Loughborough Design School

An evaluation of the potential order and priority of research methods, design methods and design heuristics within an Assistive Technology new product development process

by

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Abstract

This commentary reflects on a series of published research articles, 1996-2013, that form a PhD thesis by publication. The articles offer evidence of research into best practice relating to Assistive Technology (AT) product design as a specialist section of Industrial Design (ID). The aim of the research has been to provide AT product developers with a methodology that ordered and prioritised the application of proven research methods, design methods and design heuristics; as well as, to highlight the fundamental concepts that underpin the methodology.

This commentary provides a review of the methods applied and discussion of their efficacy within each case study. The series of articles, evaluated at a meta-analysis level in the second part of the commentary, address the following research questions: 1) What is the optimum order and priority of conventional design methods, heuristics and research methods when applied within a new product development process for assistive technology products?, 2) Through a meta-analysis of case studies, are there key aspects that underpin an optimum AT-ID process?

From the review, 61 research methods, design methods and heuristics were defined. An order of methods and heuristics identified some methods that were used throughout all phases of a NPD process that included literature review, benchmarking, mixed methods and participatory research. The methods and heuristics used in all phases highlighted a user-centred approach and the close collaboration with end users and stakeholders. There was also a focus of methods and heuristics around phase 2 of the 5 design process phases defined by Martin and Hannington. The critical review also highlighted key underpinning aspects that helped optimise an Industrial Design approach to ID-AT NPD. These were 1) creating a format for dialogue within the constraints of perception and 2) previous experience and the application of ethically sound protocols for the whole process. Lastly the change of terminology and attitudes of those working the Assistive Technology industry highlighted the need for more research into social acceptance of all aspects of Assistive Technology and the perception of disability from those living with impairment and by UK society as a whole.

Keywords: *Industrial Design, Assistive Technology, Methods, Heuristics*

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Whilst all these individuals have given so much, the one person who has enabled me to complete this commentary is my wife. Julie, this is for you.

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Commentary

1 Introduction

This commentary reflects on a series of published research articles, 1996-2013, that form a PhD thesis by publication. The articles offer evidence of research into best practice relating to Assistive Technology (AT) product design as a specialist section of Industrial Design (ID).

The **aim** of the research has been to provide AT product developers with a methodology that ordered and prioritised the application of proven research methods, design methods and design heuristics; as well as, to highlight the fundamental concepts that underpin the methodology.

The need for such a methodology came from the demands of the market and stakeholders who influenced the purchase of AT products. The demand was for evidence-based design outcomes. This commentary documents the way the author's methodology developed over the period of the published articles to be compatible with the transition from assistive technology equipment into inclusive designed products.

From 1990 onwards the author was aware that healthcare professionals, such as occupational therapists and physiotherapists, practiced evidence-based medicine. They expected the products being designed for an AT product market to provide similar evidence of efficacy. Efficacy in this context is defined as the effectiveness of a design intervention for its defined user population and its cost-viable application. The National Health Service (NHS) and Social Services at that time provided the majority of AT equipment for patients, with little being produced for direct sale to the end user. The medical model of healthcare applied at that time resulted in a predominantly bioengineering-based process being applied to the design of most AT products. (Conway 2008: 27-43) The result was that the physical functionality of AT products was effectively delivered, but little attention was paid to wider issues of social functionality or value.

Over the period in which the collected articles have been published, AT product design had changed to encompass social inclusion through Inclusive Design and Universal Design. This reflected changing attitudes towards people with physical and cognitive impairment within United Kingdom (UK) society. There has also been a socio-economic shift towards user-purchased AT products and a user-centred approach to AT product design. (Clarkson and Coleman 2015: 235-247)

Originally, it was the author's perception that within the Industrial Design profession there was a lack of awareness of research and associated methods to validate AT product design. The author realised that the lack of evidence to validate a new design would limit acceptance by healthcare professionals and market forums, restricting sales.

In 1994, after working for four years as a practicing designer in the field of AT new product development, the author concluded that there were some processes, research and design methods, and heuristics that were more suited to AT product validation. However, research publications of the time lacked clear guidance for the priority or order of their application for designers. The author identified the need to determine an optimum combination of methods for AT product design and specific design methods to enhance critical elements, such as physical interface design and social acceptance. This PhD details the research programme to establish a design process to be able to effectively communicate an optimum way of working to student and practicing designers. The programme of work built upon existing methodologies, such as "Userfit" (Poulson, et al 1996) and latterly paralleled work led by Clarkson and Coleman[1]

The articles included in this thesis describe a wide range of methods and heuristics, but within the boundaries of an ID process. The definition of Industrial design is one developed by the author. Industrial design provides the social and cultural functionality (or social value) to a product, within the constraints of cost and

[1] The I~Design project, funded by the Engineering and Physical Sciences Research Council since 2000, has been addressing the needs of an aging population. Available from: (https://www-edc.eng.cam.ac.uk/idesign3/), [Accessed 12/05/2015]

manufacture. From this statement Industrial design activity within a design process, as defined here, is related more to market research, the end user needs and aspirations for a product or service. The physical functionality is delivered through methods and heuristics related to engineering. There are many references from Cross's model (1989: 21), Hollins and Pugh's model (Hollins and Pugh 1990: 49-51.,Pugh 1991: 6.), to Ulrich and Eppinger's process (Ulrich and Eppinger, 2000: 9). The detail of these boundaries is documented in the following section.

2 Scope

The case studies presented in this thesis were focused on human-scale Assistive Technology products and designs that were either hand-held or body worn, which included wheelchair accessories. The viewpoint taken in all studies was from that of an Industrial Designer, as defined in the following terminology section. Methods and heuristics that fall outside the support of an Industrial design focused process are not discussed. The context of the evaluation was from within the support and funding structures of United Kingdom (UK) based healthcare. Reference to other International healthcare structures and viewpoints were translated into, or compared with, a UK context. The context and terminology from definitions related to a Design discipline were from a UK perspective.

The design of medical products, such as those used in secondary care (Medical Hospitals) for example; interior design or architectural issues, such as accessibility and space design, was beyond the scope of the studies. Similarly, issues of creativity, design decision-making and innovation were not addressed in these studies for the pragmatic reasons of the available time and resource to the author in each study.

The journals and textbooks in which the articles were published assumed some background knowledge of design or engineering processes. Statistical validation of outcomes were mentioned, but not discussed in detail across all the studies. The

author's experience as a practicing designer and educator was that the choice of statistical validation method would be done with the advice of a statistician.

With the aim and scope of the study defined, the following section defines the research questions and study objectives.

3 Research questions and study objectives

This programme addressed the following research questions:

1. ***What are the groups and categories of research methods, design methods and design heuristics that could be applied to an appropriately structured new product development process for assistive technology products?***
2. ***Through a meta-analysis of case studies, are there key aspects that underpin an optimum AT-ID[2] process?***

The ten published articles present a series of case studies in the design of AT products. This commentary is in two parts. First, (in Sections 4 and 5), the research is introduced and the articles are summarised. Second, (in Sections 6 to 7), a meta-analysis of the case studies is presented in order to provide answers to the two research questions.

Whilst answering the question 'what is an optimum order of methods and heuristics' may appear straightforward, to clearly communicate key findings drawn from the articles requires further explanation of what is meant by 'priority'. The priority was considered to be the importance of the design method, research method or design heuristic for a given point in an Industrial Design (ID) new product development (NPD) process. The author was already aware that some methods and heuristics

[2] This abbreviation refers to an Assistive Technology specific Industrial Design process.

within an ID NPD process were frequently applied. He was also aware that there may be other elements within an ID NPD process applied to Assistive Technology (AT) products that underpin its efficacy that have not been previously explicitly highlighted within the literature. The following objectives were produced to provide the steps towards a considered ordering of methods and heuristics; definition of a meta-method or methodology for an Assistive Technology-Industrial Design (AT-ID) process; and, highlighting key methods and heuristics that underpin the methodology.

The objectives were to:

- Evaluate and reflect on the priority and order of application of a defined effective methodology and process within the context of Assistive Technology-Industrial Design (AT-ID), matched against available design methods, design heuristics and research methods;
- Evaluate the effectiveness and cost-viable application of specific design methods, design heuristics and research methods through practical application within AT product design development;
- Reflect on the preferences for defined research and design methods and design heuristics following their application by undergraduate industrial design students, special education school teachers and pupils living with physical and cognitive impairment;
- Present a critical path for the application of research methods, design methods and heuristics within a conventional AT-ID process;
- Highlight research methods, design methods and design heuristics that have been found to be useful throughout an AT-ID new product development process, which make an important contributing element to an effective outcome;
- Reflect on the development of the AT-ID methodology within the published articles; and,
- Highlight any aspects of an AT-ID process that appear to underpin a design process in this specific field.

The breadth of studies to be reviewed encompassed a multi-disciplinary approach involving the professional practice of design, engineering, ergonomics and business management. The published articles presented within the thesis required an explanation of nomenclature or terminology.

4 Terminology

To conduct the meta analysis in the second part of the commentary, the nomenclature of methods and heuristics defined in the ten articles were matched with those applied within current conventional design processes. This provided background knowledge to better answer the research questions in section 3. The review of references against which to compare the studies within the articles followed a conventional literature review, as described by Bruce (1994) and Bourner (1996).

Research methods, design methods and design heuristics were defined from a review of text-books. Textbooks provided a consensus of what were conventional methods and heuristics. A stable base of proven and well-used methods and heuristics was needed against which a comparison could be made with defined methods and heuristics within the AT-ID methodology. The current design management British Standard for inclusive design was also used as a guide (British standards 2005). The transition from medical and engineering model to social and design model can even be seen in the change in terminology in the title of the British standards for AT terminology in 2002, "Technical aids for persons with disabilities – Classification and terminology" to the equivalent title in 2011, " Assistive products for persons with disability – Classification and terminology." The semantics indicate assistive product over technical aid; a more holistic description over the original.

A wide range of textbooks were reviewed, as shown in the bibliography at the end of this commentary. The bibliography contains the books and articles reviewed for the purpose of identifying the nomenclature of conventional research methods, design methods and design heuristics. Research methods, design methods and design heuristics within the articles were defined based on nomenclature current at the time of publication. To ensure clarity for the reader, the following three terms were defined from the textbooks. Where necessary, the definitions are augmented from a number of sources.

4.1 Research methods

Research is a systematic study directed toward greater knowledge or understanding of the fundamental aspects of a phenomena. (Cohen et al 2007). Research methods are categorised under three main forms: exploratory; constructive; and, empirical research (Allison et al 1996: 6). The two ways in which these forms of research may be applied are qualitative and quantitative research. (Creswell 2009)

4.2 Design Methods

Design methods are a systematic way of doing something within a sequence of operations, actions or events that are called a design process. (Jones 1970) The application of techniques and use of heuristics in a timely sequence provide the operator with a simplified set of variables on which design decisions may be made, within the complexity of a real-world problem. (Cross 1989)

4.3 Design Heuristics

Design heuristics are mental short-cuts or rules applied to ease the cognitive load when making timely design decisions. (Karwowski et al 2011: 112) Heuristics are rules often based on past experience and learned behaviours, (e.g. rule of thumb). They can also be a collective consensus of opinion on a specific set of variables. (Martin and Hanington 2012: 98) Heuristics may help in categorising, organising or prioritising. Heuristics can also be used to generate options from which design decisions may be made.

Professional connoisseurship and the author's past experience were used to make the value judgements on the classification of elements from the ten publications in preparation for this review.

The majority of methods and heuristics were documented in three text-books by Martin and Hanington (2012); Lidwell et al (1996); and, Wilson and Corlett (2002).

Only well-tested methods and heuristics were included. The author used textbooks because they were most likely to contain well-tested methods and heuristics that had been applied previously and have a consensus of professional practitioners behind their application. Research articles and conference papers were considered to present new and innovative approaches to research and design methods and design heuristics. New approaches to the application of existing methods or novel developments were less likely to have been widely used or demonstrated as effective.

The ten articles reviewed span seventeen years of design practice and research study. It was notable that some of the terminology used in the earliest articles is different to that used to describe similar aspects in later publications. The change in language and terminology reflected the shift towards a social model of healthcare. The change in the AT market and perceptions of stakeholders who influence the AT-ID process have already been highlighted in the introduction. The change from a medical model to that of a social model of healthcare, as well as to a more user-centred approach to a design process was reflected in the development of the meta-method or methodology shown in the later articles.

The following section introduces the ten published articles. Each article describes and highlights evidence of effectiveness of method and cost-viability, through case study. The critical review of the studies in the second part of the commentary is used to extract methods and heuristics for meta-analysis of the design process described in each of the articles.

5 The case studies in the articles

The studies described within the ten published articles provide evidence towards answering the research questions posed in section 3. The studies described in the articles highlight methods and heuristics applied to real-world product designs, as well as student projects supervised by the author. The articles will be critically reviewed from the viewpoint of a meta-method or methodology development.

Two levels of analysis will be applied to the ten articles: 1) highlighting evidence of the efficacy of the methods from their outcomes, as shown within each article through case study; and, 2) a meta-analysis of the order and priority of methods and heuristics applied across all ten publications. The meta-analysis will be used to identify and highlight any aspects that appear to fundamentally underpin the AT-ID process.

Case study is used in the articles to describe the application of methods towards a specific outcome. Case study is a research method involving in-depth and detailed examination of a subject of study (the case), within related contextual conditions or environments. (Cohen et al 2007: 34) Case study is used in the context of this commentary to evaluate and reflect on the efficacy of individual methods as described in each article.

Case study is also used to reflect on their collective application within a developing design process over the period of the articles presented. Each case study is reviewed to provide evidence for a meta-analysis of individual articles. The critical review of the case study within each article was collated into a series of tables for meta-analysis.

Specific aspects within each design development are reviewed in terms of efficacy for that particular design intervention. The metrics used are the quality of the outcomes that matched the Product Design Specification (PDS) and the cost viability of the applied process. Cost is considered ultimately in terms of financial cost. Cost of

resources and time are highlighted in the cited articles. The cost-viability of the methods and heuristics evaluated was secondary to their effectiveness.

The application of case study at a meta-analysis level has been to place the method or heuristic within the sequence of an AT-ID methodology or approach; and, highlight fundamental unpinning aspects. The underpinning aspects were predicted to be common themes defined in the group of case studies as well as issues frequently highlighted in each. A qualitative, interpretive approach to this part of the meta-analysis has been done initially through the groupings, defined within the meta-analysis tables, and then the author's reflection on and interpretation of the common themes described in each study.

Research methods, design methods and design heuristics described in each article have been grouped into three levels of action to aid the meta-analysis of each article; providing more accessible 'chunks' for evaluation. The levels are: Macro; Mezzo; and, Micro. The articles grouped within each level are presented in chronological order, as shown in Table 1.

The grouping of methods and heuristics has provided an opportunity to critically review the development of the AT-ID process over the period of the articles. The levels addressed the following elements within a new product development process:

1. The micro-level of evaluation was through application of specific design methods, heuristics and research methods, linked to efficacy of outcome.
2. The mezzo level was an evaluation of combined design methods and heuristics along with associated research methods utilised in each specific case study, but still linked to outcome.
3. Macro level involved reflection and analysis at meta-methods level, where order and priority, or importance, of each method was evaluated within an AT-ID process. Underpinning

There was some overlap between the levels in specific articles; the author had made an allocation based on a 'best fit' judgement for their allocation. The allocation was based on what was being discussed within the case study in the article, e.g. method specific, group of methods or methodology.

Table 1. A list of published articles in this Thesis, including author percentage contribution.

Article.	Outline of methodology	Author contribution	%
	Micro level		
5.1.1	Torrens, G.E., Marshall, R., Burkitt, J. and Kay, G., 1996. Using modularity to produce more competitive assistive technology products, Proceedings of the 13th Irish Manufacturing Committee, Limerick, Ireland, pp 797-804		50
5.1.2	Torrens, G.E., Williams, G., Huxley, R., 2001. Can you open this jar for me please: A pilot study of the physical nature of jar opening, Contemporary Ergonomics 2001, (ed) McCabe, P.T., Hanson, M.A. and Robertson, S.A., Taylor and Francis, Ergonomics Society Annual Conference, UK, Taylor & Francis, London. pp83-89		80
	Mezzo level		
5.1.3	Torrens, G.E., Hann, J., Webley, M., Joy, J. and Sutherland, I.A., 2000. Hand performance assessment of ten people with rheumatoid arthritis when using a range of specified saucepans, Disability and Rehabilitation, 22 (3), pp 123-133		80
5.1.4	Torrens, G., McDonagh-Philp, D., Newman, A., 2001. Getting a grip, Ergonomics in Design: The quarterly of Human Factors Applications, 9 (2), pp7-13		80
5.1.5	Torrens, G.E. and Smith, N.C.S., 2013. Evaluation of an assistive technology product design using a paired comparisons method within a mixed methods approach: a case study evaluating preferences for four types of cutlery with 34 upper limb impaired participants, Disability and Rehabilitation: Assistive Technology, 8, (4). pp 340–347.		70
5.1.6	Torrens, G.E., and Newton, H., 2013. Getting the Most from Working with Higher Education: A review of methods used within a participatory design activity involving KS3 special school pupils and undergraduate and post-graduate industrial design students., Design and Technology Education: an international journal, 18 (1), pp 58-71		80
	Macro level		
5.1.7	Torrens GE, 1998. Design for Ageing and disability at Key Stage 4: An introduction to the nature of designing, available teaching materials and resources, National Association for Design Education (NADE) Journal 2 December		100
5.1.8	Torrens, G. 2000. Understanding the product user: The implementation of a user-centred design approach by student industrial designers when designing for elderly and disabled people, The Design Journal, 3, (1), Bloomsbury (formerly Berg), London. pp15-330		100
5.1.9	Torrens, G.E., 2011. Universal Design: empathy and affinity, Chapter , In. Handbook of Human Factors and Ergonomics in Consumer Products, (Ed), Waldemar, K., Soares, M., Stanton, N.A., Taylor & Francis, London.		100
5.1.10	Torrens, G.E., 2012. Assistive Technology product to Universal design: A way forward, Design For All India, 7 (7), pp.182-205.		100

5.1 Reviewing the Cases against an ID methodology

As discussed in the introduction and terminology sections, a conventional current structure of ID methodology has been used to help define and order research methods, design methods and design heuristics. Martin and Hanington (2012) defined five phases of a design process that were useful in ordering the methods and heuristics applied in the ten studies. Their phases were:

1. Market possibilities
2. Market choice
3. Design possibilities
4. Design choice
5. New market possibilities

Figures 1 and 2 provide a visualisation of the five phases; Figure 1 is based on a diagram within article 5.1.10 (Torrens 2012, p185). Figure 2 is a refinement of the phases shown in Figure 1, based on the additional content from Martin and Hanington's definition.

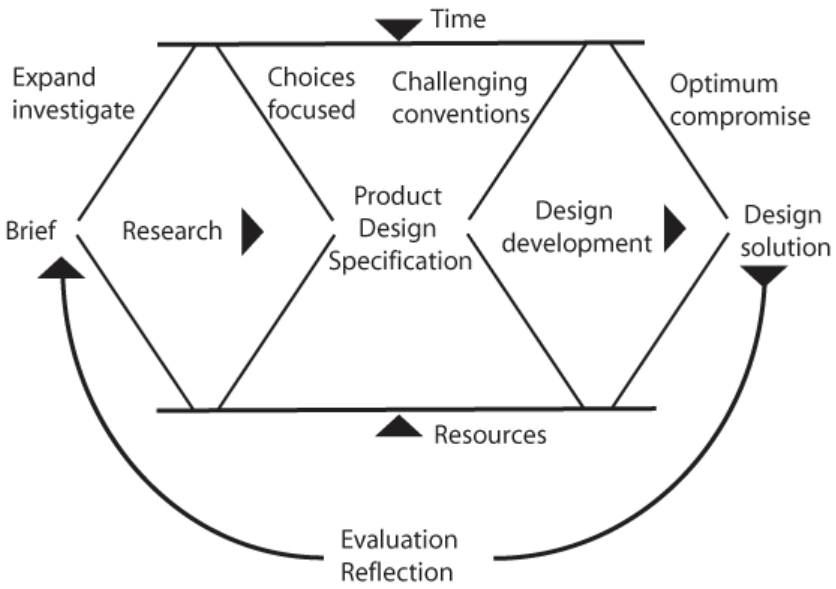


Figure 1. Design development process promoted by the Design Council, modified by the author (Torrens 2012).

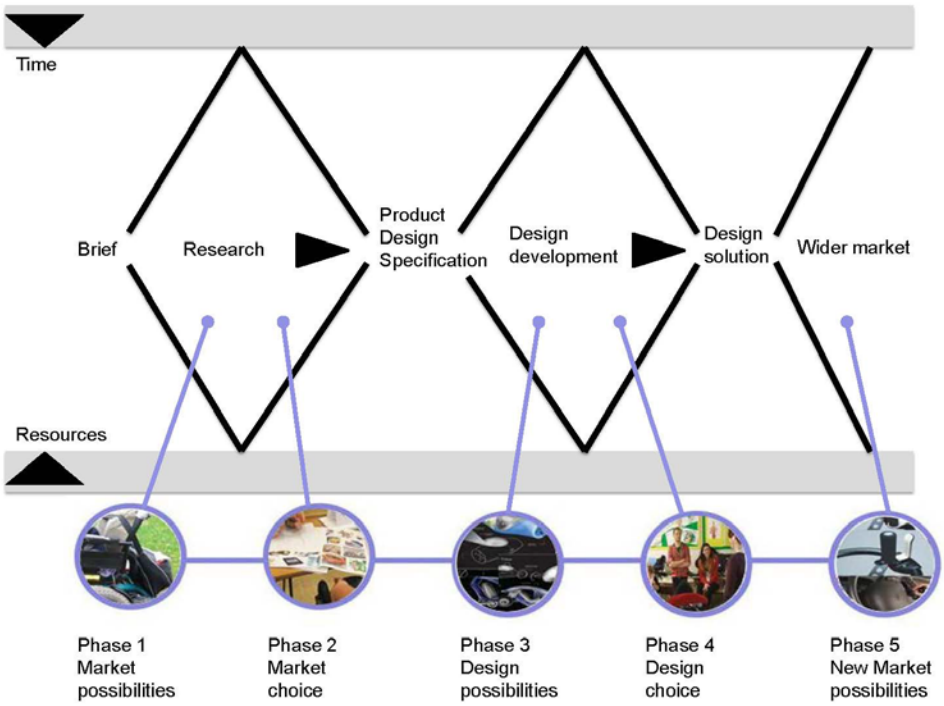


Figure 2. Five phases of Martin and Hanington (2012) combined with the author's description of an AT-ID process (Torrens 2012).

A comparison between the Martin and Hanington modified five phases and the British Standard, 'Managing inclusive design' (British Standard 2005) shows they match with stages one to seven in the Standard. (See Figure 3). Stages eight to eleven in the Standard are an iteration of phases one and five from the Martin and Hanington model.

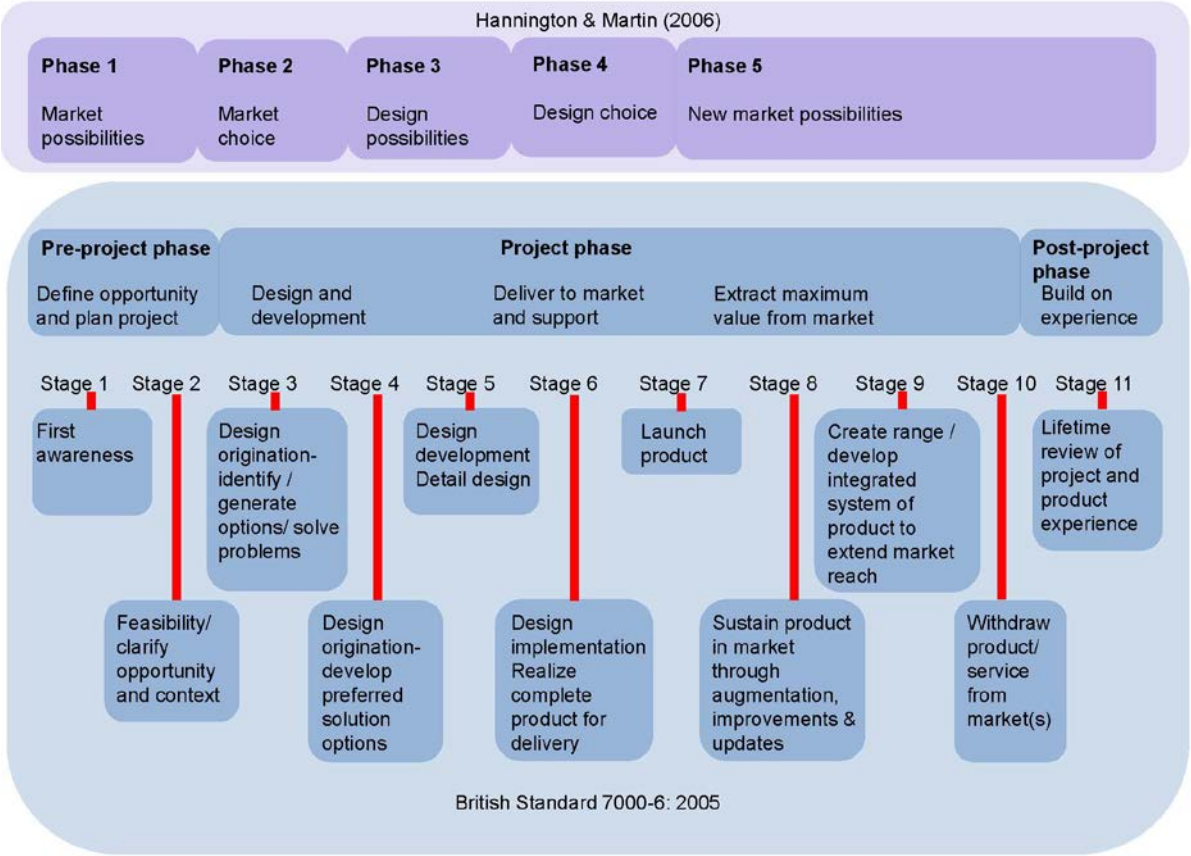


Figure 3. A comparison of the five phases of Martin and Hanington (2012) and the defined phases within the British Standard 'Managing inclusive design' (British Standard 2005).

Whilst the process shown in the three figures appears linear in application, the phases are cyclic, with iterations within each phase. From any point in the process reflection and return to the beginning may be done. However, this would not be a cost-viable option. Return to the original market research would suggest a failure in some aspects of the process applied. An example of a failure or flaw would be in the form of omissions in market research evidence that would enable effective design decision-making.

A context for the given AT-ID process has been described, along with the phases on which specific evaluation of individual case studies could be done. The following sections will discuss the efficacy, the priority and order of methods applied in the ten

articles, based around the three levels and five phases. The ten articles have been reviewed from a number of viewpoints. These include:

- development of individual methods and heuristics through to a methodology;
- effectiveness of methods and methodology;
- cost viability of the application of methods and methodology; and,
- identification of aspects with a design process that underpin the activity.

The following summary of background, method and outcomes from each article provided an opportunity to compare aspects from each viewpoint and enable a more effective meta-analysis to be achieved.

The following summaries of the articles have been grouped to make review from the different viewpoints easier. The three levels introduced in Section 5 have been applied to the grouping of the articles. The first to be reviewed is the micro level finishing with the macro level. Building on the blocks of individual methods and heuristics review, leading to a review of groups of methods and heuristics, was considered a logical approach to making a more informed meta-analysis of the overarching methodology and its architecture.

Micro level

The first two articles to be reviewed were based on the earliest studies published. They focused on design methods and heuristics applied from engineering origins. The research methods applied were based around a model of physical interaction between an individual and the objects they control. The early version of the model has its origins in physical ergonomics and biomechanics.

5.1.1 Torrens, G.E., Marshall, R., Burkitt, J. and Kay, G., Using modularity to produce more competitive assistive technology products, Proceedings of the 13th Irish Manufacturing Committee , Limerick, Ireland, 1996, pp 797-804

Background

This article was one of the earliest descriptions of design heuristics used to realise an AT product and make it viable for the marketplace. It evaluates the heuristic of modularity at a micro level.

Young and Sandhu (1995) highlighted the issues associated with AT products being within a disparate, niche market. John Young (Young 1994) provided an appropriate description of modularity and the benefits of it being a (sub) system that has self-contained and testable function that combine with other units to form a working product.

Method

Case study was used to demonstrate the effectiveness of modularity, based on the design development of a commercial AT product; a powered arm support for the Motor Neurone Disease Association.

Outcomes

The results demonstrated a reduction in the number of parts and associated production cost through standardisation of components and assembly interfaces.

(See Figures 1, 2 and 3 in the article). The case study also highlighted the benefits of modularity as a marketing tool, offering a range of options to the end user through the standardised interfaces. A 'plug-and-play' design approach that is now commonly applied in PC-based computer peripherals. Words of caution were given that the fundamental requirements from the end user should have priority. In addition, the availability of Original Equipment Manufacturer (OEM) components should not drive or overtly influence the product design specification (PDS) or the initial concept design. The reduction in component parts, whilst increasing available product options were evidence of effectiveness. The product in the documented specification was commercially available for over five years.

5.1.2 Torrens, G.E., Williams, G., Huxley, R., 2001 Can you open this jar for me please: A pilot study of the physical nature of jar opening, Contemporary Ergonomics 2001, (ed) McCabe, P.T., Hanson, M.A. and Robertson, S.A., Taylor and Francis, Ergonomics Society Annual Conference, UK, Taylor & Francis, London. pp 83-89

Background

The article evaluated the application of a Human and object physical interaction (HOPI) model at a micro level through the evaluation of a given task; opening a jar. Detailed analysis was done due to the need to address issues highlighted with the opening of packaging (DTI 1999, DTI 2000). This article provided a comprehensive validation of the application of the HOPI model defined by Torrens and Gyi (1999). The article provided an introduction to the potential role a mixed methods approach could make to a new product develop, as described in the later article 3.1.5.

Method

A case study was used to describe a quantitative approach to the evaluation of opening a jar. A series of quantitative measurements of human physical performance and physical characterisation of the task object (a jar) were used. These measurements of force, friction and body posture were combined into a taxonomy

that led towards a systematic approach to understanding the physical characteristics within a task analysis method. Qualitative perceptions of discomfort and ease of use were recorded through a questionnaire.

Outcomes

To the author's knowledge, there had not been a comprehensive physical characterisation of jar opening previously published at that time. The link between observed and measured physical characteristics of individual, task and object provided a novel approach leading to the comprehensive understanding of the physical nature of this task; and, the use of the HOPI model as a predictive design tool in future design and research studies.

Summary of Micro level

The two articles provide evidence through case study that a detailed physical assessment within a task analysis method provide a good evidence base for the optimisation of a user-product physical interface; and, that the principles of standardisation and modularity applied to design decision-making enhanced the cost viability of a new product design. The introduction of a mixed methods approach provided new product developers with an opportunity to gain a more holistic set of data on which to base design decision-making.

Mezzo level

Evidence is presented of the baseline of physical measurement within a task analysis method being combined with qualitative and statistical methods of validation. This builds on the introduction of a mixed methods approach documented in articles 5.1.1 and 5.1.2.

5.1.3 Torrens, G.E., Hann, J., Webley, M., Joy, J. and Sutherland, I.A., 2000. Hand performance assessment of ten people with rheumatoid arthritis when using a range of specified saucepans, Disability and Rehabilitation , 22 (3), pp 123-133

Background

This was the first article in the series to discuss what was to become popularly known as a 'mixed methods' approach to user evaluation. This article reflects on methods at a mezzo level, combining those methods described at a micro level.

Method

The methods applied in this article were quantitative measurements in the form of anthropometric survey; physical performance (grip and pinch strength); and, task analysis (from video recording and direct observation). This information was augmented by qualitative user preference choice of saucepan handles (hall/rank testing), user interview and survey/questionnaire.

Outcomes

The outcomes provided a comprehensive review of the performance of ten participants handling who were living with forms of Arthritis. Characterising the user, task and environment were seen as critical to establishing a user functional requirements for an AT product. It was suggested the predominantly human factors based evaluation methods would augment not replace existing clinical methods of evaluation. The issue of accessing participants for evaluation trials was highlighted. The documented approach appeared effective and cost-effective when considering the validation of preference for a larger AT niche market. The article provided a demonstration of a more comprehensive understanding of how individuals hold objects and control their physical environment. This was to improve the efficiency of these objects in use. It also provided evidence of an effective application of a mixed methods approach.

5.1.4 Torrens, G., McDonagh-Philp, D., Newman, A., Getting a grip, Ergonomics in Design: The quarterly of Human Factors Applications, 9 (2), 2001, pp7-13

Background

The article evaluated and discussed the physical characterisation of individuals, their performance and their preferences for cutlery products, at a mezzo level. The article introduces the application of a model of human and object physical interaction, (HOPI), combined with qualitative evaluation methods when used to develop a commercial cutlery set for people living with weak grip and limited dexterity. This article built on articles 5.1.1, 5.1.2 and 5.1.3, providing a comprehensive taxonomy of physical interaction and its context within a user-centred and mixed methods approach.

Method

A case study comprising of a mixed methods approach: quantitative measurement of physical characteristics of the user, physical characteristics of the product (cutlery) and environment; qualitative ranking and interview/questionnaire; and, AT production detailing.

Outcomes

The results provided Industrial designers with a combination of design heuristics and research methods that validated user acceptance. This acceptance was in the form of grip performance and social acceptance/aesthetic appeal. The case study provided an effective and cost-viable design process template leading from research methods to a detailed product design specification; and, subsequent realised commercial products. The cutlery range has now been in production for over ten years, which provides some indication of the effectiveness of the methodology used to produce an optimum design outcome.

5.1.5 Torrens, G.E. and Smith, N.C.S., 2013. Evaluation of an assistive technology product design using a paired comparisons method within a mixed methods approach: a case study evaluating preferences for four types of cutlery with 34 upper limb impaired participants, Disability and Rehabilitation: Assistive Technology, 8, Informahealthcare, London.

Background

The article evaluated at a mezzo level a paired comparison method within a mixed methods approach. The method complemented those presented in the studies in articles 5.1.3 and 5.1.4. The context of a mixed methods approach is discussed in this article, citing Creswell (2007) for a comprehensive description. The issue of bias is discussed in detail, augmenting the guidance given by Sinclair (1999) with Bröckenholt (2002) and Geer and Mulhern (2002).

Method

A case study was presented of a paired comparison method applied to the preferences for AT cutlery of 34 people living with upper limb impairment.

Outcomes

This article provided a detailed description of how Industrial designers may apply this method to AT product design. The issue of bias and how to avoid it was discussed in detail, along with the protocol for application of a paired comparison technique. The choice of non-parametric statistical methods of processing the data and its interpretation was also discussed in detail. The article was written for an audience of less experienced design researchers and those being introduced to statistical analysis within a new product development (NPD) process.

5.1.6 Torrens,G.E., Newton, H, Getting the Most from Working with Higher Education: A review of methods used within a participatory design activity involving KS3 special school pupils and undergraduate and post-graduate industrial design students., *Design and Technology Education: an international journal*, 18(1), 15th February 2013, 58-71

Background

The article was focused on the evaluation of a specific set of methods at a Mezzo level. The chosen methods were defined from previous work, shown in articles 5.1.4 to 5.1.5. The aim of the article was to identify which research methods, design methods and heuristics were found most useful within a new product design development. The study was aligned to conventional research methods cited within textbooks (Cohen 2007, Creswell 2009, Wilson et al 1995).

The methods and heuristics could be applied in all five phases of the given design process diagram, (Figure 1, section 1.1).

Method

A qualitative approach was taken to data collection. The reflection on the research and design methods applied by undergraduate industrial design students, co-designing school pupils and teaching staff was collected using questionnaires. The questionnaire applied Likert ranking scales and qualitative responses to questions relating to how useful they found each method and why.

Outcomes

The results highlighted the importance of designers undertaking a literature review of the background of their end users and developing a dialogue with them. Co-designing was considered the most effective design method. The dialogue format of the co-design activity was also considered important. The narrowed viewpoint through which pupils could perceive a given stimuli challenged conventional methods of co-design for the undergraduate students. The undergraduate student designers found drawing templates, mood boards, visual prompts and low-resolution

models, alongside role play, to be very effective means to communicate new concepts or identify needs. A number of the communication formats were non-visual based.

The article provided evidence of a qualitative evaluation of the AT-ID methodology through used by Industrial design students, end users and stakeholders of the value of specific methods and heuristics was also captured.

Summary of mezzo level

The application of a more sophisticated HOPI model; use of questionnaire and semi-structured interview for qualitative data; and, specific non-parametric statistic validation methods for larger populations provided a more holistic combination of methods. It reflected their use within a mixed methods approach, as described by Creswell et al (Creswell 2009, Creswell et al 2007), within an Industrial design based new product development that was neither solely engineering function nor reflective ergonomic evaluation. The approach was introduced in the earlier articles 5.1.1 and 5.1.2.

The evidence within each case study presented suggested the combined methods were both effective and cost viable, as they resulted in commercial products. Article 5.1.6 provided some insights into the perceived priority of importance of methods expressed by Industrial design undergraduate students, end users and associated stakeholders. They highlighted literature review and participatory design as important aspects. Effective dialogue was also highlighted as critical to a successful research and design outcome. Students indicated that co-design offered an effective range of ways in which dialogue could be achieved beyond visualisation. The need for a range of communication formats was also highlighted, due to the physical and cognitive impairments of the potential users to be accommodated.

Macro level

The application of a larger group of methods and heuristics are described in this final section. The group of articles introduced a more comprehensive set of methods and heuristics that demonstrate the holistic nature of an Industrial design-based new product design process. The order of the case studies presented reflects the development of an AT-ID methodology.

5.1.7 Torrens GE, 1998. Design for Ageing and disability at Key Stage 4: An introduction to the nature of designing, available teaching materials and resources, National Association for Design Education (NADE) Journal

Background

At a macro level, this is one of the author's earliest attempts to provide designers with a comprehensive approach to Assistive Technology New Product Development (AT NPD). There had been a number of earlier publications outlining a proposed methodology (Torrens and Kay 1995, Burkitt et al 1996, Burkitt et al 1996), but not as detailed as the one defined in this article. In this article earlier experience in developing AT products and the approach to AT NPD was highlighted, along with resources for other user-centred design methods (Poulson et al 1996). This specific AT approach was matched against conventional approaches to NPD (Ulirch and Eppinger 1995, Lorenz 1990). Social acceptance was also highlighted as an issue (Maynard 1995). The demography of people registered with disabilities across Europe (Sandhu and Wood 1990) was used to highlight the large, but splintered market user group.

Method

Case study was used to demonstrate different aspects of AT NPD at a Macro level. At the micro level, examples of templates for design heuristics were given within the methodology related to the evaluation and redesign of cutlery. These included

empathic modelling, mood boards, bubble diagrams (mind mapping) and product analysis (expert review).

Outcomes

The case study and templates for application were presented for use by School teachers and pupils doing AT product related projects. Sign-posting to additional background resources was also provided relating to information about the market and lifestyle of the end users.

5.1.8 Torrens, G. 2000. Understanding the product user: The implementation of a user-centred design approach by student industrial designers when designing for elderly and disabled people, The Design Journal, 3, (1), Bloomsbury (formerly Berg), London. pp15-330

Background

The case study in this article was more focused on the application of methods advocated in article 5.1.6 by 61 undergraduate industrial design students over a two-year period. The transition from medical to social model was highlighted (Turner et al 1996).

Method

The case study provided a template of working with resources, (at a macro level), highlighted in article 5.1.6, through which the undergraduate students worked directly with target user groups. A qualitative survey, in the form of a questionnaire, was used with some of the students providing initial indications of level of satisfaction with the approach and resources. The survey combined Likert scales and open-ended questions about how the approach could be improved.

Outcomes

Through the surveys the issue of logistics related to participant recruitment were highlighted. Example projects that were considered potentially commercially viable

products were presented as evidence of efficacy of the defined process. Students highlighted the benefit of direct communication with end users. From observations of the teaching supervisor, the benefit of reviewing background information to enhance the effectiveness of design outcome was also highlighted. Additionally, it was considered by the author that the collaboration between academia and UK charitable organisations could provide a cost-effective way to generate solutions to problems faced by the individuals that the Charities represented.

5.1.9 Torrens, G.E., 2011. Universal Design: empathy and affinity, Chapter 16, In. Handbook of Human Factors and Ergonomics in Consumer Products: Methods and Techniques, (Ed), Waldemar, K., Soares, M., Stanton, N.A., Taylor & Francis, London.

Background

This book chapter provided a more complete example of the approach to AT NPD advocated by the author. The field had evolved in the eleven years between publications, along with the context for an AT-ID process. During the period between the previous journal article (5.1.8) and this publication the AT-ID approach had been refined and developed. The refined approach included acknowledgement of the now more defined field of Inclusive design. The term is primarily UK based, with Universal design being more widely used in other parts of the world.

Method

Case study was used to describe the design methods, design heuristics and research methods used. The combination of qualitative and quantitative research methods were grouped under the term mixed methods. Case studies involving the development of a pace clock for blind swimmers was used to demonstrate the efficacy of the approach. Generic methods of predicting 'break even points' to demonstrate commercial viability of an AT product were also described. This built on the earliest study, 5.1.1, describing the use of standardisation and modularity.

Outcomes

Templates and points to consider when applying the design methods, heuristics and research methods were given. These provided additional detail of product probes, predictive modelling and co-design. Co-design had developed into a defined design method from the more generic participatory design. An example application of a novel design heuristic, 'persona foot-print', was provided. It had been developed by the author from generic mechanisms of perception (based mainly on principles of Gestalt such as foreground-background definition) and product semantics; another area of design that had developed over the previous decade. The emphasis of an AT NPD approach was now focused on qualitative rather than quantitative evidence, with social acceptance being an important influence on the design decision-making process. The author had coined the term 'blacksmith approach' to reflect the close working relationship between end users, stakeholders and designers that was possible within AT NPD. This term combined co-design and user-centred design methods alongside production engineering and rapid manufacturing techniques. This provided personalised design solutions for what was seen as a niche market.

5.1.10 Torrens, G.E., 2012. Assistive Technology product to Universal design: A way forward, Design For All India, 7 (7), pp.182-205.

Background

The article provided the most recent description of what was described as the Loughborough Assistive Technology-User centred Design (LAT-UCD) methodology, evaluated at a Macro level. The article cited the earlier versions of the approach, but added much more detail to the issue of social inclusion, highlighted by Philips (1993), Fuhruer (2003) as well as the discrimination of people living with disabilities (Barnes 2011).

Method

Case study was used to demonstrate good practice relating to usability evaluation and implementation. A series of examples of award-winning final year student projects, which had been under the supervision of the author, were used to demonstrate efficacy of specific groups of methods and heuristics. A specific example was shown in Figure 17 in article 5.1.10, which demonstrated how a change in semantics could reframe the perception of hearing aids. The examples presented an opportunity for Industrial designers to reframe the perception of a mainstream UK population towards AT product design. Manipulation of product semantics demonstrated the potential commercial viability of this approach.

Outcomes

The shift from predominantly medical condition and physical engineering to social inclusion and acceptance was clearly demonstrated over the four articles. The focus on the social and cultural functionality of an AT product reflected the move towards inclusion within a UK society.

The comparative list of Barnes' statements about discrimination vs what Industrial designers could do to promote inclusion through their particular skill set provided a starting point for the application of specific AT associated methods. The diagram of the LAT-UCD process, shown in Figure 2 within the article 5.1.10, enabled practicing and student designers to map their own skill set against it and to gauge what they need to acquire to work in this field. The demonstration of reframing through semantics highlighted the need for practicing and student industrial designers to fully exploit these skills through a formal understanding of product semantics.

Summary of Macro level

There is a clear development of sophistication from a basic methodology shown in article 5.1.7 from 2000 to the final article published 5.1.10 in 2012. A mixed methods approach was a common theme within the three articles. Specific novel methods and heuristics were shown in the latter two articles, indicating the progression of the applied methodology. Reflecting beyond the efficacy of individual methods and

heuristics, the latter two articles highlighted the social change in this field that influence the AT design process. All three articles advocated individual participant to larger group involvement in research and validation, which suited a mixed method approach. The small sample size with a range of data collected pointed to the use of case study as a main method of documenting and describing the AT design process presented.

The final article highlighted the need for more research into social acceptance, which may be considered beyond the conventional practice of engineering or medical science. The manipulation of individual and social perception through the cultural coding of artefacts (product semantics) can be seen as a core skill of Industrial Designers.

The ethics code of practice applied to all the studies within the articles was one of the underpinning aspects that focus the process on social gain, within the limits of cost-viability. Placing people at the centre of a design process was clearly defined in article 5.1.10 as a user-centred approach to AT design, the Loughborough Assistive Technology-User Centred Design (LAT-UCD).

The combined findings highlighted in the section are discussed in more detail in the next section, Key findings.

6 Key findings: Reviewing the findings for 1) order and priority 2) underpinning aspects

The following section provides an analysis of and reflection on the methods applied within the ten articles presented in the commentary. The evaluation, presented within the three levels of action, macro, mezzo and micro, provides a structure within which the priority of methods and heuristics may be considered.

Presented within the three levels of action the order of research methods, design methods and design heuristics have been grouped within the five stages of an ID process, as defined by Martin and Hanington (2012) . A critical path analysis has then been applied to provide a sequential order for application based on the author's past experience and the evaluation of the case studies in the ten articles. The following findings highlight the development of methods and heuristics within the defined levels of action. Table 2 shows the initial grouping of research methods, design methods and design heuristics within each phase of an AT-ID new product development process. Phases 1 and 5 are combined because they serve the same purpose, defining anew market or markets. The other methods and heuristics were grouped in sequence order of the phases, 1-5, left to right. For example, the methods only used in Phase 4 are clearly shown in the table, as they are not used in any other phase of design process.

6.1 Micro level

The initial stage of analysis in this review is to define the research methods, design methods and design heuristics within the ten articles. The number of defined methods and heuristics categorised in Table 2 led to a sequential grouping. The following points provide some insights into the initial analysis.

- Table 2 shows that eighteen out of the sixty-one methods and heuristics were applied throughout an AT-ID process, nearly a third of the total applied within the ten studies.
- Table 2 highlights that phase two of an AT-ID process has the most intense activity for an Industrial Designer, with twenty-four methods and heuristics were applied in the section; phase one and five being the next most active with nine elements .

Table 2. 61 research and design methods and heuristics applied within the documents ten publications

Article No.	Author contribution	AT Market Literature review	AT Observation	Sketching	AT Participatory research	Champion user	Blacksmith approach	AT market Stakeholders	Mixed methods	AT Market User, Task, Environment	AT Market Focus Group	BS7000:6	Universal Design principles	Web Diagram	Benchmarking	AT Market definition	Grip strength	Anthropometry	Case Study	AT Market Ethnography	Mind mapping	Brainstorming	AT Market Cultural probes	Word clouds	AT market Empathic modelling	AT Brand analysis	Grounded theory	AT Real-World deconstruction	AT market Interview	Mood boards	AT market Teleconferencing	Task analysis	Sketch models	AT market Participatory co design	AT Market Story boards	AT User Experience	AT Market Role play	AT market Predictive modelling tools	Persona footprint	Ranking	Presentation boards	AT product Standardisation	AT product Modularity	AT product Batch Production/Break even point	Prototyping	AT product Usability evaluation	Motion capture	Finger friction meter	Universal grip dynamometer	Video Analysis	Value analysis	HOPI	AT Market Personas	AT market On-line survey	AT Market Survey	Cognitive framing	Original Equipment Manufacturer	AT Product Semantics	Paired comparisons	Expert review	Eye tracking	Rapid manufacturing
	Micro level																																																													
1	Torrens, G.E., Williams, G., Huxley, R., 2001 Can you open this jar for me please: A pilot study of the physical nature of jar opening, Contemporary Ergonomics 2001, (ed) McCabe, P.T., Hanson, M.A. and Robertson, S.A., Taylor and Francis, Ergonomics Society Annual Conference, UK, Taylor & Francis, London. pp83-89	1	1		1				1	1						1	1	1											1			1				1				1						1	1	1	1	1		1						1				
2	Torrens, G., McDonagh-Philp, D., Newman, A., Getting a grip, Ergonomics in Design: The quarterly of Human Factors Applications, 9 (2), 2001, pp7-13	1	1	1	1		1		1	1	1	1			1	1	1	1	1	1									1			1								1					1	1		1		1		1		1								
	Mezzo level																																																													
3	Torrens, G.E., Hann, J., Webley, M., Joy, J. and Sutherland, I.A., Hand performance assessment of ten people with rheumatoid arthritis when using a range of specified saucepans, Disability and Rehabilitation , 22(3) , 2000, pp 123-133	1	1		1			1		1	1				1		1	1	1											1			1				1				1					1	1				1					1					1		
4	Torrens, G.E. and Smith, N.C.S., 2013. Evaluation of an assistive technology product design using a paired comparisons method within a mixed methods approach: a case study evaluating preferences for four types of cutlery with 34 upper limb impaired participants, Disability and Rehabilitation: Assistive Technology, 8, (4). pp 340–347	1	1		1				1						1		1	1	1											1											1						1									1				1			
5	Torrens,GE ,Newton,H, Getting the Most from Working with Higher Education: A review of methods used within a participatory design activity involving KS3 special school pupils and undergraduate and post-graduate industrial design students., *Design and Technology Education: an international journal* , 18(1), 15th February 2013, 58-71	1	1	1	1	1	1	1	1	1			1		1	1			1	1	1	1		1	1				1	1		1	1	1	1	1	1			1	1				1	1						1		1	1					1		
	Macro level																																																													
6	Torrens, G.E., Marshall, R., Burkitt, J. and Kay, G., Using modularity to produce more competitive assistive technology products, Proceedings of the 13th Irish Manufacturing Committee , Limerick, Ireland, 1996, pp 797-804	1	1	1	1			1		1	1				1	1	1	1	1													1	1	1		1				1		1	1	1	1	1					1						1			1	1	
7	Torrens GE, Design for Ageing and disability at Key Stage 4: An introduction to the nature of designing, available teaching materials and resources, National Association for Design Education (NADE) Journal 2 December, 1998	1	1	1	1			1	1	1	1					1	1	1	1	1	1	1			1				1	1		1	1	1	1	1				1	1				1	1									1					1		
8	Torrens, G. 2000, Understanding the product user: The implementation of a user-centred design approach by student industrial designers when designing for elderly and disabled people, The Design Journal, 3, (1), Bloomsbury (formerly Berg), London. pp15-330	1	1	1	1			1		1	1					1			1		1				1				1			1			1	1	1				1	1	1			1									1					1		
9	Torrens, G.E., Universal Design: empathy and affinity, Chapter , In. Handbook of Human Factors and Ergonomics in Consumer Products, (Ed), Soares, M., (2011), Taylor & Francis, London.	1	1	1	1	1	1	1	1	1	1	1	1			1			1	1	1		1	1	1		1		1			1		1				1	1			1	1	1		1							1	1	1	1	1	1				1
10	Torrens, G.E., Assistive Technology product to Universal design: A way forward, Design For All India, 7 (7), 2012, pp.182-205.	1	1	1	1	1	1	1	1	1	1	1	1	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1	1	1	1	1	1	1	1	1	1	1
	Phase 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																																		
	Phase 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1										
	Phase 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1				
	Phase 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Phase 5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																																		
	Method or huersistic number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
		All Phases																		Phases 1 &5									Phase 2																								Phase 3						Phase 4			

Methods & heuristics	Phase specific application	Overall application
Phase 1	9	27
Phase 2	24	49
Phase 3	6	47
Phase 4	4	50
Phase 5	9	27
All Phases	18	18

6.2 Mezzo level

Following the definition and analysis at a methods and heuristics level, the following points provided some evidence of the priority and importance of the methods.

- AT participatory design was seen as one of the most effective design methods through which design decision-making could be accelerated, reducing time taken to achieve a design solution. This is important to the viability of a NPD as designers are paid on an hourly rate.
- Paired comparison was considered a useful research method and design tool in that it could be used to define a priority order of preferences from a sample group representing a much larger target market, but also used to help make design decisions more effectively regarding the order of criteria for a product design specification (PDS). Validation of a design outcome through non-parametric statistics was seen as providing persuasive evidence for Industrial designers. For example, order and priority of preference for AT cutlery, by people with weak grip and limited dexterity, as described in article 5.1.5.
- AT participatory co-design was highlighted as an effective method for rapid product development when taking the 'blacksmith' approach to NPD. The small to large approach in gaining insights from a target market was demonstrated as effective and cost viable in the four articles grouped at this level.
- What was also clear was the importance of a high-quality of dialogue between the designer and all others involved when applying AT participatory co-design. Figure 4 visually describes the reduction of the 'bandwidth' of potential dialogue from a mainstream level to that restricted by cognitive and physical impairment. To combat this restriction of lines of communication Table 3 shows a taxonomy of conventional design methods mapped onto mechanisms of human perception. The formats of communication were grouped within design

methods or heuristics shown in Table 2. The ticked boxes highlight where the formats were applied in the ten articles.

- The majority of conventional communication methods were visual; however, a number of them were defined as three-dimensional and interactive. These communication methods were found the most useful in cases of compound impairment. The more three-dimensional communication methods stimulated more senses. Whilst useful for those living with compound impairment, the methods were universal and applicable to a mainstream population.
- The underlying reasons for not using more interactive methods of communication were linked with time and cost. A sketch may take only seconds to produce, whereas a model would take much more time.
- When undertaking research and design activities with end users and stakeholders the cost of logistics in time and money within a niche market further highlighted the need for representative individuals to be defined. This was supported in the micro level.
- The design heuristics highlighted in Table 2 were predominantly categorisational and prioritisational; although around half were defined as generative. Only around a quarter of the heuristics were considered quantitative in character.
- The use of role play to quickly respond to limitations in the realisation of a product design specification, embodied within the concept being visualised, was found to be an effective design method to enhance the use of sketch models.
- The choice of dialogue format, as shown in Table 3, is critical to the successful and cost-effective delivery of AT products or services. Figure 4 shows the restriction of possible format choices from Table 3 due to the severity of impairment.

Table 3. A taxonomy of different forms of communication and their relationship to innate perception (visceral stimuli) within the context of Figure 4.

	Innate perception								
Format of communication	visual	sound	Taste	Smell	Temperature	Vibration	Haptic/ tactile	Body movement	Associated design method
Line drawing 2D single line weight	✓								Sketching
Line drawing 2D multiple line weight	✓								
line drawing 2D with shading	✓								
Line drawing 2D with texture	✓								
Line diagram 2D-flow	✓								
Engineering drawing 2D	✓								
Engineering drawing	✓								
CAD diagram-animation									
CAD line drawing-3D-animation	✓								Presentation boards
Illustrations 2D rendered	✓								
Illustrations CAD 3D rendered	✓								
Illustrations CAD 3D photo-realistic	✓								
Light on-off	✓								
Light colour	✓								
Visualisation greyscale	✓								
Visualisation colour	✓								
Photographs	✓								
Storyboard	✓								
Surface texture	✓				✓	✓	✓	✓	Sketch model
Low-fedelity sketch model	✓				✓	✓	✓	✓	
High-fidelity sketch model	✓				✓	✓	✓	✓	
Appearance model	✓				✓	✓	✓	✓	
Functional prototype	✓				✓	✓	✓	✓	
Edible solid									
Edible liquid									
Low-fedelity sketch model	✓				✓	✓	✓	✓	
Movement via machine	✓					✓	✓	✓	
Temperature via machine									
Role play single person	✓	✓							Role play
Role play multiple people	✓	✓							
Verbal storytelling with emotion									
Singing-explanation									
Music via instrument									
Music via percussion-rythm									
Movement- body language-emotion	✓	✓							
Movement-gestures sign language									
Movement-rhythm-dance									
Verbal explanation scientific		✓							

Legend
Available stimuli
Stimuli for Physical impairment
Stimuli for Cognitive and Physical impairment
Available stimuli used in studies ✓

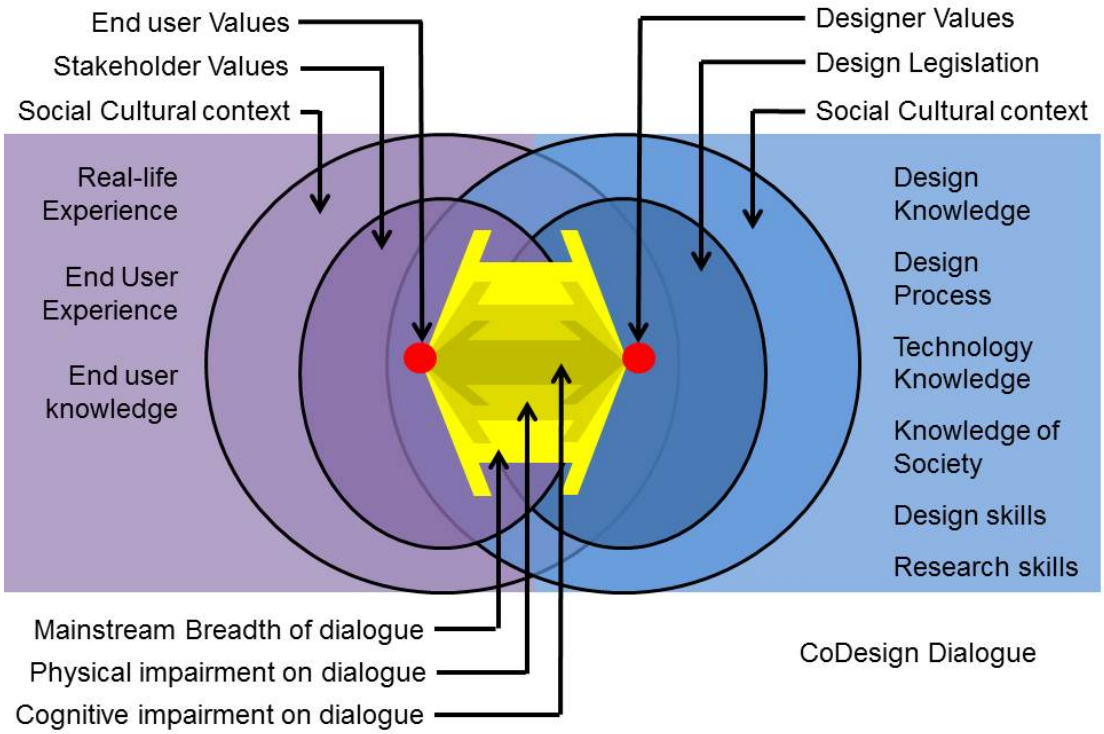


Figure 4. Shows a Venn diagram of the context of AT participatory co-design dialogue and its restriction by impairment.

6.3 Macro level

The previously defined order of methods and heuristics, and the highlighting of those important to an AT-ID approach, have led to a more reflective level. At this level context and the aspects that underpin the proposed AT-ID process are considered. The following points contribute to the reflection on the stated approach and those aspects that underpin its efficacy.

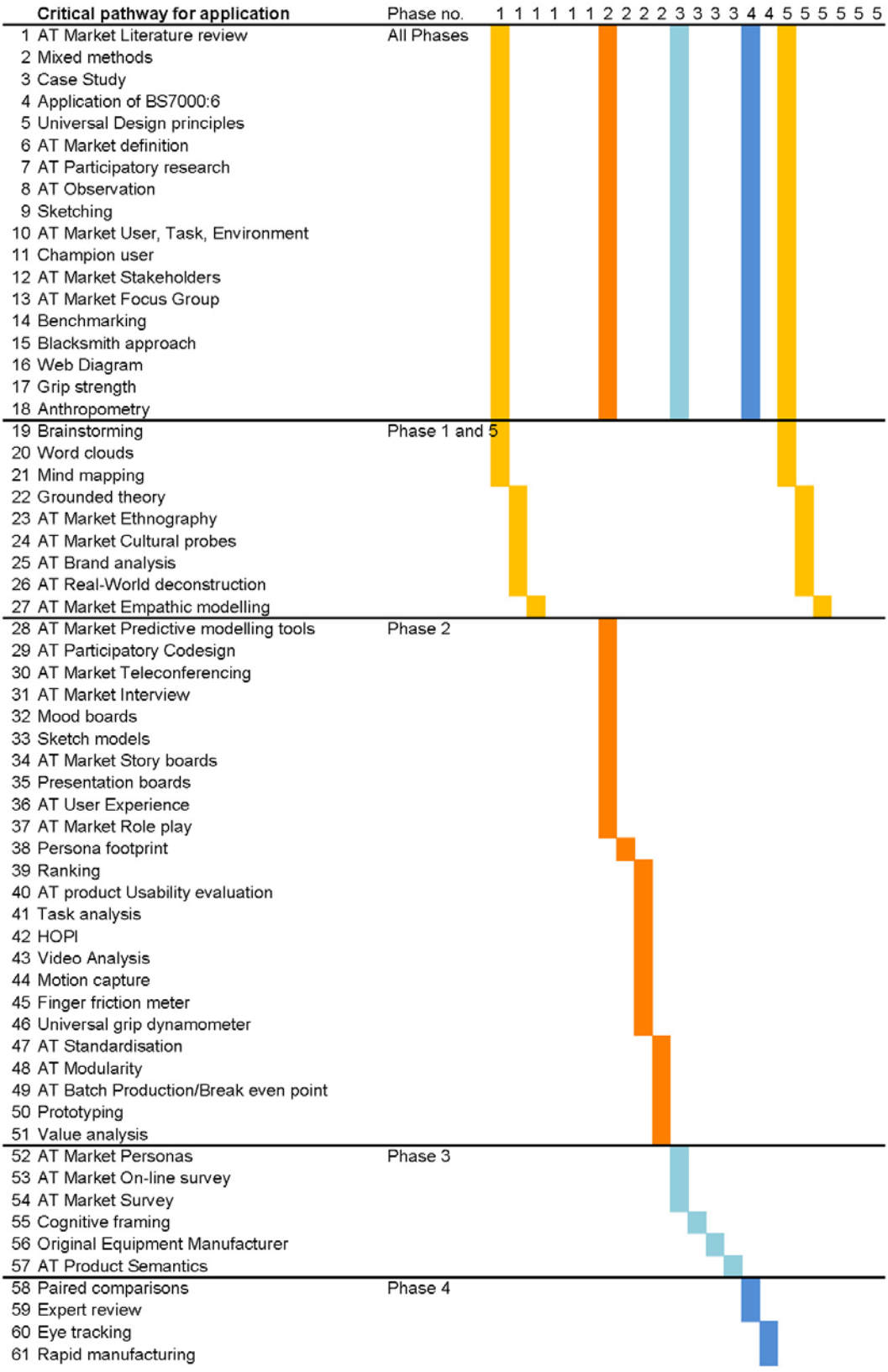
- The context of the Loughborough Assistive Technology- User Centred Design (AT-LUCD) process had changed within the last seventeen years from a functional physical and cognitive interface and equipment

(medical model) to a value and performance driven product (social model). The introduction of an Inclusive design section to the British standards design management series 7000 indicated how the field has emerged as an important sub-component of NPD. (British standards 2006).

- Through matching to available literature, the identification of 61 research methods, design methods and design heuristics that were applied within the ten studies has been possible.
- From the analysis of the ten articles there appear to be an optimum order of application of design methods and heuristics, within the limitations of groups.
- The order in which they were applied is shown in Table 4. Using critical path analysis (Milosevic 2003: 184-192) the author has placed the grouped methods and heuristics into a Gantt chart as a 'look-up' table for application within the five phases of a design process.
- Some design methods, heuristics and research methods were applied across all phases of Assistive Technology new product development. (See Table 4) For example, Sketching and literature review.
- The associated research methods were aligned with a user-centred, evidence-based methodology validated through a mixed methods approach.
- A champion user/blacksmith design approach (going from a defined representative individual to a group validation of the market for an AT product design) was found most appropriate by undergraduate designers, end users and stakeholders in article 5.1.7.
- Case study (as presented in all of the articles) appeared to satisfy the need for a dialogue between designers, as highlighted by Poggenpohl (Poggenpohl and Sato 2009). A mixed methods approach was applied in most of the ten articles to help validate elements within each case study.

Table 4. shows critical path analysis of the application of design methods, research methods and heuristics within an AT product development.

	Critical pathway for application	Phase no.
1	AT Market Literature review	All Phases
2	Mixed methods	
3	Case Study	
4	Application of BS7000:6	
5	Universal Design principles	
6	AT Market definition	
7	AT Participatory research	
8	AT Observation	
9	Sketching	
10	AT Market User, Task, Environment	
11	Champion user	
12	AT Market Stakeholders	
13	AT Market Focus Group	
14	Benchmarking	
15	Blacksmith approach	
16	Web Diagram	
17	Grip strength	
18	Anthropometry	
19	Brainstorming	Phase 1 and 5
20	Word clouds	
21	Mind mapping	
22	Grounded theory	
23	AT Market Ethnography	
24	AT Market Cultural probes	
25	AT Brand analysis	
26	AT Real-World deconstruction	
27	AT Market Empathic modelling	
28	AT Market Predictive modelling tools	Phase 2
29	AT Participatory Codesign	
30	AT Market Teleconferencing	
31	AT Market Interview	
32	Mood boards	
33	Sketch models	
34	AT Market Story boards	
35	Presentation boards	
36	AT User Experience	
37	AT Market Role play	
38	Persona footprint	
39	Ranking	
40	AT product Usability evaluation	
41	Task analysis	
42	HOPI	
43	Video Analysis	
44	Motion capture	
45	Finger friction meter	
46	Universal grip dynamometer	
47	AT Standardisation	
48	AT Modularity	
49	AT Batch Production/Break even point	
50	Prototyping	
51	Value analysis	
52	AT Market Personas	Phase 3
53	AT Market On-line survey	
54	AT Market Survey	
55	Cognitive framing	
56	Original Equipment Manufacturer	
57	AT Product Semantics	
58	Paired comparisons	Phase 4
59	Expert review	
60	Eye tracking	
61	Rapid manufacturing	



7. Conclusion

The ten published articles within the commentary had an overlap of descriptions of design research methods and heuristics. However, the order of application of the design research methods and heuristics did not vary outside the defined five phases of development. Table 2 showed the distribution of sixty-one methods and heuristics described across the ten articles. The methods and heuristics had been identified as conventional research methods, design methods and design heuristics defined from a review of literature shown in the Bibliography.

The eight case studies described within the articles included:

- Four commercialised products produced by the author as an individual designer or as part of a design team;
- Two products taken to pre-production prototype stage produced by the author;
- Six undergraduate student functional prototype designs, supervised by the author; and,
- Fifteen undergraduate student concept designs, supervised by the author.

A number of the student projects were also shortlisted in National design competitions. One of the commercialised designs has also been short-listed for an award.

From the defined context and terminologies, it was clear that there was an overlap of techniques, processes within the articles presented; with refinement of terminology and application of methods taking place over time. Using the Martin and Hanington (2012) and Lidwell *et al* (1996) compendiums as a starting point enabled a review of design methods, research methods and design heuristics to be completed cost effectively within available resources of the author undertaking this commentary as a part-time student.

A visual summary of the context of AT product design, incorporating the three-dimensional aspect of design and the market, is shown in Figure 5. It can be seen that Industrial Design (ID) sits within social and cultural function and overlaps with Engineering and physical function. AT product design overlaps ID and Engineering, with some AT products having physical function only.

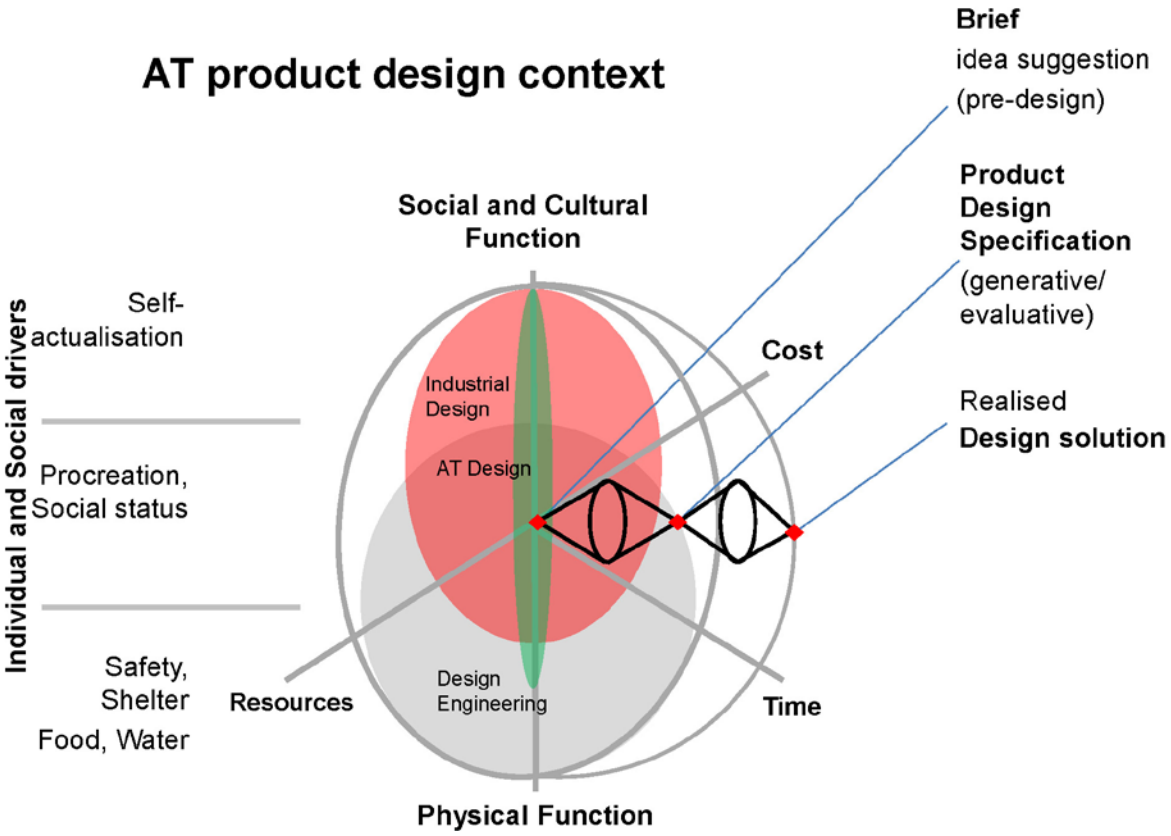


Figure 5 An illustration of the context within which ID is practiced and an example process followed to a design outcome.

What can be learned from the reviewed case studies? From the descriptions of the design research methods within the articles and literature reviewed they facilitate insights about or from the target market. Design heuristics may be considered to help designers collate and prioritise information gained from design research methods and reduce complexity of data to make timely decisions.

Over the seventeen-year period, the author identified, used and reviewed the sixty-one methods and heuristics, shown in Table 2. An order for the application of the methods was defined from the review of methods and heuristics, shown in Table 3. It

can be seen there were a number of methods and heuristics that are applicable to all phases of design development; some are specific to individual phases. Figure 6 summarised 61 of the methods and heuristics into the five phases defined in Figure 2.

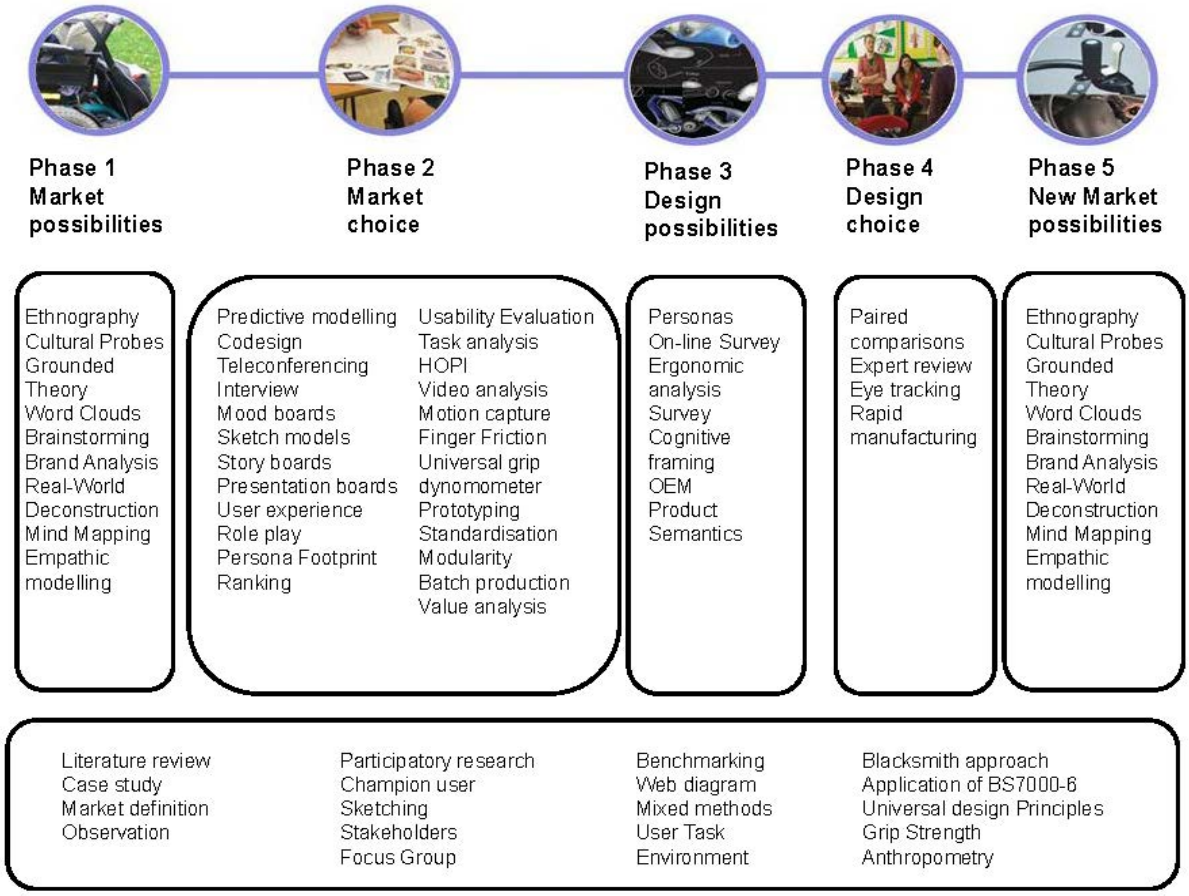


Figure 6. Summarises the priority and order of the application of 61 research methods, design methods and design heuristics as documented in the 10 articles.

The aim of this research programme was to identify, order and prioritise design research methods and design heuristics to enhance the efficacy of an AT new product development process. Figure 6 and Table 4 provide the conclusions, validated through the publications; and, the data collected from the cases studies contained within them.

The focus on social and cultural function within the pre-defined definition of industrial design process is shown in Table 4, Figures 5 and 6. Phase two of the Gantt chart has the majority of research and design methods and design heuristics. Table 2 shows twenty four out of sixty one of the methods and heuristics were specific to this phase; more than twice the number specifically used in any other phase. The number of methods and heuristics within phase two of the LAT-UCD process matches the author's definition focus on market needs and aspirations over engineering functionality. The process works within the constraints of function and cost, as described in the introduction.

Due to the small size of individual markets within the AT product field, a champion user and 'blacksmith' approach has been demonstrated to be the most cost-effective. An individual target user of an AT product has been shown to be often representative of a much greater percentage than an equivalent using a mainstream product; i.e. representing hundreds or thousands rather than millions. The UK charities already provide high quality information about their members as demonstrated though the case studies. This resource enables a designer to compare their champion user against the wider descriptions given by charitable support organisations. The information also provides sign-posting for a literature review. Academic researchers can help deliver baseline and long-term studies in the AT market to reduce the risk for new or small design businesses coming to this market.

A key element of a blacksmith approach (coined by the author in article 5.1.9) and of AT participatory co-designing is the development of a dialogue as shown in article 5.1.7. Using conventional design visualisation methods as a basis, Table 3 provided a novel insight into how a dialogue may be enhanced through the use of conventional methods of design communication.

In the introduction it was stated this was an on-going research programme. The methods and heuristics appropriate to be applied within an AT new product development process have been identified, prioritised and ordered for application.

Additional aspects that underpin the efficacy of the methodology are the ethics protocols required for every study. Ethics protocols have only recently been widely applied within an ID process. The protocols demand consideration of the requirements for all parties involved in research and development of new products. Another aspect underpinning an AT-ID process is dialogue. The effective and efficient establishment of a relationship and format for communication between designer, user and associated stakeholders is critical to the effectiveness and cost-viability of an AT-ID process. The two aspects highlighted have contributed to a paradigm change towards a more user-centric approach to an AT-ID process. This matches the paradigm shift towards the social model from the medical model of healthcare over the period of the articles.

The commentary has highlighted a number of novel elements over and above the previously described design outcomes:

- Development of the HOPI model to assist in optimising physical interfaces of AT products;
- Development of the persona footprint heuristic to bring forward the visual personality of an AT product end user;
- The highlighting of the importance of dialogue to the proposed AT-ID process (LAT-UCD);
- The use of a 'Blacksmith approach' and 'Champion user' to cost-effectively reach design decisions; and,
- The awareness of the narrowing of options for dialogue as the severity of impairment increases (as shown in Figure 4) and the associated look-up table (Table 3) of dialogue formats matched to impairment.

Further validation of the appropriateness of the methods and heuristics shown in Table 6 is required with a larger design audience, as many of the decisions for identification and placement of elements were based on qualitative decision-making.

What has also been highlighted is the need for more investigation into ways in which the perception of AT products may be made more inclusive for those who use them and by UK society.

7.1 Future work

Further validation of the selection, order and priority of the design methods and heuristics is required. The methods identified within the ten articles have only been grouped under the five phases. Further studies focusing on the efficacy of methods and heuristics within the individual phases are required. A Delphi study or expert review may be applied to gain consensus from those working in the AT industry that the prioritised methods and their order are optimum for human-scale and body-worn products.

Replication of the review of methods and heuristics should be done in other countries. For example, the insurance-driven healthcare system applied in the United States may give a different priority balance for the methods in the methodology presented.

Additional investigation is also required into the efficacy of the different methods of design communication within co-design activities.

How to deliver 'Resonant design', as defined by Graham Pullin (2009), within the context of social acceptance is the priority challenge for AT product designers in the future. The mechanisms of why reading glasses may be considered 'cool' and wheelchairs 'not' need clarification. The associated design methods and heuristics that manipulate individual and societal perception also require definition. This should lead to positive and inclusive reframing of this product group and Society's view of the individuals who use them.

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