design and development, user data gathering and testing iteratively repeat within the duration of the design process, converging on the final design and prototype. Here, product design means the design of physical, three-dimensional objects or services, while communications design refers to the design of communications content and media. Blackwell and colleagues [4], reporting on a series of multi-disciplinary workshops, emphasized the commonalities between disciplines. However, in doing so, they do not deny that differences exist.

2.3.2 The GUIDE UCD Process

A working plan for design was developed to enable academic, user-representative and technological partners operate together in an integrated way to deliver the right data, models and activities in a well-managed way (Fig. 2.1). The ultimate aim was to create a foundation for actual research and development work by identification of requirements from users as well as application and framework developers. The goal was the elements and components of the GUIDE framework and applications, specifically, the User Model in the form of clustered personas and profiles along with an algorithm and data structure that would support its use in the GUIDE framework. This plan was formulated during the first months of the project and adopted as it integrated iterative cycles of both design and the trials extra-ordinary user capability that were expected. The use of the proposed iDTV interfaces for testing usage cases of interaction and adaptions also conveniently provided test conditions for experimental trials.

2.3.3 User Requirements in Design Decisions at Development – Some Lessons Learnt

The GUIDE development approach is based on the concurrent requirements management process described in more detail in the next chapter. The basis of this is that requirements established during the user centered design process are incorporated into the software design in parallel with the collection of data from users regarding the efficacy of the interventions made in the latest cycle of design development. This process, permits continuing continuous updating of requirements after development cycles, requirements coverage can be seen as a metric for validation for the system development and design effort.

The primary aim of early stages in the process depicted in Fig. 2.1 required literature review and collection of user data from current interaction and accessibility literature. This was accompanied by early paper or PowerPoint based focus groups and small scale low-fidelity studies using elderly users. The main study and subsequent iterations of user trials were based on experimental trials combined with video analysis and retrospective protocol analysis. The initial data was aggregated and used to specify the items for a user survey carried out over the entire GUIDE user sample. The aim was to make accurate objective and subjective measures of perceptual, cognitive and physical capability of each user enabling selection of users based on a stratified sampling strategy. Furthermore this approach allowed comparisons of survey results with trial performance. Details of the survey, results and other HCD outcomes in GUIDE are available on the GUIDE website. The original aim of the process was to create a table of technical requirements for development, however due to the large volume of usability issues generated by the first pilot trials this was annotated with all requirements including those generated by UCD and usability considerations. This then unified the technical and UCD process as it was found to be necessary for developers to consider usability issues such as: speed of system response during controller manipulation and gesture detection, and lack of system feedback. The aim was to ensure programmers would prioritise elderly usability in their continuing development.

Two major issues emerged during the iterations of design and user trial cycles. First, the recruitment and management of older users for trials, especially in a number of different countries (UK. Germany, Spain) required considerably more resources than were specified for software development alone. Secondly, sampling required a stratification of users into groups to represent the proportions of specific impairments. This was managed using an analysis based on a combination of type of impairments and their severity required for a complete sample along with predicted disability levels from Inclusive design data sets. The survey was used as a selection and filtering tool. Significant numbers of users were required leading to strain on resources and time. A parallel difficulty with technical development was the lack of fidelity of the experimental system due to the early stages of development. The Low fidelity of the GUI and interactions used in trials were directly associated with poor usability outcomes in that speed of response was slow and accessibility features were not fully implemented. This reduced the usefulness of the trial results for improving usability and adaption. Because of this, the requirements generated by the UCD process were generally prioritised lower than development as the primary goal was seen as making the system more robust and faster in response in order to satisfy basic usability requirements for older users. Furthermore it was assumed by developers that implementation of adaptions and multimodal channels would solve the interaction problems that elderly and impaired users were experiencing. However, this was not the case, as was confirmed by a strict no-intervention usability study carried out on the system at a later stage. It may therefore be that linking UCD and development process in the manner described in GUIDE (Fig. 2.1) creates both advantages and disadvantages. The main issue may be that developers are generally reliant on validation studies at the end of a development phase rather than iterative evaluation during development. This then decouples usability and accessibility issues from development making it harder to ensure requirements are satisfied.

2.4 HCD and Validation

There is a complex relationship between the level of detail of validation against its generality. Unfortunately this implies that full validation is very often beyond the resource of a project such as GUIDE, as for example, it was attempted to validate the GUIDE system for all European countries. The cost in time and resources increase with increasing levels of validation required: For example, as part of their simulator model development for the GUIDE framework, Cambridge carried out detailed Simulator validation studies of disabled users, performance at specific tasks. Such trials were very costly and time consuming but valuable for predicting specific circumstances through their input into general models [3, 22].

The GUIDE HCD trials attempt to predict the performance of a large number of potential users from a minimal sample. This corresponds to weak generalisation but ensures good design, based on mild and moderately impaired users, with optimal cost. If the results achieved for the anticipated user groups can be validated as good, it will anticipate the results future projects like ICT-PSP which aims to validate technologies already developed with samples about 5,000 users in different European countries.

2.4.1 Guide Specific Requirements

GUIDE aimed to apply iterative user centered design in order to yield a good design representing users' needs, wants and preferences. A realistic goal was a framework implementations that will be generalisable and effective for EU "mild to moderately impaired users", particularly the elderly. Users will require an overall interaction experience that they want, find agreeable and feel is effective. Guide has adopted an inclusive user centered design method to address many of these issues, such as that of representing users' needs and wants, as well as to ensure an iterative improvement of design during the development process. By necessity this required tradeoffs to allow technology development decisions and to make it possible to define the sample of users who may be included. It should also be remembered that GUIDE had incorporated into it a user modelling approach that enables generalization of the frameworks responses beyond the original user validation sets. GUIDE adaption further permits the system to adjust its generality. The accuracy of these approaches is unknown. For example, the model is dependent on the validity of the user modelling process and adaption also is subject to the same constraints.

Because of the resulting uncertainty, in order to measure validity, further techniques are necessary, including: the establishment of Face validity from accessibility system researchers and reviewers as well as developers and end users; the measurement of metrics of user performance taken with, without GUIDE interventions; the qualitative and observational gathering of societal and ecologically valid factors to assess the impact of the system on end-users in their natural home environments or with developers at work. The effectiveness of such validation partially depends on procedures for changing the systems performance in response to metrics that are used. One further way of validating GUIDE's approach and findings would be a comparison between the GUIDE development and HCD process and that of a similar project with the same overall goals. Serendipitously, such a comparison was possible with the EU MyUI project also aimed at developing a self adapting interface based on a completely different user modelling approach [25].

2.5 Comparison with MyUI Project

2.5.1 Evaluation of Adaptive Systems

The GUIDE & MyUI Collaboration on End User Validation: A Joint validation plan document describes the details of joint validation. Van Velsen et al. [44] reviewed 63 experimental studies where adaptive systems were evaluated. Most concerned personal computer applications that were not intended for use by older or impaired populations [44].

With respect to 'personalised systems' and referring to previous researchers findings [14, 15] their criticisms centre on the following specific design implications:

- The weakness of the widespread use of a non-personalised system as a comparison condition
- User bias towards personalised systems
- Experimenter effects (users may guess hypothesis or play "good subject")
- Shortness of experimental trials when measuring the full effect of adaption
- Irrelevance to overall usability
- Lack of Ecological validity of lab-based trials
- Status resulting from use of varying fidelity prototypes
- Pitfalls of using quantitative and data log analysis
- Lack of compatibility of expert review with user data

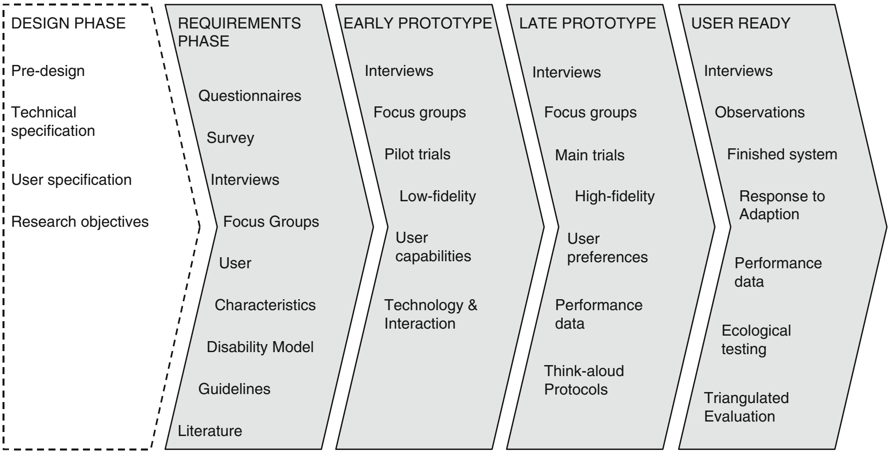

Fig. 2.2 After Van Velsen et al. [44]. Proposed appropriate approaches at differing iterative design stages based on GUIDE and MyUI

On the other hand they report positive assessment for various evaluative methods such as:

- Questionnaires
- Interviews and focus groups
- Thinking aloud protocols (concurrent protocol analysis)
- The use of triangulated data (e.g quantitative measures plus questionnaires plus expert review)

2.5.2 Discussion – Applicability to Research and Development

These considerations of Evaluation and other literature cited above suggests that a triangulated approach [9] combining multiple methods may be most effective and that this should include protocol analysis, observation over long durations in ecologically valid context. Justifications are given for the use of various qualitative measures in a previous section. In addition, as discussed above, the goal of evaluation is not equivalent to that of validation, although many of the conclusions in terms of operationalisation of studies may be the same. The rationale for validation in GUIDE, detailed above, reached similar conclusions to the Van Velsen review and proposes methodological approach based on triangulation (Fig. 2.2).

The testing or validation of adaption for ageing and impairment, rather than personalisation is not subject to the same criticisms as it is possible to conceive of and technically present a non-adapted interface that is not simply a weaker version of the adapted interface. In fact, it may be qualitatively and quantitatively different but there is no reason to suppose that it is somehow 'weaker'. On the contrary, it is assumed in the GUIDE/MyUI adaption approaches that the adapted interface may not look attractive or superior to others than that for which its adaptations apply. This may be due to the enlargement of buttons and inter-button spacing's, the use of colours to combat colour blindness; the use of input adaption to combat physical movement problems, and the modification of sound for hearing issues. Finally, the approach to the suitability of particular methods to design stages is presented in Van Velsen et al. [44] with a simplistic account that does not take into account the complexity of iterative user-centered design. As the GUIDE approach describe above illustrates, evidence from differing stages of prototyping can be fed back to the design process continuously, its value being assessed on the basis of the quality of the data resulting from various levels of prototyping. Different approaches and considerations will be most effective at each progressive design stage. The criteria for the effectiveness of sampling is discussed above in the context of an Inclusive Design approach, further illustrating the difficulties arising from the diversity of capability and the introduction of inaccuracies in obtaining quantitative measures as a result of sampling. This underlines the necessity for triangulated mixture of qualitative, usability and quantitative measures. For this reason GUIDE has employed a number of measures including usability, retrospective protocol analysis and quantitative controlled trials of adaption. It also planned ecologically valid trials of long term use on people's homes.

2.6 Future Scope

A new approach to interaction design is required when the anticipated users are elderly or impaired and the system to be developed is adaptive to these impairments. This new Inclusive Interaction Design should be based on the approaches discussed including yoking of technical requirements to user centered design requirement and the use of a triangulated approach to data collection with trials at different stages and as the design stages proceed through iterations of the design process.

Future research on adaptive interfaces can take advantage of the findings of the GUIDE and MyUI studies in order to maximize the effectiveness of UCD combined with Development trials. This should take the form of triangulated studies aggregating and interpreting data from questionnaires, experimental trials, and retrospective protocol analysis during the design cycle, and evaluating in the light of users' degree of acceptance in daily use in their own homes.

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