THE DEVELOPMENT OF AN ELECTRONICALLY OPERATED WATER CONTROL SYSTEM INCORPORATING A MAJOR THEME OF INCLUSIVE DESIGN

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ABSTRACT

This case study followed the development of an electronically operated water control system, using a structured product development process and incorporating a major theme of inclusive design. Three project objectives were identified for this project:

1. Use the Product Development Process to successfully develop an electronically operated water control system to a stage that is near ready for manufacture.

2. To understand and implement an inclusive design approach to the development of an electronically operated water control system to ensure that the product is usable by people regardless of age or ability.

3. To understand to what effect design decisions, related to the usability of a product, have upon the desirability of the product to all users.

The product development process used in the development of this product was successful. It resulted in an innovative new product idea that has associated intellectual property, currently under patent application. The product was identified as both usable to people with a wide range of impairments and desirable to a majority of all potential users.

The research methodology relating to inclusive design resulted in the finding that some design decisions relating to the usability of products do in fact affect the desirability of the product to other potential users, and hence could potentially affect the financial success of the product. A set of activities were identified from the process used in this case study and recommended for further product development projects, which will help to ensure that the product is made more usable while still retaining its desirability.

KEYWORDS

Product Development Process, New Products, Inclusive Design, Consumer Based Design, Successful Products, Elderly and Disabled

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For your motivation, love, support and help that got me through

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For your love, understanding and good sense which has kept me sane throughout, and seen me through to the end

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

In the developed world, we live in a society, which is reliant on products to perform the everyday tasks of living. We need cars and bikes and trains and buses to get to work in order to make money to buy food, which we purchase using eftpos and credit cards. We need stoves and microwaves to cook our food, and knives, forks and plates to eat it. Every single minute of every day involves an interaction in some way with a man made product. These products, which we are so reliant upon, include the physical objects and the human activities, which go with them. Furthermore, products include the knowledge about how they work, how to repair them, design them and make them. This package, which encompasses a product, is often termed technology or innovation.

How technology has influenced our society and similarly how society has influenced technology has been the topic of many literary debates. Theories such as 'technological determinism' claim that change in technology is the most important cause of change in society. There are two fundamentals to this line of argument. The first is that technology is separate from society, and the second is that technological change causes social change. Authors such as MacKenzie and Wajcman (1985) have argued against these fundamentals convincingly showing that indeed society does influence technology and not the other way around. MacKenzie and Wajcman (1985) provides a very accurate portrayal of the relationship between the two "A new device merely opens doors, it does not compel one to enter".

Societal influences on technology include demographics, culture, economics, and politics. These influences are both local and global and are forever changing the direction technology is following. A specific societal trend, which will be investigated as a major theme in this research, is "inclusive or universal design". Inclusive design relates specifically to the development of products and processes to be usable by people with the widest range of abilities possible.

There is a second major influence on technology in our present day, which enables society to have such a major effect on the path, which technology follows. This second influence comes from the corporations and companies producing new technologies and their need for return on investment. A product, which does not meet the requirements or needs of society, will fail to achieve an acceptable level of profit for the organisation or company involved. The factors which influence a positive return on investment include the uniqueness of the product, the investment provided by the company, and the total size of the markets into which it is being sold. As far as companies are concerned "profitability is the key, and the contribution that product generated income makes to this will be seen as the most important factor in assessing the worth of the product to the company," (Wright 1990).

Product development is the process whereby societies needs can be accommodated by the development of new technologies or improvement of existing technologies. It is defined as 'a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product.'(Ulrich and Eppinger 1995). The product development process is a decision making process which allows product developers and product development teams to consider and compromise between any number of factors which may influence the product outcome. These factors include things such as: the natural environment, product environment, development cost, development time, usability, safety and many more. It is the developer or individuals within development teams, who choose which factors to consider in these decisions; and obviously, in order to develop a successful product, the developers need to consider the factors which best reflect societies needs.

1.1 PROJECT INTRODUCTION

At the end of 2003 a market opportunity was recognized for the replacement of taps with an electronic alternative. Existing taps and faucets offered problems to people with certain special needs; in particular people with neuromuscular impairments, people with skeletal impairments, and people with sensory impairments such as loss of sight and touch sensation. The introduction of ceramic disk technology and new lever systems has made life easier but problems still exist with the use of these products. A number of electronic versions of tap and faucets are already available but they restrict the users ability to control such things as water temperature and flow. A review of available technologies, which may be used for the purpose of controlling water, led to the belief that a product could be developed, which would allow for the electronic control of both water temperature and flow. As a result the following product concept was outlined.

Product Concept: An electronically operated water control system, which allows users to control both temperature and flow from a user interface. The system and corresponding interface is intended to be used by users with a wide range of abilities and needs. The unit can be installed on any sink, bath or shower both as new or retro fit, and irrespective of the hot water system used feeding the facility.

An in depth market analysis was undertaken and showed interest from a number of areas. As well as the special needs groups who would directly benefit from such a product, facilities such as retirement homes, hospitals, schools and prisons all registered a high interest in the product. There was also a very high interest shown by the domestic market on the premise that the product would be offered in a competitive price range with conventional products. This research led to the design development and testing of an initial prototype. The results proved that the product was technically and financially feasible, meaning that the idea could work and it could be produced for an amount of money consumers were prepared to pay. The project was then taken over by an industry sponsor.

The industry sponsor was not interested in manufacturing and selling this product. They wished to develop the product further, in order to increase its worth to companies who may be potentially interested in manufacturing it.

The product incorporates two major systems, the user interface is the first and the valve system is the second. The initial prototype offered a very primitive form of both and the company realised that in order to increase the products worth both these systems would have to be developed in far greater depth. The development of the two systems involves very different activities. The interface development is very consumer orientated where as the valve development was very technically orientated.

1.1.1 Inclusive Design

As previously stated Inclusive design is a major social trend, which has begun to influence technology. The following passage about inclusive design was taken from a website dedicated to universal design www.udeducation.org. The passage is typical of the literature relating to inclusive design. (Bamforth and Brookes 2002; Bleamish 2003; Include 2004; RSA 2004)

"Inclusive Design is not a fad or a trend but an enduring design approach that originates from the belief that the broad range of human ability is ordinary, not special. Inclusive design accommodates people with disabilities, older people, children, and others who are non-average in a way that is not stigmatising and benefits all users. After all, stereo equipment labels that can be read by someone with low vision are easier for everyone to read; public telephones in noisy locations that have volume controls are easier for everyone to hear; and building entrances without stairs assist equally someone who moves furniture, pushes a baby stroller, or uses a wheelchair. Designing for a broad range of users from the beginning of the process can increase usability of an environment or product without significantly increasing its cost. It results in easier use for everyone and it reduces the need for design modifications later when abilities or circumstances change."

The passage represents the social influence that is being brought into this project; a product that is usable by everybody. However the second influence, profitability, does not result from a product that is **usable by everybody**, it results from a product that is **usable by everybody and is desirable by everybody**. In other terms it could be said that the product needs to be *usable* and *desirable*.

1.2 THESIS FOCUS

This thesis will focus on the development of an electronically operated water control system giving a description of the development process and outcomes as a case study. The development will result in a prototype product, which can be used for both demonstration purposes to potential buyers, and further consumer testing.

A major theme of inclusive design will also be explored. The tools techniques and its association with the product development process will be demonstrated in the development of this product.

1.3 AIM

To use the Product Development (PD) Process to develop an electronically operated water control system that is commercially successful and meets the needs of users with the widest range of abilities as possible.

1.4 OBJECTIVES

4. Use the Product Development Process to successfully develop an electronically operated water control system to a stage that is near ready for manufacture.
5. To understand and implement an inclusive design approach to the development of an electronically operated water control system to ensure that the product is usable by people regardless of age or ability.
6. To understand to what effect design decisions, related to the usability of a product, have upon the desirability of the product to all users.

1.5 OUTCOMES

- A working prototype of an electronically operated water control system that is usable and desirable by people with the widest range of abilities as possible. The prototype should be in a form that can be used to demonstrate the product to potential customers and manufacturers.

- A case study of an electronically operated water control system following the New Product Development Process used.
- A demonstration of the inclusive design principles, and how they were put into practice within this project.
- An investigation into the effect decisions relating to usability, have upon the overall desirability of this product.

1.6 THESIS OUTLINE

Chapter two provides a context for the case study and research through a review of the literature. It looks at the product development process and its relevance to this case study. It also reviews the secondary theme of inclusive design looking at its application to the development process. Also reviewed is any literature relating to the development of the technical components of this case study, the interface and valve system.

Chapter three describes the product development process used in this case study and outlines the methodologies which were used in the research portion of this thesis. Product development and inclusive design tools and techniques, which will be used, will also be outlined in this chapter.

Chapters four, five, and six present the case study. Chapter four focuses on the initial stages of the interface development process. Chapter five focuses on design conflicts raised in chapter four between usability and desirability of the interface. Chapter six presents the development of the valve system.

Chapter seven presents the conclusions of the case study relating to the product development process used and inclusive design.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Chapter two provides a context for this case study by examining the literature surrounding product development and inclusive design. It is split into a number of major sections. The first section reviews the research relating to the development of successful products in an attempt to identify actions, which will ensure the commercial success of this product. The next two sections review these identified actions in further detail specifically relating them to this project. The final section reviews the literature surrounding inclusive design. It looks at the arguments surrounding the subject and then at the application of the inclusive design within the Product Development process.

2.2 DRIVERS FOR THE DEVELOPMENT OF SUCCESSFUL PRODUCTS

The literature suggests that of the products that companies produce, new products are the most vital. (Inwood and Hammond 1993; Ali 1994; Rosenau, Griffin et al. 1996; Wilson, Kennedy et al. 1996; Jones 1997; Cooper 2001; McGrath 2004). Approximately 40% of successful companies profits come from products that have been introduced within the last five years (Cooper 2001; Crawford and Benedetto 2003). New products come in many forms from improvement on existing products to products that are completely new and have never been seen before. Crawford measures product newness or innovativeness on three levels: pioneering, adaptive and imitation. Cooper (2003) uses similar labels for levels of innovativeness, which reflect Crawford's measures in a simpler way. These are low, medium and high levels of innovation. These schemes for categorizing innovation reflect both the new technology used in a product and their level of resemblance to existing products. Regardless of the categorisation used for a new product it is apparent that for companies to continuously progress in terms of monetary success they must continuously improve the products or services they offer. The literature offers four main drivers, which have led to this constant need for improvement.

The first driver is the consumer and their ever changing needs and desires. Every consumer has needs or desires and they now have choices in products to measures these against (Visilash 1989; Griffin and Hauser 1993; Cooper 2001). Customers purchase a firm's products only when they find those products to be most effective in meeting their needs. These needs are continually changing. Every group of customers whether they are industrial or individual are themselves developing. They are becoming better educated, and are exposed to more and better communications and are hence becoming more discerning with higher expectations. The very act of consuming or using products changes the consumer.

The second driver is competition. Cooper (2001) painted the picture brightly, when he suggests that corporations everywhere are engaged in a new product war, where "The battlefields are the marketplaces around the world. The combatants are the many companies who vie for a better position, a better share, or new territory on each battle field or marketplace". If a company is to be successful or even stay in business, its products must be more valuable to their customers than other alternatives. It is a point that is made by many authors (Wright 1990; Inwood and Hammond 1993; Wilson, Kennedy et al. 1996; Jones 1997; Ellet and Brookes 2000; Crawford and Benedetto 2003; Swaddling and Miller 2003; McGrath 2004; Ulrich and Eppinger 2005).

The third driver comes from technological advances. Development in technology has not only led to new product possibility and better more affordable designs, but has paved the way for these products to be manufactured marketed and sold in larger numbers, for less money and to more consumers around the world. It has increased global competition, "giving access to foreign markets like never before, but at the same time turning domestic markets into somebody else's international market" (Cooper 2001).

The fourth driver is social expectations. Increasing technological advances, changing consumer needs and increased competition has lead to societies expectation of better quality products for less money. Cooper (2001) refers to a study conducted by A.D. Little, which shows that product life cycles have decreased by 400% over the last fifty years. New products no longer have a life span of five to ten years. Within a few years, even months, a product maybe replaced or superseded by a competitive entry, rendering it obsolete and necessitating the development of a new one.

Product development is a risky business. Although it is necessary to develop new products, many attempts fail. According to Christensen and Raynor (2003) three in five new product development efforts are scuttled before they even reach the market. Of the ones that do reach the market, 40% never become profitable and simply disappear. Cooper (2001) states similar figures quoting "An estimated 46 percent of the resources that firms spend on the conception development and launch of new products are spent on products that either fail commercially in the market place or never make it to the market". These statistics are however based on all types of new products. It is suggested that highly innovative, new to the world products have a much higher risk of failure than products which are simply new to a company (Rosenau, Griffin et al. 1996). However the monetary rewards for a highly innovative product are much greater than their counterparts. Avoiding all risk is impossible and would mean a company would have to avoid innovation, which would probably result in a slow death. However there must be ways of reducing this risk.

A number of studies have been undertaken to determine critical success factors in product development. Critical success factors deal with ways of reducing risk. Lynn, Abel et al. (1999) developed a model of the determinants of new product development success. They sent informants a series of case studies and ten key factors were identified as a result. Lester (1998) identified a range of potential problems that could derail well-intentioned New Product Development (NPD) efforts. By working through these problems, Lester discovered fifteen critical success factors in five areas of new product development. Barclay and Poolton (1998) identified a set of six variables that have been consistently identified in the literature as being associated with successful NPD. Cooper (2001) studied hundreds of cases to reveal what makes the difference between winning and losing. He extracted fifteen critical factors in ensuring success in new product development. Table 2-1 represents a summary of the critical success factors resulting from these studies. It should be noted that the projects used to obtain these success factors where measured as successful in monetary terms.

Table 2-1 Critical success factors for NPD identified by previous researchers

Study	Critical success Factors Identified
Lynn et al. (1999)	1. Having a structured NPD process 2. Having a clear and shared vision on the team 3. Developing and launching a product within the proper time frame 4. Refining a product after launch and having a long term view 5. Possessing the optimal team skills 6. Understanding the market and its dynamics 7. Securing top management support 8. Applying lessons learnt from past projects 9. Securing good team chemistry 10. Retaining team members with relevant experience
Lester (1998)	1. Senior management commitment 2. The culture of the organisation 3. Cross functional teams 4. Focus on adding value to the efforts of the venture team 5. Provide strategy and fundamental guidelines 6. Share a common understanding of the process 7. Innovation requires expertise, skills and motivation 8. Generating good ideas 9. Team formation events 10. A detailed project tactical plan 11. Clear goals and milestone measures 12. Shift to an external focus to run the new product venture 13. Understanding in the venture team 14. Communication to management 15. The insight gained through reassessment efforts
Poolton and Barclay (1998)	1. Top management support for innovation 2. Long term strategy with innovation focus 3. Long term commitment to major projects 4. Flexibility and responsiveness to change 5. Top management acceptance of risk 6. Support for an entrepreneurial culture
Cooper (2001)	1. Unique superior product 2. Customer focused NPD process 3. International orientation to product design 4. Predevelopment Work 5. Sharp stable and early product and project definition 6. A well planned adequately researched and proficiently executed product launch 7. The right organisational structure, design and climate 8. Top management support 9. Leveraging core competencies 10. Market attractiveness 11. Build tough Go/Kill decision points into the NPD process 12. Emphasis on completeness, consistency, and quality of execution of key tasks from beginning to end of project 13. Resources in place 14. Increase time of market but not at the expense of quality 15. Follow a structured stage gate NPD process

The critical success factors resulting from these studies are not all exactly the same, and it is in fact difficult to generate a common set of factors. The success factors relevant to this research have been identified. These relevant factors have been categorised into three core groups. These are company focused success factors, team focused success factors and project focused success factors.

Company focused success factors are those that appear to be aimed at entire organisations. The critical success factor, which is common amongst all studies and fits into this category, is "securing top management support." The other critical success factors in this group are focused on ensuring the company is prepared to back new ideas. Any new ideas should also be aligned with the company strategy and core competencies. This group of success factors is most relevant to larger companies and are not overly relevant to this case study. It should be mentioned that the sponsor company of this project has a high involvement in the development of this project and has given their full support to the development efforts.

The team focused critical success factors revolve around having a cross-functional development team, which has adequate skills, knowledge and expertise to develop a successful product. It is suggested that the core of the team be made up of individuals from the marketing, design and manufacturing functions of the company (Rosenau, Griffin et al. 1996; Cooper 2001; Crawford and Benedetto 2003; Ulrich and Eppinger 2005) with the inclusion of sales and finance and also individuals who may have specific skills relating to the project (Ulrich and Eppinger 2005). This project will not involve the use of a cross functional team. A single product developer will undertake a majority of the work with other company members available to offer help and insight.

By far the most relevant critical success factors to this project, which can be directly reflected on within this case study, are the ones which fit into the project focused group. I have categorised the critical success factors within this group under four headings, which serves to group the factors from each study into common critical success factors. This is shown in Table 2-2.

Table 2-2 Critical success factors in new product development relevant to this project

A unique superior product	
Lester (1998)	8. Generate good ideas
Cooper (2001)	1. Unique, superior product
Structured NPD process	
Lynn et al. (1999)	11. Having a structure NPD process
Cooper (2001)	11. Build tough Go/Kill decisions into the NPD process
	15. Follow a structured stage gate NPD process
Lester (1998)	10. A detailed project tactical plan
	11. Clear goals and milestone measures
Customer focused NPD process	
Lester (1998)	12. Shift to an external focus to run the venture
Cooper (2001)	2. Customer focused NPD process
Good management of the NPD process	
Lynn et al. (1999)	3. Develop and launch the product with in the proper time frame
	4. Refine the product after launch and a have a long term view
	6. Understand the market and its dynamics
Lester (1998)	5. Provide strategy and fundamental guidelines
Cooper (2001)	4. Predevelopment work
	5. Sharp, stable and early product and project definition
	6. A well planned adequately researched and proficiently executed product launch
	10. Market attractiveness
	12. Emphasis on completeness, consistency, and quality of execution of key tasks from beginning to end of project

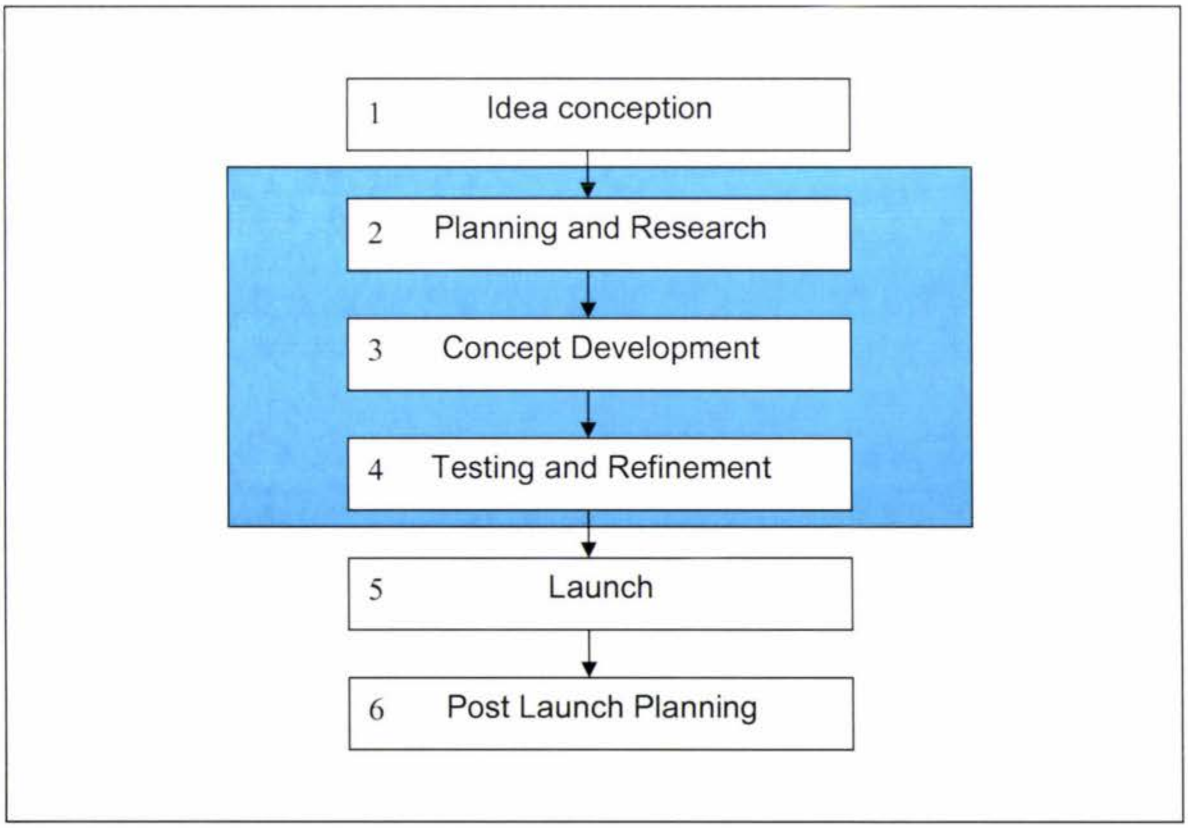
These four success factors have been identified as crucial to the success of this development project. For this reason the success factors will be a point of focus and will be discussed were relevant throughout the remainder of the literature review and case study.

2.3 NEW PRODUCT DEVELOPMENT PROCESS

The New Product Development (NPD) process is in a state of constant change (Veryzer and Robert 1998; Crawford and Benedetto 2003). As new organizational structures are adopted, new technologies become available and product development strategies are redefined. The core NPD process itself is continually being modified to embrace and accommodate these changes (Crawford and Benedetto 2003). The product development process has evolved from one that is managed and moves sequentially through the development stages, to one in which the overlapping nature of the various stages is recognised and managed (Cooper 2001; Crawford and Benedetto 2003).

Considerable variations exist in the processes adopted by different designers and different companies. An individual product may demand a modified process for its development, sometimes because of the need to incorporate new technology, and sometimes to meet specific market requirements (Wright 1990; Crawford and Benedetto 2003; Ulrich and Eppinger 2005). Despite these variations, the development process has been frequently modelled to explain the various stages, and help organisations plan product development more effectively. Authors such as Cooper (2001), Ulrich and Eppinger (1995) and Crawford (2003) have all suggested various NPD processes, and although different, they tend to have the same basic progression of activities over the coarse of the process. These activities have been shown in Figure 2-1, which represent this basic progression. It should be noted, that this case study revolves around activities, two, three and four, which have been highlighted with the blue box.

Figure 2-1 Basic Progression of activities in the NPD process



Although NPD best involves input from all functions of an organisation, three have been identified as being the most important; Marketing, Design and Manufacturing (Ulrich and Eppinger 2005). Cooper (2001) quotes a Stanford Innovation Project study of new product launches in high technology firms, which reveals that a critical distinguishing factor between success and failure is the "simultaneous involvement of create, make and market functions" (Cooper 2001). A review of these functions and their influence upon this case study is given below.

2.3.1 Marketing

The marketing function is what mediates the interaction between the firm and its customers. Marketing often facilitates the identification of product opportunities the definition of market segments and the identification of consumer needs. Marketing also typically arranges for communication between the firm and its customers, sets target prices, and overseas the launch and promotion of the product (Ulrich and Eppinger 2005).

As shown by the blue box in Figure 2-1 this case study only involves a portion of the NPD process. For this reason marketing's main purpose will be to ensure that the NPD process follows a consumer based design approach as mentioned to be one of the critical success factors earlier. This means that the marketing function will primarily focus on supplying the correct information from the customer that will allow design and manufacturing functions to make design decisions based on these desires.

2.3.2 Design

Design plays a lead role in defining the physical form of the product that best meets the customer needs. In this context the design function includes engineering design and industrial design.

Industrial Design focuses on the aesthetic side of the product, what it looks like, and how the user interacts with it. It is the most important function in determining how desirable the users find the product simply because it involves the development of the user related aspects.

Engineering Design focuses on the design of products so they function well mechanically (Crawford and Benedetto 2003). It includes structural, electrical, mechanical and other engineering focused aspects of the product (Ulrich and

Eppinger 2005). The engineering design function basically turns the industrial designed solution into a working functional product.

Clearly many of the requirements of both types of design will be in conflict, and it is up to the product developer to achieve all of them simultaneously (Crawford and Benedetto 2003). The design function with in NPD plays a major role in this case study. Both aspects of design, engineering and industrial will be demonstrated.

2.3.3 Manufacturing

The manufacturing function is primarily responsible for designing and operating the production system in order to produce the product.

This function generally falls outside the scope of this case study however considerations for manufacturing possibilities must be considered throughout the design of the product.

2.3.4 Decision Making Process

Many decisions have to be made within the NPD process. Marketing decisions, design decisions, manufacturing decisions and many more, all of which have effects and influences upon the overall success of the product. One of the main decision within product development that is commonly mentioned in the literature is that of the Go/Kill decisions proposed by Cooper (2001).

Cooper (2001) recommended building "Go / Kill" decisions into the process as an important way of reducing risk within the project. The reasons for this are simple. At the beginning of a project the amount of investment is generally very low however the uncertainty of the outcome is very high. As the project progresses the financial investment increases exponentially, increasing the risks if the project does fail. If the risk in the project is to be managed successfully the uncertainty of the outcome must deliberately be driven down as the stakes increase. "Uncertainties and the amounts at stake must be kept in balance" (Cooper 2001). The decision points in the stage gate process provide a means for driving down the risk. Each stage incorporates a set of activities undertaken by members from all functional areas within an organisation (Rosenau, Griffin et al. 1996; Cooper 2001; Crawford and Benedetto 2003; Ulrich and Eppinger 2005) which are designed to gather information used to make the decision as to whether the project should progress to the next stage. Each stage costs more money than the previous one, increasing the stakes. If the information gathered is perceived to be inadequate or does not decrease the uncertainty of the outcome then the decision is made to discontinue the development or wait for more information before the decision is revised (Rosenau, Griffin et al. 1996; Cooper 2001).

In this project a "Go / Kill" decisions was made at the beginning of this case study and another will have to be made at the conclusion of it. However, there are other, frequent, decisions, which will need to be made and portrayed, throughout this case study, and these are design decisions.

Concept selection is one of the most important design decisions which will be made within the scope of this project. A number of approaches have been identified. These range from "pro and con" lists, following intuitive feel, or having the decisions made by a concept champion, to using customer surveys or structured rating schemes or building and testing prototypes. Of these structured rating schemes provide the best combination of "discipline, flexibility, and amount of time and effort required", (Stoll 1999). The general procedure for using a structured rating scheme is as follows:

1. Develop evaluation criteria
2. Assign an importance weighting to each evaluation criterion
3. Rate each concept alternative with respect to each evaluation criterion
4. Compute an overall score for each concept alternative that can be used for comparison and/or ranking purposes

Structured rating schemes come in many forms 1) The utility function method (Stoll 1999) 2) Pughs method (Stoll 1999; Eppinger and Ulrich 2002) 3) Concept scoring matrix (Eppinger and Ulrich 2002). The utility function method and concept scoring matrix are relatively complex and are best used when rigourous analysis of competing requirements are required. Pughs method on the other hand is simple to use and can be applied quickly.

Design decisions, mentioned earlier define how the product looks and works. In order to make the product successful, the aesthetics and functional control should reflect the users needs and desires better than any of the competing products (Swaddling and Miller 2003). This means incorporating the consumer wants and desires into the NPD process. The next section of this literature review examines the research relating to this topic. It specifically looks at the methodologies and related tools and techniques, which result in a consumer, based, design approach.

2.4 CONSUMER BASED DESIGN APPROACH

A consumer based design approach is one where the needs of the consumer are incorporate and reflected on throughout the NPD process. The resulting product should therefore be designed in a way that best reflects the consumer's needs and wants (Ulrich and Eppinger 2005), resulting in a product that is desirable to the consumer.

Even in this product situation (where the product idea originated from a technical possibility identified, in contrast to a market demand) there still should be considerable consumer input (Cooper 2001) after all society needs to adopt the product in order to ensure financial success. Although the consumer may have little influence on the technical side of the product, it is necessary to involve the consumer and determine their need and wants with regard to the aesthetic and functional forms the product interface will take (Belliveau, Griffin et al. 2004). These are the aspects the user interacts with so by doing this it ensures the desirability of the product to society.

There are two definitive parts to a consumer based design approach. The first is actually hearing and recording the voice of the customer, and the second is incorporating the voice of the customer in the NPD process.

2.4.1 Voice of the Customer

In order to be able to meet the needs of the customer it is necessary for a designer to hear the voice of the customer (Griffin and Hauser 1993)

The term 'voice of the customer' relates to the process of identifying customer needs and turning these needs into hierarchal attributes. In this way the customer input can be used to affect both strategic and operational decisions during the products lifecycle. (Griffin and Hauser 1993; Development 2004; Ulrich and Eppinger 2005). More specifically, the voice of the customer is defined as "a complete set of customer wants and needs expressed in the customers own language, affinities and priorities"(Katz 2001). It is apparent from this definition that there is a number of phases involved in identifying the voice of the customer.

Before identification of customer needs can be undertaken, predevelopment work needs to be undertaken to understand which customers to incorporate into the needs definition. Although not a simple task, it can be made easier by firstly establishing some clear definitional project boundaries (Belliveau, Griffin et al. 2004; Ulrich and Eppinger 2005). These boundaries should encompass the scope of the project considering things such as product description, stakeholders, and constraints on the project, key business goals, and intended markets. Once some clear boundaries have been put around the project it makes it easier to identify which stakeholders will be beneficial in providing the voice of the customer (Belliveau, Griffin et al. 2004).

There are a number of suggestions as to which customers provide the greatest source of information. A commonly suggested method is to elicit the voice of lead users (Crawford and Benedetto 2003; Belliveau, Griffin et al. 2004). It is suggested that lead users have a better understanding of the problems. This project has no real lead users. It is a domestic product that everybody uses on a daily basis and therefore has infinite possibilities of customers who could provide information. It is suggested that an attempt be made to cover all bases of customers who could potentially use the product considering, demographics, geographical differences, user environments etc. Consideration should also be given for customers who have decision making authority or influence over the purchase of the product (Griffin and Hauser 1993; Belliveau, Griffin et al. 2004; Ulrich and Eppinger 2005).

The next phase involves actually gathering the needs and wants of the customer. This is done using, what is commonly referred to, as market research techniques. The literature provides numerous sources for different market research techniques. Overviews of accepted sources are given by, amongst others, (Ulrich and Eppinger

2005), (Griffin and Hauser 1993), and (Cooper 2001). A publication by the Design for Aging Network (1999) provides a structured overview of both traditional and emerging market research techniques. A summary of some of the more common techniques is given below in Table 2-3.

Table 2-3 Overview of market research techniques

Method	Description of Method
Beta testing	Working Prototypes are placed with selected customers to test the influence of environmental factors and customer satisfaction
Empathic modelling	Role-play, using adapted items such as eyewear, is used to simulate a physical disability
Expert user Groups	Participants with experience of a particular environment, process or artefact engaging in design evaluation
Focus groups	Discursive interactions between participants focusing on particular issues and moderated by a facilitator
Method description photo-essays	A photographic record of an activity, process or an interaction between a person and an artefact
Mixed design group	A customer workshop where designers and engineers work together with customers to generate product ideas.
Observation	A third party is watched and notes taken to record the activity of the interaction
Physical measurement of use	The anthropometrics, range of movement, grip strength, etc are measured to understand user capability
Product in use	The observation of people using products in real life
Questionnaires	The qualitative or quantitative collection of data
Scenario of use workshop	Customers take part in a role-play where facilitators act out an aspect of product usage and the identification of needs and ideas are recorded in real time
Structured interviews	A one-on-one discussion, with open questions, with conversational prompts rather than questioning
Task analysis	Defining and recording the actions and interactions of a person carrying out a particular task
Usability trials	Product evaluation and prototype testing by the target consumer population
User Diary	A record of participants interactions and activities within a defined environment and time span

While market research can be time consuming and costly (Aaker, Kumar et al. 1997) it is a necessary activity in the process of developing a product to fulfil the needs of the customer. Market research methods vary in the resources they require for implementation and the type of information they generate. The PRESENCE group (Netherlands Design Institute 2000) has produced a tool called the Methods Lab that enables the identification of marketing methods suitable for a given project, based upon the attributes of the methods and the needs of the project.

As stated earlier, the whole point of the voice of the customer is to obtain the customers needs and desires. Ironically it is suggested the *worst* way to extract the customer needs and desires is to ask directly, " what are your needs and desires?" (Belliveau, Griffin et al. 2004) Instead, it is suggested that customer's experiences and desired outcomes should be focused upon. What the customer uses the product for, what it is the customer is trying to accomplish and what things get in the way. Ulrich and Eppinger (2005) provide some helpful questions:

- When do you use this type of product?
- Walk us through a typical session using the product
- What do you like about the existing product?
- What do you dislike about the existing product?
- What issues do you consider when purchasing the product?
- What improvements would you make to the product?

Customer needs are expressed as written statements and are the result of interpreting the need underlying the raw data gathered from the customers. Each statement or observation may be translated into any number of customer needs (Ulrich and Eppinger 2005).

Once identified the needs must be arranged into a usable form. Generally the needs will be sorted into groups by placing similar needs into each group (Belliveau, Griffin et al. 2004; Ulrich and Eppinger 2005). The needs within groups are then placed into a hierarchal order with more detailed needs at the lower levels and more tactical and strategic needs at the higher levels. Usually this will result in three levels of needs, primary, secondary and tertiary. Tertiary needs will be allocated to a secondary need and secondary needs will be associated with a specific primary need. The design team most commonly performs this activity. However (Griffin and Hauser 1993) suggested that customers be used to sort the needs into a hierarchy instead of the design team. The advantages of this are that the resulting structure represents how the customers think, instead of how the design team thinks.

The next step is to establish priorities for the customer needs in the form of importance weightings. These weightings aid in allocating the engineering resources and guide the development, when tradeoffs must be made between needs. Generally consumers are asked to rank the needs on some form of numbered scale, which represents the importance of each need. Three such scales are suggested by Griffin and Hauser (1993) and they are:

(1) 9-point direct rating scale in which customers answer for each need, " how important is it or would it be if....(need)?" were 9 is most important and 1 is not important.

(2) Constant sum scale in which customers allocate 100 points between the primary needs, then allocate 100 points to each set of secondary needs and 100 points to each set of tertiary needs.

(3) Anchored scale in which customers allocate 10 points to the most important primary need and up to 10 points for the other primary needs. Similarly up to 10 points are allocated to each secondary need corresponding to a primary need and also to tertiary needs corresponding to secondary needs.

Ulrich and Eppinger (1995) suggest a similar scale to the 9-point scale but with only five points. The points range from 1. Feature is undesirable; I would not consider a product with this feature, through to 5. Feature is critical; I would not consider a product without this feature. The authors also point out the fact that few customers will respond when asked to rank 100 needs, so typically, customers will only be presented with a subset of needs.

An important question, which is raised, is how many customers need to be researched to identify all of the needs? It is a question that was answered in a study by Griffen and Hauser (1993). Their findings are widely accepted and referred to in product development literature including Ulrich and Eppinger (2005), and Cooper (2001). There conclusions showed that 30 one on one interviews each lasting 45 minutes, produced nearly 100% of all the needs, and 20 interviews produced nearly 90% of all needs. This is an area that most literature agrees with and it is suggested that between 20 and 30 customers should be researched to identify a majority of the needs. It should also be noted that this number is significant with respect to statistics commonly being cited as a good sample size for adequate statistical analysis.

2.4.2 Incorporating the Voice of the Customer into the NPD Process

Having gathered the voice of the customer, the next phase is to incorporate this input into the product development process. As with the process of identifying the voice of the customer, tools and methods are also available to assist in the incorporation of the customers voice into the design process. Such tools and methods include Quality Function Deployment (Visilash 1989; Griffin and Hauser 1993; Berquist and Abeysekera 1996; Wu 2002), Concurrent Engineering (Bamforth 2003), Strategic Design (Huthwaite 1995), Requirement Trees (Wright 1990) and the needs metrics matrix (Ulrich and Eppinger 2005). These tools and methods focus on turning the user needs into a form, which will guide the development; either specifications or design guidelines, which can be used as measures to test the developed concepts against. Concept selection is an important aspect Verification, through out the process, is undertaken to determine whether the resulting concepts are meeting the initial needs identified and hence desirable to the user.

The literature used to gather the above information both concerning the voice of the customer and its inclusion in the NPD process, related to relatively well-defined existing product categories. This means that the consumer had a fairly good idea of what the product might look like and how it worked; they may have even used similar existing products before. This case study, however, involves the development of a product that is highly innovative. There are currently no electronic taps, which allow users to control all the functions they can currently control with conventional taps. For this reason, the review of the literature surrounding the development of what's called "new to the world" products was undertaken (Belliveau, Griffin et al. 2004).

2.4.3 NPD of New-to the World Products

Although New to the World products are sometimes hard to comprehend and have sometimes never been seen before, there are usually alternative products that people use to accomplish the same type of task (Belliveau, Griffin et al. 2004). In this situation, conventional taps are used to accomplish the same task. Consumers can therefore be asked questions relating to the use of existing taps, and the problems and benefits of these can be obtained. However, it is still important to understand users needs with regard to the new technology. It is suggested that it may be necessary to present the user with initial concepts with which they can discuss their likes, dislikes, questions and doubts (Belliveau, Griffin et al. 2004). This process is made a little more complicated because of the incorporation of concepts.

2.5 INCLUSIVE DESIGN

2.5.1 What is Inclusive Design?

"Inclusive design is a process whereby designers, manufacturers and service providers ensure that their products and environments address the widest possible audience, irrespective of age or ability" (RSA 2004). There are many references to this general idea in the literature, however, they use various other names as well, such as Universal Design (Design 2004) and Design for All (Include 2004). The aim of this approach to design is to include the needs of the people who are currently excluded or marginalized by mainstream design practices, (Design 2004; Include 2004; RSA 2004). The literature suggests that these people are the elderly and disabled. The needs which are excluded or marginalized are mainly related to the usability of products (Vanderheiden 1990; Include 2004; RSA 2004). It is commonly acknowledged that it is impossible to design products so that 100% of people can use them (Vanderheiden 1990; Include 2004; RSA 2004), however, the intent is that all people who have a drive to purchase and use a product should be able to do so.

2.5.2 Why Inclusive Design is important

A majority of the literature was found from websites put together by a number of organisations which include: RSA (Royal Society for Encouraging Arts, Manufacturing and Commerce), INCLUDE (the result of a four year cooperation between European experts in the areas of telematics applications and elderly and disabled people), and The Centre for Universal Design.

The literature focuses on three real drivers of inclusive design. These are population ageing and the trend to bring disabled people into the mainstream of society;

increased recognition that inclusive design can be a tool for commercial growth; and growing anti-discrimination legislation.

2.5.2.1 Demographics

It is well documented and consistently mentioned in inclusive design literature that both the number of older and disabled people and their proportion in the total population is increasing (Vanderheiden 1990; Coleman 1993; Haigh 1993; Peters 1994; Myerson 2002; Design 2004; RSA 2004). This is due to the decline in the birth-rate, increase in life expectancy and decrease in mortality rates at higher ages. These phenomenon have been attributed to healthier living, better medicines and vaccines, and health facilities. The majority of this literature quotes American or British disability statistics. Out of interest, a review of the 2001 New Zealand Disability survey was undertaken to determine the trend in NZ. The results from the 2001 survey show that:

- One in five New Zealanders has a disability - A total of 743,800 people reported having some form of disability - An increase of 41,800 since 1997.
- Disability increases with age. Eleven percent of children (0-14 years) have a disability; compared with thirteen percent of adults (15-44 years), and twenty five percent of adults (45-64 years). Fifty four percent of people aged 65 years and over reported having a disability.

The various arguments relating to age and disability issues are based around a number of points.

1. Elderly and disabled people are no longer a minority (Vanderheiden 1990; Myerson 2002; Design 2004; RSA 2004);. This is true in New Zealand; 20% of the population registered having some form of disability in 2001. This reflects perfectly one of the identified drivers of NPD; that of changing market needs. Obviously, as the demographics of the market changes than so do the needs, which represent that market.
2. Disabilities are everyone's future (Caplan 1992). Caplan points out that everybody will be disabled at some point in their life. Broken arms,

pregnancies, and especially old age all are a form of disability. "If you don't have special needs now, be patient: you will" (Caplan 1992).

3. People aren't disabled by disability they are disabled by design (Covington 1994; Include 2004). George Covington, a legally blind activist, journalist and lawyer, makes this point. He states "our individual disability becomes a handicap only when we encounter a barrier. Designers, not god, created most of the barriers we face."(Covington 1994)

2.5.2.2 Legislation

Recent and forthcoming legislation on a global scale will place significant obligations on employers, building managers, retailers and service providers, and eventually manufacturers, not to discriminate against people on the basis of age or capability. It is a point raised by numerous sources (Design 2004; RSA 2004). However, legislation currently applies to universally designed residential and commercial facilities. It has been predicted however, that the focus of legislation may change and begin to extend to consumer products.

2.5.2.3 Business Sense

It has been stated that taking an inclusive approach to design can yield additional financial benefits (Vanderheiden 1990; Include 2004; RSA 2004). (Tischler 2004) provides a real life example of a company whose profits increased only once the CEO became disabled, and they began incorporating the needs of the disabled into the design of their products. Vanderheiden (1990) approaches the subject by pointing out two key points. The first is that, Inclusive design can be undertaken with little or no cost and he even provides examples where inclusive design has decreased manufacturing and maintenance costs. It is a point which is also made by other authors (Covington 1994). His second point is that inclusive design can increase the functionality of products for able-bodied users. A product that is usable by people with disabilities should also be very usable by able-bodied users. (Benktzon 1993) The changing market identified earlier in the section provides a perfect opportunity for companies to differentiate themselves from their competition. The changing market represents changing needs and any company who addresses these needs will undoubtedly increase their chance for success.

Arguments against inclusive design of consumer products are not frequently found in the literature. Comments that have been made, however, include arguments that inclusive or universal design may lead to a mainstream society that doesn't allow people enough of an opportunity to be individuals. (Bevington 1992)

The drivers for inclusive design are stated merely to make designers and product developers aware of the opportunities inclusive design offers. The literature suggests that the approach is not only ethical but makes good business sense as well. It is up to the Product Developer to decide for him or her self whether or not to take this approach. Deciding to develop products based on an inclusive approach to design is however only one side of the coin, the other is actually doing it.

2.5.3 Inclusive Design and the Product Development Process

The act of designing products that are inclusive is very similar to that of designing any product. The same success factors are applicable and the same methodologies tools and techniques reviewed in previous sections of this chapter should be used (Vanderheiden 1990; Design 2004; Include 2004). What does change are the consumers that these methodologies, tools and techniques are applied to. The acknowledgment that it is elderly and disabled users who have specific usability needs that are currently being ignored has led to strong arguments within inclusive design literature for carrying out research among groups, which have the most difficulty (Design 2004; Include 2004; RSA 2004). The Netherlands Design Institute put it 'if designers succeed in understanding the problems and limitations of older and disabled users and apply this knowledge, a much larger group of non-model consumers will stand to gain - getting things right for them, might hold the key to getting things right for all of us'. RICA backs this claim up and has consistently found, that designs, which accommodate the people who have the most difficulty, are easier for everyone else too.

A number of resources are available on line, which outline design guidelines concerning usability issues for consumer and electronic products. Of these the Trace guidelines are the most relevant and can be found at www.trace.wisc.edu. These resources have identified design options which when incorporated allow easier use by those users whose needs are currently neglected.

Websites such as www.stakes.fi/include/1-4.htm and www.inclusivedesign.org.uk provide various examples of product development efforts, which have taken an inclusive design approach. These consistently show the use of elderly and special needs users in obtaining the voice of customer and continued concept testing. The projects also involve a strong focus on usability testing, ensuring that the product is adequately usable by all consumers.

2.6 DESIRABILITY IN INCLUSIVE DESIGN

"Desirability" is a term, which will be used throughout this research to describe a users want for a product. The term reflects the ability of a product to satisfy its total potential market. Inclusive design literature commonly acknowledges the financial pressure, which so heavily influences the product development processes (Ward 1990; Moggridge 1993; RSA 2004) and agrees that a product must also be financially successful. One of the arguments for inclusive design suggests that by developing a product that Is inclusive in nature you are widening your potential consumer base and therefore increasing your chance for financial success. The problem with this assumption, however, is that at some stage in the development, desirability of the product to the entire market and usability of the product to consumers who are being included in the design approach, will conflict. Design decisions which influence the usability of a product may increase the desirability of the product to users who benefit directly, but what effect, positive or negative, does this have on the desirability of the product to other potential users? I can find no evidence in the literature, which suggests that these issues are even considered, let alone resolved.

2.7 CONCLUSION

Any product development project has associated financial risks to the sponsor company. The literature suggests the risk involved in developing a new product can be managed and reduced. Ways of doing this were identified in the form of Critical success factors, which outline factors that have been demonstrated to affect the commercial success of development efforts. Critical success factors, which are relevant to this project, were identified in Table 2-2. These were then categorised into the following four major headings:

1. A unique superior product
2. Structured NPD process
3. Customer Focused NPD process
4. Good management of the NPD process

1. The product being developed in this project is an automatically operated water control systems. There are major benefits associated with the product concept that will differentiate this product from all other existing water control systems. The product will not only be easier to use by people with impairments but offers superior features that potentially will benefit everybody.

2. The New Product Development process to be used in the development of this product focuses mainly on three specific stages, Planning and Research, Concept Development and Concept Refinement. These are generic stages and will be split into further stages in chapter three which outlines the development methodology to be used.

3. The initial stages, of a customer focused product development process, involves listening to, and then recording, the voice of the customer. Methods, tools, and techniques currently in best practice, were reviewed in the body of this literature review. These will be discussed further, and employed were applicable, throughout this case study. The needs and wants reflected through the voice of the customer must then be adapted into a set of specifications, which can be used to guide the development. The specifications can be presented in a number of forms. Firstly

design specifications, which reflect qualitative needs such as "The interface doesn't have sharp corners", and secondly metrics which represent quantitative needs such as "The torque provided by the drive motor is at least 6.5 Nm".

4. Three core functions are crucial to successful product development; these include marketing manufacturing and design. In a company environment individuals from each of these functions would form the development team, which would be managed by a single project manager. This project utilises a similar structure with less personnel. A single product developer will be responsible for the development of this product with input from other personal who have expertise in the relevant areas required, such as marketing, design, manufacturing, engineering and electronics.

This product potentially offers superior benefits to the special needs market. Literature surrounding the development of products for users with special needs was reviewed. Inclusive design was identified as an approach, which could potentially be used to incorporate the needs of users with impairments into the NPD process. The literature identifies inclusive design as an approach to design, which considers the needs of the widest audience as possible irrespective of age or ability. The needs, which are identified as being neglected at present, are usability needs. It is suggested that these needs are addressed by taking a consumer based design approach revolved around customers who potentially will have the greatest difficulty using the product. The literature provides large amounts of evidence, which suggests that doing this results in products which not only accommodate users who have impairments but are easier for all users to use. Understandably inclusive design has a major focus on the adaptation of external features of the product such as interface size and colouring. There is however little indication within the literature reflecting what impact these usability changes have upon the desirability of the product to other potential users.

The literature review has led to a number of outcomes. Firstly the identification of strategies, methodologies, tools and techniques, which should help, reduce the financial risk involved in the development of this product. A structured consumer based design approach will be taken. The design methodology and tools and techniques to be used through out the development are discussed in further detail in chapter three.

Secondly the literature review has identified inclusive design as an appropriate approach to be taken in this case study. The approach and effect this approach has upon the potential success of the product will feature as a major theme in this case study. The investigation will focus upon design decisions relating to the usability of the product and the resulting effect this has upon the desirability of the product to other users. The methodology to be used in this investigation is outlined and discussed in chapter three.

CHAPTER 3

PRODUCT DEFINITION AND DEVELOPMENT METHODOLOGY

Chapter three outlines the design methodologies, which will be used to achieve the project and research objectives identified in chapters one and two. The chapter is arranged in three specific sections. The first section introduces the project and its major components outlining the overall design methodology to be used. The later sections look at the development methodologies for the two major project components in greater detail, introducing the tools and techniques identified in chapter two where applicable.

3.1 PROJECT OUTLINE

The product description is given below. It outlines the purpose and proposed design parameters that the product must meet.

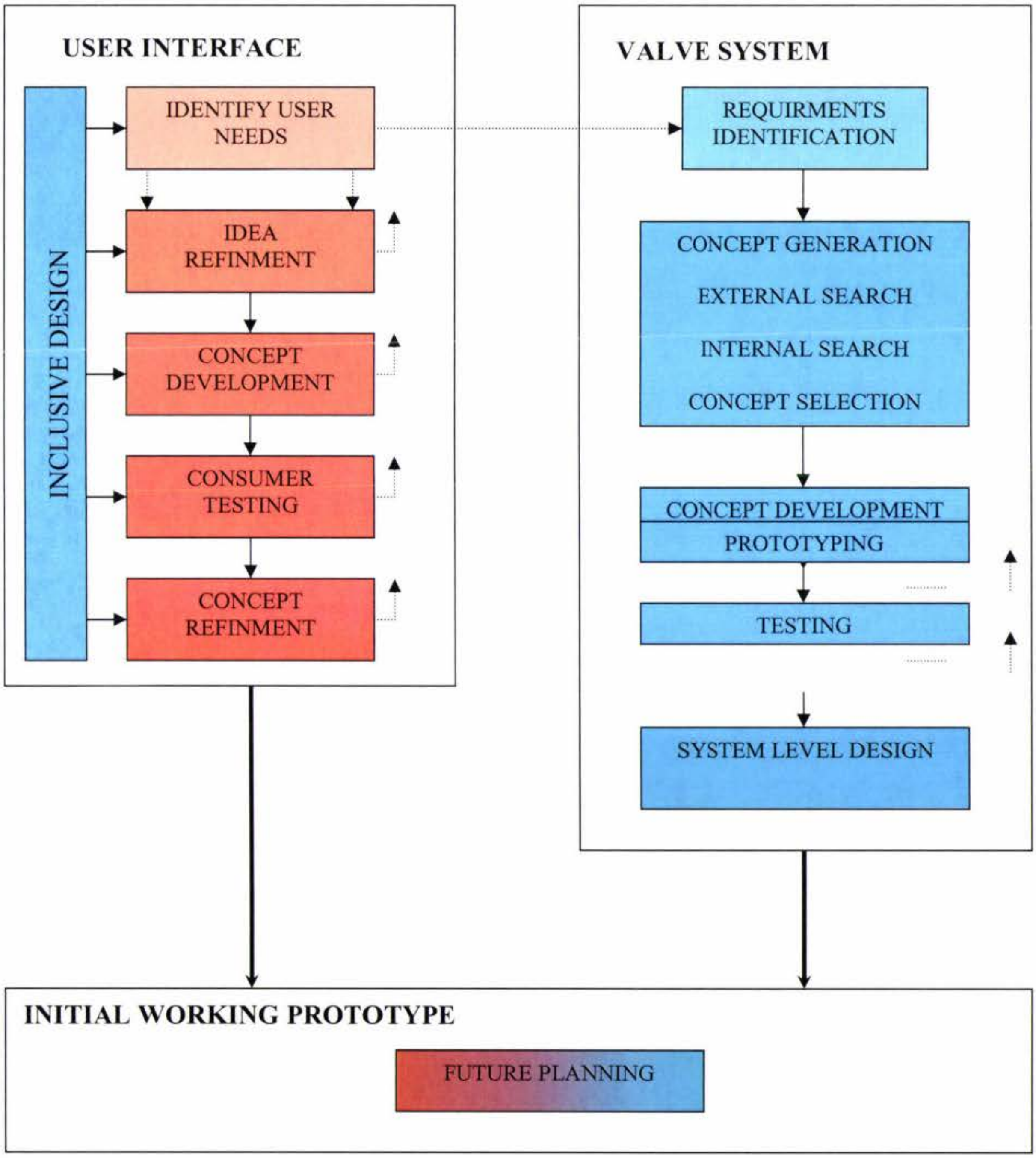
Product Description: An electronically operated water control system to replace manually operated water control systems. It will be as safe and reliable and perform all functions currently controlled by existing manually operated systems.

This product was made up of two major components. These were:

1. The User Interface – Provided the user with the capability to control the water characteristics. Essentially was the product from the consumers point of view.
2. The Valve System – Provided the manipulations, which controlled the out flowing water's characteristics. This part of the product was essentially invisible to the user and only affected such product features as its price and reliability.

The two systems are very different and both required separate approaches in their development. This is represented in shown Figure 3-1which outlines the design methodology to be followed in this case study. The stages included in the design methodology were identified from the NPD processes reviewed in chapter two and were deemed necessary to reach the project outcomes. Justification for inclusion of these stages is described in the next two sections of this chapter.

Figure 3-1 Development Process for this case study



3.2 USER INTERFACE DEVELOPMENT METHODOLOGY

This section discusses the methodology outlined in Figure 3-1 relating to the development of the user interface. It focuses upon inclusive design and the methodologies associated with both its application and the effect this has upon the process. It then outlines each of the stages involved in the interface development along with the methodologies, tools and techniques to be used with in them.

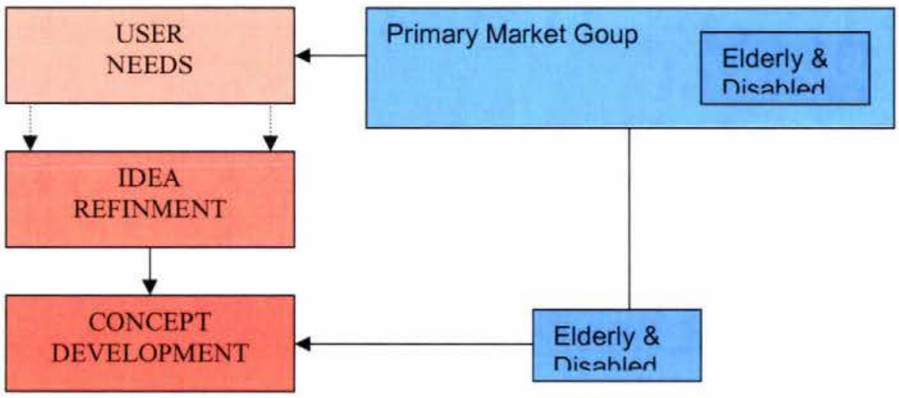
3.2.1 Inclusive Design

As stated previously the user interface provided the interaction between the user and the product. For this reason it was the component of the product was influenced the most by taking an inclusive approach to design. This meant ensuring that the product met the needs of users with the widest range of abilities as possible. The literature reviewed in chapter two identified the accepted methodology for taking an inclusive approach to design.

3.2.1.1 Inclusive Design Methodology

Inclusive design is achieved through the inclusion of the needs of elderly and disabled users in the initial stages of the NPD process. This basically meant that the primary market was not limited to able-bodied users but branched out to include all potential users of the product. The needs gained from the inclusion of these groups mainly relate to usability issues and should provide the product developer with insights into the features, which affect the products usability to these people. It was recommended, that the design decisions made throughout the concept development phase be influenced and tested by the users who have the greatest difficulty using associated parts of the product. In following through this process, the main product architecture was outlined by all users but specific features relating to the usability of the product were altered in the concept development phase with the help of users who had the greatest difficulty, in order to achieve a product that was more usable by all. This process demonstrated in Figure 3-2, shows the initial stages of the NPD process, used and the users who influenced each stage.

Figure 3-2 User influence on the initial stages of the NPD process when taking an inclusive approach to design.



The research objective identified as a result of the literature review relating to inclusive design aimed to investigate the effect that design decisions influenced by users with the greatest impairment, had upon the desirability of the product to other users. It was recommended that the primary market group be split into two distinct market groups. The first group included those users that inclusive design literature suggests should influence the usability design decisions (Special needs users); and, the second group included the users who might have been affected by those decisions (able bodied users).

Primary market group: All users who had an intention to use a water control facility such as sink, shower or bath were potentially users of this product, however a focus was put on home owners as it was those people who would most probably be purchasing the product. This primary market will be broken into two market groups.

Market Group 1(MG 1). Special Needs Users – Included all people regardless of age that had some form of impairment and intentionally wished to operate a water control facility.

Market Group 2 (MG 2). Able-bodied users – This group included users of all ages that did not have some form of impairment and intentionally wished to operate a water control facility. This group would generally be considered the primary market from a conventional design approach perspective.

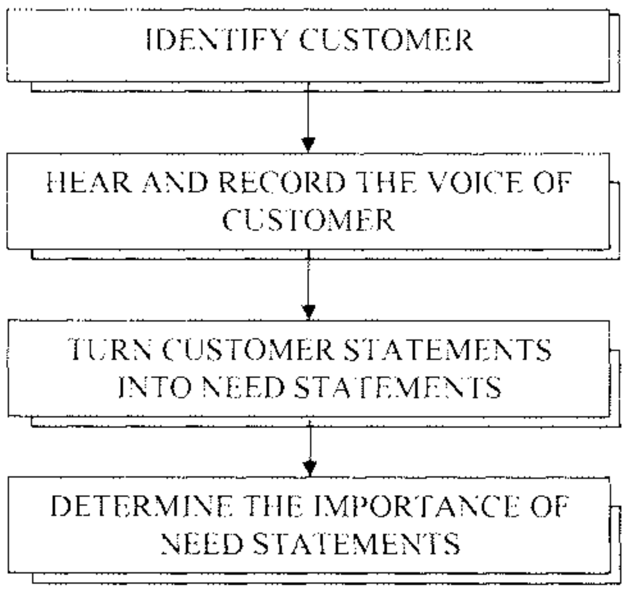
As stated by the inclusive design methodology, and shown in Figure 3-2 design decisions relating to the usability of the product will be made based on the needs of users with the greatest impairment and will therefore come from market group 1. These design decisions should then be tested against able-bodied users (MG-2) to determine the effect this has upon their needs and desires, and therefore the resulting possible success of the product.

This methodology will have a profound effect on the concept development stage, and is described in detail in section 3.2.4 Concept Development.

3.2.2 Identify Customer Needs

An outline of the methodology used to identify user needs is given in Figure 3-3. The stages shown have been identified from a number of literature sources, including (Griffin and Hauser 1993), Eppinger and Ulrich (2002) and Cooper (2001).

Figure 3-3 Process for identifying consumer needs



3.2.2.1 Identifying the Customer

The term 'identify the customer' doesn't purely relate to the person who is going to purchase the product. It is a term used to represent the people who will be included in the consumer research phase of the development process. ((Belliveau, Griffin et al. 2004). This section will review the methodology used to identify stakeholders from special needs users (MG-1) and able-bodied users (MG-2).

Special needs users (MG-1) included all people regardless of age that had some form of impairment or special need and intentionally wished to operate a water control facility. Specifically, people who suffered from the following: neuromuscular impairments, skeletal impairments, and sensory impairments, such as loss of sight and touch sensation.

- People who suffered from these conditions including the elderly
- Organisations who represented people with these conditions
- Rehabilitation and housing facilities for people with these conditions

Market group 2 included all Able- bodied users who intentionally wished to operate a water control facility. Able-bodied respondents were chosen at random to ensure a wide range of ages; socio-economic groups and ethnicities were represented. As well as this however, consumers who were homeowners were of special interest to the product developer, as it was these consumers who potentially would purchase the product.

Other stakeholders considered were, the companies, manufacturers, retailers and people involved in maintenance and installation of the product. At this early stage however neither potential manufacturers nor maintenance and installation specialists were identified. For this reason research was limited to potential retailers of the product and further investigation was done into other aspects once development had progressed to a stage that allowed the identification of other stakeholders.

As recommended by the literature between 20-30 participants from each market group were sought to identify the user needs. The sampling methods used to find respondents for each market research technique are discussed in relevant sections.

3.2.2.2 Hear the Voice of the Customer and Record it.

Three qualitative methods for obtaining the voice of the customer. were chosen for use in the initial stages of this development project. These methods were all conducted by a sole developer and did not infringe on any of the financial or time limits set for this part of the development. The three methods used were interviews, focus groups and observations. Table 3-1 shows each method along with market group it was applied to, the desired number of respondents and the desired outcomes from the research.

Table 3-1 Table summarising the research method to be used, market group to be researched, number of required respondents, and desired outcome.

Research Method	Market Group	# Respondents	Desired outcome
Interviews	Market Group 1 Market Group 2 Retailers	15-20 15-20 5-10	List of general needs
Focus groups	Market Group 2	10-15	In depth look at specific usability needs
Observation	Market Group 1 Market group 2	10-20 10-20	Understanding of facility operating parameters such as temperature and flow

3.2.2.2.1 Interviews

This section outlines the methodologies used to identify respondents and conduct the one on one interview. Many authors describe interview strategies and methodologies, those that have been reviewed for this research include Aaker and Kumer, et al.(1997), The Methods Lab (1999), Belliveau and Griffin et al. (2004) and Eppinger and Ulrich (2005).

3.2.2.2.1.1 Respondents

Market group 1 consisted of seventeen respondents. A number of the respondents, nine, consisted of elderly users who suffered from a range of impairments. These respondents were all residents at two different rest and retirement homes in the Manawatu which will remain unnamed for privacy purposes. Disability organisations were approached and briefed about the project. The remaining eight respondents were acquired in this manor and consisted of users with varying impairments and ranges of abilities.

Twenty-one respondents from market group 2 were identified. A list of over fifty respondents was compiled of people willing to participate in the interview process. The respondents were chosen to represent different ages, culture, and socio-economic classes

Six kitchen and bathroom retailers were included in the interviews. Four of the retailers were from the Manawatu region, one from Hawkes Bay and one from Auckland. The interview skeleton for these groups differed from that below and typically included questions asking about the types of products people by and why, problems that they may have come across with existing products, issues that may need to be resolved in the development etc.

3.2.2.2.1.2 Interview Skeleton

The interviews typically took the form of a structured conversation. Respondents were prompted with an interview skeleton, which consisted of the following questions.

- When and why do you use a sink? Bath? Shower?
- What have you come to expect of existing water control systems?
- What do you like about existing water control systems?
- What do you not like about existing water control systems?
- What issues do you or would you consider if purchasing a water control system?
- What improvements or features would you like to see incorporated into a water control system?

3.2.2.2.2 Focus Groups

Focus groups were used as a tool to further understand the specific usability needs of special needs users (MG-1).The aim was to try and understand each of the impairments better and the functional limitations each may cause with regard to the interface. Many authors describe focus group strategies and methodologies, those that have been reviewed for this research include Aaker and Kumer, et al.(1997), The Methods Lab (1999), Belliveau and Griffin et al. (2004), Bamforth (2003), and Eppinger and Ulrich (2005).

3.2.2.2.2.1 Focus Group Respondents

The special needs market group was split into its three main areas; Physical impairments, sensory impairments, and cognitive or language impairments. Each of the focus groups was made up of people who suffer from or work with people who suffer from each of the impairments.

The physical impairments focus group included four occupational therapists that work with a wide range of physically disabled people and two members from the Arthritis foundation of New Zealand.

The sensory impairments focus group included two active members of the blind community, three employees of the NZ foundation of the blind and two members of the deaf association of NZ.

The cognitive impairments focus group consisted of two nurses and a manager of a facility for people with Down's syndrome.

3.2.2.2.2.2 Focus group Skeleton

There are two parts to the interface, which at this stage will affect the interfaces usability.

1. Outputs and Display.
2. Input and Controls.

The initial aim of the focus groups was to fully understand the impairments and the functional limitations that were a result of these impairments. The groups then focused on how these functional limitations affected the two areas of usability identified for the interface. This was done by identifying the activities the functional limitations could prevent users from doing with regards to both displays and controls. These were then reversed and turned into statements outlining activities that the user must be able to do. From these statements design ideas or guidelines were outlined which would make the statements true.

3.2.2.2.3 Observation

This research technique was implemented to understand operating characteristics of facilities, which will be controlled by this product. Specifically the temperatures and flows used in domestic water control facilities sink, showers and baths.

3.2.2.2.3.1 Respondents

Seven households consisting of twenty consumers were given instruments to measure and record the water temperature. The test group consisted of consumers from a cross section of both market groups.

3.2.2.2.3.2 Methodology

Users were firstly asked to measure the water temperature and record it every time a water facility was used. This included sinks, baths and showers. If users ran the water at either maximum hot or cold they were asked simply just to indicate this with a C or H. The second thing users were asked to indicate was the approximate flow of the water they were using. Given the following scale users were asked to indicate with an appropriate number the approximate flow used. The survey was conducted over a three-day period.

Once the results were tabulated they were taken back to the consumer for a debrief and discussion of the findings.

3.2.2.3 Customer Needs Statements

The following are the guidelines suggested by Ulrich and Eppinger (1995) for translating customer statements into needs statements. The guidelines will be followed and the resulting needs recorded.

- Express the need in terms of what the product has to do, not in terms of how it might do it.
- Express the need as specifically as the raw data.
- Use positive, not negative, phrasing.
- Express the need as an attribute of the product.

- Avoid the words must and should.

The needs were grouped based on similar properties.

3.2.2.4 Determine the Importance of each Need Statement

Throughout the development tradeoffs between specifications were made. By ranking the needs for importance it made it possible to keep features, which the consumer saw as being critical to the product. Consumers were asked to rank the importance of each need based on the following five-point scale (Beliveau, A. Griffen, et al. 2004):

1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it.
3. Feature would be nice to have, but is not necessary.
4. Feature is highly desirable, but I would consider a product with out it.
5. Feature is critical. I would not consider a product without this feature.

Users were also asked to indicate if they felt the need was unique, exciting and/or unexpected. The responses from each of the market groups were tabulated to identify any differences between market groups.

3.2.3 Idea Refinement

The idea refinement stage was considered as the second part to the identification of user needs. The product was new to the world product meaning users have never used anything like it before. There were a few similar products available on the market but many potential users had never seen or used these either. As a result of this users, found it hard to express their needs based on a product they had to imagine. The literature suggested that products such as this should incorporate an extra stage in the identification of needs process. This stage involved users being shown potential concepts for the product and asked to discuss their needs based upon these concepts. This was done, and potential concepts based on the needs already identified were generated which represented different interface styles and which could potentially be used to control the product. This stage was then taken a step further and used to refine the interface style to be used as a basis for development down to one that all users find desirable and could potentially use. The idea refinement methodology is as follows:

Initial searches were done to explore existing technologies, which were being used to control products. Standard products such as cell phones, computers, remote controls, existing electronic sinks, and interface terminals were looked at and ideas generated around these technologies. Secondly products specifically designed for people with disabilities, were reviewed in order to specify solutions that may be used by everybody. As many concepts as possible, were generated, based on the findings from these searches.

The concepts were then put through an informal screening process with the sponsor company. Each concept was screened against a number of criteria. The criteria included potential restraints on the project that might prevent it from being completed and also potential benefits that the concept may offer. This initial screening was fairly informal. It was intended that between five and ten potential concepts be identified from this screening process. The criteria were:

- Development Cost – How much money it would cost to develop the potential concept.
- Development time – How long it would take to develop the potential concept
- Technical expertise required – How much outside assistance would be required to develop the potential concept.
- Potential benefits which can be seen from the concept

The chosen concepts were then tested with the potential users for usability and desirability. Storyboards of each of the chosen concepts were compiled. A survey of at least thirty participants from each identified market group was undertaken to understand which of the concepts was suitable for further development. Users were shown the storyboards and asked a number of question relating to them. These questions were:

1) Could you use the proposed concept? Respondents were asked to answer either; 'yes' they could use an interface with this style of control, or 'no' they could not use an interface of this style, or 'maybe' they could, more information would be required to make a decision.

2) Would you want to use the proposed concept? After all the product had to be purchased by consumers in order for the company to make a profit and justify its development. Again respondents were asked to answer either 'yes' they would want to use an interface with this style of control, 'no' they would not want to use an interface with this style of control or 'maybe' they would, further information would be required in order to make a decision. In a situation where users were not able to use the interface style, the reasoning for this was noted. This was done in case the storyboard portrayed something about the interface that wasn't typical of the interface style.

The results obtained from this study were used to refine the needs identified in the earlier stage of needs identification. Each of the needs affected different aspects of the product such as its colour, size, shape and control. All of these major components of the interface were identified and the needs categorised under the components, which they affected. Doing this resulted in an interface structure with relevant identified needs that could be addressed during concept development.

Initial specifications outlined in the needs identification and idea refinement stages were identified. These specifications were used as a starting point for the concepts developed. The methodology used to outline intial specifications was taken from Wright (1990). This methodology identifies three levels within which the specifications can be written; product alternatives, product types and product features. Each level involves more depth on the previous. Product alternatives formed the intial specifications and outlines the overall needs for the system. The document included the needs identified along with measurable metrics that related to the entire system.

3.2.4 Concept Development

Concept development involved the development of concepts to meet the needs identified in the previous stages of the process. This stage involved numerous design decisions, which ultimately affected the functionality, usability and aesthetics of the product. The methodology for approaching the development is outlined below.

The inclusive design methodology identified in section 3.2.1.1 stated that design decisions should be influenced by users who had specific needs relating to that aspect of the product. As a result each of the major interface components which were identified earlier, were subjected to an analysis identifying the users from market group 1 who were affected the most by that part of the product These users were then used both in developing and considering different solutions to the design problems for that specific area of the product. This process resulted in a set of concepts, which were believed to be usable by the widest range of users possible. These concepts were referred to as Concept Group A.

In order to comply with the project research objectives it was necessary to check each of these design decisions, which were influenced by users from market group 1 with users from market group 2. Any conflicting opinions on the decisions made were then resolved in a separate set of concepts which reflected the needs and wants of able-bodied users (MG-2), neglected in the initial set of concepts developed. These concepts were referred to as Concept Group B.

3.2.5 Consumer Testing

The two sets of concepts, which resulted from the concept development stage, were then tested against the entire user market. A methodology was developed to understand a number of questions. These questions are shown below: The variation within and between market groups was explored for each of the questions shown below.

- Which concepts does the entire user population consider to be the most usable? Why are these concepts easier to use? Is there a considerable difference in the perception of usability between concepts?

- Which concepts does the entire user population consider to be the most desirable? Why are these concepts more desirable? Is there a considerable difference in the perceived desirability between concepts?
- Does knowledge that concepts are designed to allow more people to use them change users opinions of the usability and desirability of the concepts?

Thirty consumers were identified as the required sample size for each market group to enable the groups to adequately represent the market populations and provide reliable statistical data. Market group 1 was split into a number of separate segments. One group represented the market group as a whole and the others represented users who were most affected by the different usability issues that were compromised in the previous stage.

Aesthetic prototypes were built to represent each of the concepts. These prototypes were then taken to the consumers who were given a questionnaire to complete, which was designed to answer the questions raised above. A copy of the questionnaire has been included in appendix 2 and has been summarised below.

The first set of questions asked revolved around usability issues. Users were given a scale as represented in Figure 3-4. They were asked to mark on the scale exactly were they felt each concept lay on the scale. In this way concepts were marked in positions corresponding to how usable the user felt each concept was. Secondly users were given a list of factors, which represented reasons for their choice. The factors represented factors of the development, which related to usability issues.

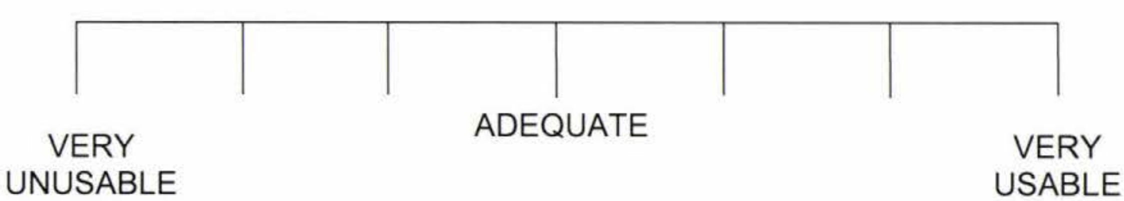


Figure 3-4 Usability scale used in consumer testing of prototypes

A similar process was then followed for desirability. A parallel scale was used for desirability, which had desirability labels, and comparable desirability factors were given as choices, which influenced users decisions.

At the beginning of the research, consumers were not given any insight into the background between concepts, meaning, reasons for differences in concepts were not given. This was done to prevent users choosing concepts based on their purpose e.g. a special needs user choosing a concept design for special needs just because it was.

At the end of the first round of questioning users were informed of the differences between concepts and the reason for this. They were then asked if this changed either their opinions on the usability or desirability of each of the concepts. The purpose of this was to understand if knowledge of the purpose of inclusive design would cause users to compromise on some of their original decisions e.g. a user who originally thought concept one to be very undesirable changing their decision to adequate because that concept was intended to be usable by a wider range of consumers.

All of the data collected from this methodology was then put through a statistical analysis to understand which concepts were usable and which concepts were desirable. The exact analysis details have been included in section 5.2.3.

3.2.6 Concept Refinement

This stage involved the finalisation of the aesthetic and functional design of the interface. The answers obtained from the consumer-testing phase were used to resolve the design conflicts, which resulted from concept development activities. The finalised concept was then retested to ensure alignment with all user needs following a similar methodology to that identified above.

3.3 VALVE

The development phases shown in Figure 3-1 summarise the activities, undertaken with regards to the development of valve. These phases have been explained below and any relevant tools, techniques and methodologies outlined.

3.3.1 Requirement Identification

The requirements identification refers to the technical requirements that guided the valves development. These requirements were obtained from three sources.

1. User needs - The user needs identified in the early stages of the keypad development affected the requirements of the valve. Some of the needs were directly transferred however others only affect the valve in minor ways.

2. Initial Prototype – The initial prototype and testing of this prototype uncovered some necessary requirements of the valve system.

3. Company – The company had requirements of the valve system, which had to be met.

The results from these three sources were combined into a list of requirements. Each of the requirements on this list was then transformed into initial design specifications and related metrics.

3.3.2 Concept Generation

The concept generation phase incorporates two stages as recommended by Cooper (2001). The first stage involves searching externally, looking at competing products or similar products that offer potential solutions. The search was mainly conducted on the Internet however contact was made with suppliers and companies to further understand opportunities.

The second stage involves searching internally, generating ideas within the company. A systematic exploration methodology was followed.

3.3.3 Concept Selection

There was only a small number of concepts to choose from however all concepts were fairly complex resulting In the need for an in depth selection methodology. For this reason the utility function method was chosen. This method follows the general procedure outlined in section 2.3.4. In this method the total effectiveness or utility of each alternative is obtained by summing numerical scores assigned to the individual constituent evaluation criterion, each weighted to balance its importance to the final result, (Stoll 1999).

3.3.3.1 Develop Evaluation Criteria

The evaluation criteria were identified from the requirements identified in earlier stages and included criteria based upon customer need, needs of the company, and engineering specifications.

3.3.3.2 Importance Weighting

Importance ratings were required because not all evaluation criteria were equal. The ratings were assigned based upon the importance values obtained within the requirement identification stage, (reflecting the importance of the requirement to potential customers) and the relative importance placed upon the criteria by the company. The ratings followed the same 1-5 scale identified in section 3.2.2.4 with 1 representing a criterion is not important and 5 representing a criterion has a extremely high importance. These importance ratings are then transformed in weightings using a methodology identified by (Stoll 1999). The weighting is expressed as the proportion of the rating compared to the total rating; a tabular representation of this procedure is shown using a hypothetical example in Table 3-2. Criterion 1 has a importance weighting of 4. Four divided by the sum of all the importance ratings, 22, gives a weighting 0.18.

Criterion	Importance Rating	Weight
1	4	0.18
2	5	0.22
3	3	0.14
4	4	0.18
5	1	0.05
6	2	0.09
7	3	0.14
Σ	22	1.00

Table 3-2 Hypothetical example of importance ratings expressed as weightings.

3.3.3.3 Scoring Methodology

The scoring method used was a symmetrical five point scale. Each of the criterion were labelled with a desired reference value. The criterions are then rated on how well it compares to the reference. The five point symmetrical scale is shown below in Table 3-3.

Relative Evaluation	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Table 3-3 Five point symmetrical scoring scale

3.3.3.4 Ranking the Alternatives

Once the concepts have been evaluated relative to each criterion, an overall score or *utility* value is calculated for each alternative using eq. (3.1).

$$U_j = \sum_{i=1}^{n} w_i x_{ij}, (j = 1,2.....m)$$

Equation 3-1 Equation used to evaluate the utility of concepts

U_j is the utility of the *jth concept* alternative, w_i the weighting coefficient or measure of importance for the *ith* evaluated criterion, x_i the point score of the *ith* evaluated criterion, n the total number of criterion, and m the total number of concept alternatives considered. The concept, which achieves the highest score, will be chosen for further development.

3.3.4 Concept Development, Prototyping and Testing

This phase included the bulk of the technical development and testing of the chosen valve concept. The concept selected from the previous phase was put through a rigorous development and testing procedure. The results where then used to weigh the concept against the initial specifications. This allowed for the identification of requirements that the concept both did and did not meet. Continued development then focused upon the requirements that were not met, and the process was repeated. This was continued until all the basic requirements were met to an acceptable level as judged by the sponsor company.

CHAPTER 4

FRONT END DEVELOPMENT OF THE USER INTERFACE

4.1 INTRODUCTION

This chapter provides and discusses the results obtained from the front-end development process, which includes identifying user needs, idea refinement, and concept development. Figure 4-1 outlines the development process covered by this chapter. The stages shown have been used to structure the chapter.

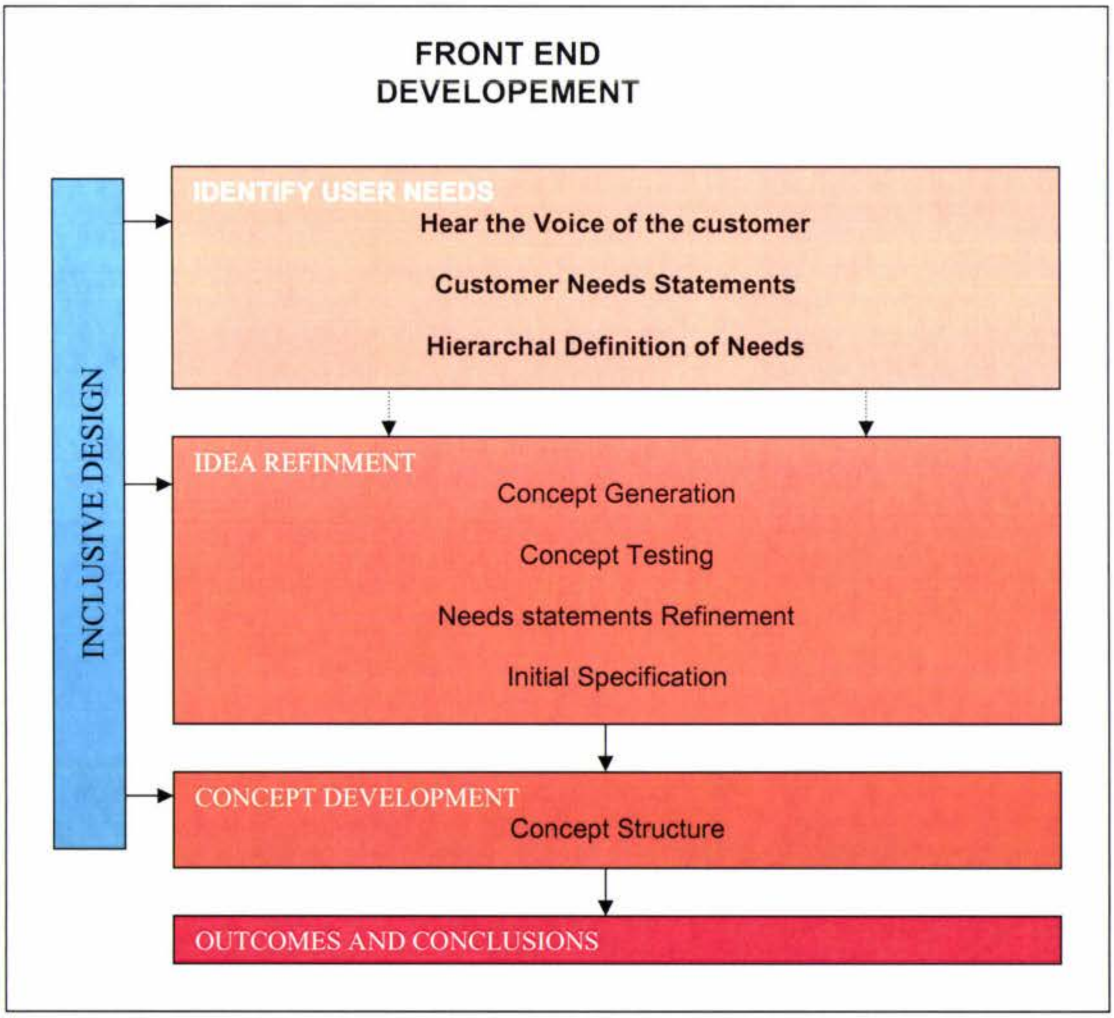


Figure 4-1 Process used in the front end development of the user interface

4.2 IDENTIFYING CUSTOMER NEEDS

The methodology used to identify the consumer needs was outlined in section 3.2.2. This section was split into three main sub sections. The first section looks at the three market research techniques used and discusses the customers identified, and information gained from using each. The second section provides the customer needs, which resulted from the consumer research. The third section provides the results and corresponding discussion to the hierarchal definition of needs.

4.2.1 Hear the Voice of the Customer and Record It

The three market research techniques used were outlined in section 3.2.2.2. Table 3-1 showed which techniques were applied to which market groups, the number of desired respondents and the desired outcome from each technique.

4.2.1.1 Interview Outcomes

Interviews were undertaken to determine the needs and wants of all users. It was intended that although the list of needs obtained from this research would include many specific needs, that it would provide a platform from which non-specific needs could be investigated more thoroughly using focus groups and observation techniques. This technique was used on both market groups. The aim was to get between fifteen and twenty respondents from each group.

Respondents from Market Group 2 commented a lot on functional aspects of the product such as its reliability, ability to control temperature and flow, possible installation issues and cleaning and maintenance of the product. Market group 1 were also very focused on the products appearance and potentially what it might look like.

Special needs users (MG-1) were also concerned with the functional issues, however, it was found that their focus was also on usability issues such as the size of the interface and type of controls it would incorporate. This was expected and raised an issue for further investigation.

The research resulted in a large number of customer statements relating to the product. These statements were analysed and turned into consumer needs statements. These need statements have been tabulated and added to statements gained form the other research techniques and are shown in section 4.2.2.

4.2.1.2 Focus Groups Outcomes

Focus groups were used as a tool to further understand the specific usability needs of Market Group 1.The aim was to try and understand each of the impairments better and the functional limitations they may cause with regard to the interface. The methodology outlined in section 3.2.2.2 was followed. The needs identified from this research have been tabulated along with the other needs identified in section 4.1.2.

4.2.1.2.1 Physical Impairments

The types of problems faced by individuals with physical impairments included poor muscle control, weakness and fatigue, difficulty talking, seeing, speaking, sensing, grasping, difficulty reaching things, and difficulty doing complex or compound manipulations. Individuals with spinal chord injuries, who may be unable to use their limbs and may use mouth sticks for most manipulations.

Activities

The User	*Has line of sight to output or display*
The user	*Can reach the controls*
The user	*Can physically operate controls*

4.2.1.2.2 Sensory Impairments

Visual and hearing impairments are the two major sensory impairments. People with visual impairments can generally be split into two categories, those with low vision and those who are legally blind. A person is termed legally blind basically when they've lost all their vision after correction. Low vision includes problems (after correction) such as dimness of vision, haziness, film over the eye, foggy vision, extreme near or farsightedness, distortion of vision, spots before the eyes, colour distortions, visual field defects, tunnel vision, no peripheral vision, abnormal sensitivity to light or glare, and night blinded ness.

Those who are legally blind rely totally on touch, memory and hearing to identify controls and activate them. Those with visual impairments have the most difficulty with visual displays and outputs. They also have problems operating controls, where labelling or actual operation is dependant on vision.

People with hearing impairments only have problems when an interface requires or gives auditory commands and prompts.

Activities

The user	*Can hear auditory output clearly enough*
The user	*Can see visual output clearly enough*
The user	*Can find the controls if they cannot see them*
The user	*Can determine the status setting of controls if they cannot see them*

4.2.1.2.3 Cognitive/Language Impairments

Cognitive impairments are varied, but may be categorised as memory, perception, problem solving, and conceptualising disabilities. Memory problems include getting information from short-term storage, long term and remote memory. This includes difficulty recognising and retrieving information. Perception problems include difficulty taking in, attending to, and discriminating sensory information. Difficulties in problem solving include recognising the problem, choosing and implementing solutions and, and evaluation of the outcome. Conceptual difficulties can include problems in sequencing; problems in generalising previously learned information, categorising, cause and effect, abstract concepts, comprehension and skills development.

Activities

The user	*Can understand the output (visual, auditory, other)*
The user	*Can understand how to use controls*

4.2.1.2.4 Multiple Impairments

It is common to find that whatever caused a single type of impairment also caused others. This is particularly true where disease or trauma is severe, or in the case of impairments caused by age. For this reason the more ways of portraying information with out overcomplicating the design, the better.

4.2.1.3 Observation outcomes

The methodology outlined in section 3.2.2.2.2 was followed. The temperatures recorded by users for each of the facilities were grouped into five-degree temperature intervals ranging from cold to hot. The frequency of times that a particular temperature range was used over the testing period was totalled tabulated and graphed. This section is broken into the four household areas investigated.

4.2.1.3.1 Kitchen Sink

Figure 4-2 represents the frequency of water temperatures used in household kitchen sinks. The findings are presented and discussed below.

- Cold water is used far more frequently than any other temperature range. It is used for tasks which were performed very frequently: drinking water, filling of kettles and pots, cleaning minor spills, quick rinsing of dishes and washing hands.
- Little or no use of water between the ranges of 20 and 30 degrees as this gives no benefits over using straight cold water.
- Small amount of usage between 30 and 40 degrees for tasks such as rinsing of plates, cleaning for reuse during cooking.
- Common use of water between 40 and 50 degrees for tasks such as washing dishes, detailed cleaning, and rinsing of dishes.
- Maximum hot water (>55°C) was used fairly infrequently for such duties as tough rinsing or scrubbing of fat and greasy dishes.

Users noted that they weren't too concerned with using an exact temperature. When wanting water, they either wanted cold, moderately hot or hot. The resulting actual temperature used fell within these general areas. This explains the diversity between 40 and 55 degrees, users felt they didn't intentionally use 40 degrees over 50 degrees the water just happened to be at that temperature when they needed to use moderately hot water.

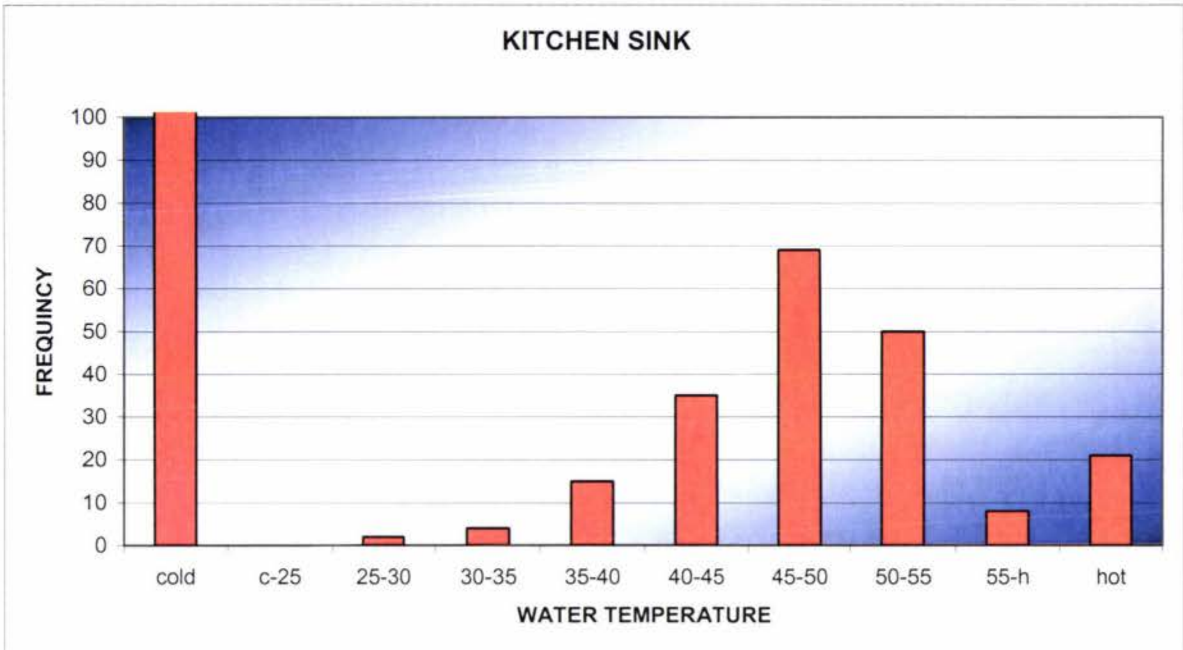


Figure 4-2 Frequency of water temperature use in the kitchen sink over a three day period by 20 users

Figure 4-3 represents the frequency of water flows used in kitchen sinks. The findings are presented and discussed below.

Users used a flow around three quarters of the full flow available a majority of the time. The graph shows some variation in flow use between about half flow and full flow. When asked to comment on this, users pointed out that the variation was due to the fact that they didn't require a specific flow and any flow 'around a bout' their desired flow was acceptable.

Users stated that they purposefully used full flow on a number of occasions for specific jobs such as rinsing. Also stated was that users purposefully used a minimum flow rate on a number of occasions for jobs like rinsing and washing vegetables.

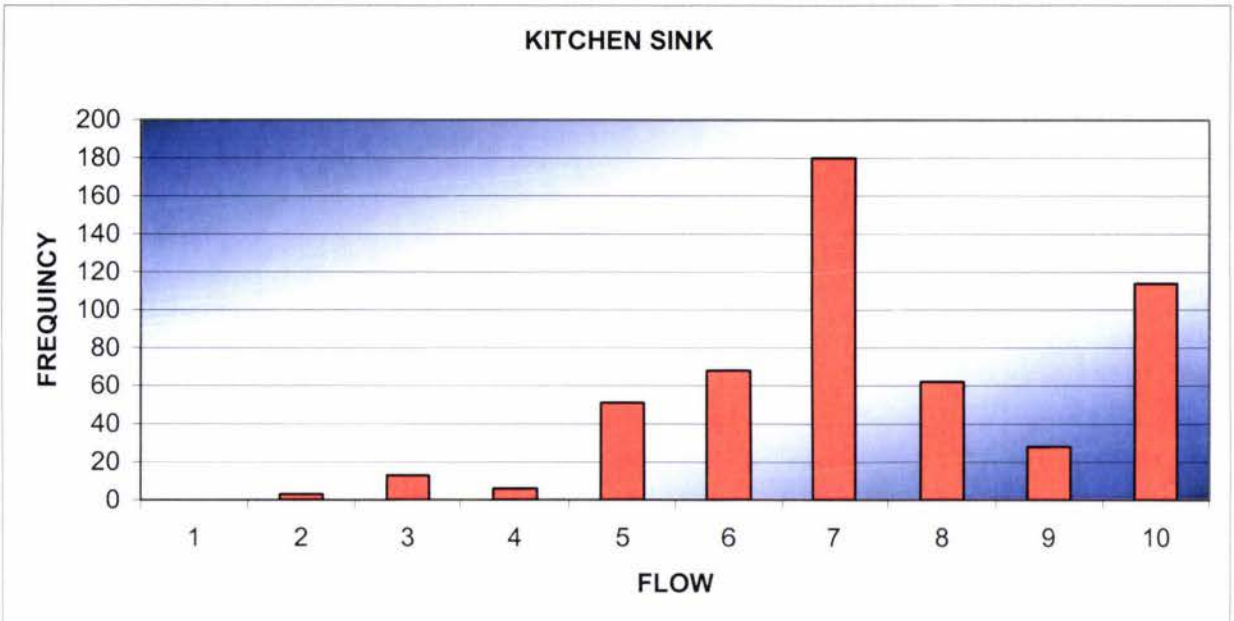


Figure 4-3 Frequency of water flow used in kitchen sinks by 20 users over a three day period. The flow numbers along the bottom represent a continuum. 10 represents full flow, 5 half flow and 1 minimum flow.

4.2.1.3.2 Bathroom Sink

Figure 4-4 presents the frequency of water temperatures used in bathroom sinks as identified by this study. Findings are presented and discussed below.

- Straight cold water was used most frequently
- Water between 40 and 55 degrees was used frequently. Water is used not only on hands but other body parts so some frequent use of water at 40 to 50 degree range.

Again users weren't specific on the actual temperature they required. They just had a preconception of the how hot they wanted the water and altered the temperature until approximately that temperature was reached.

Figure 4-5 represents the frequency of water temperatures used within this study. Findings are given and discussed below.:

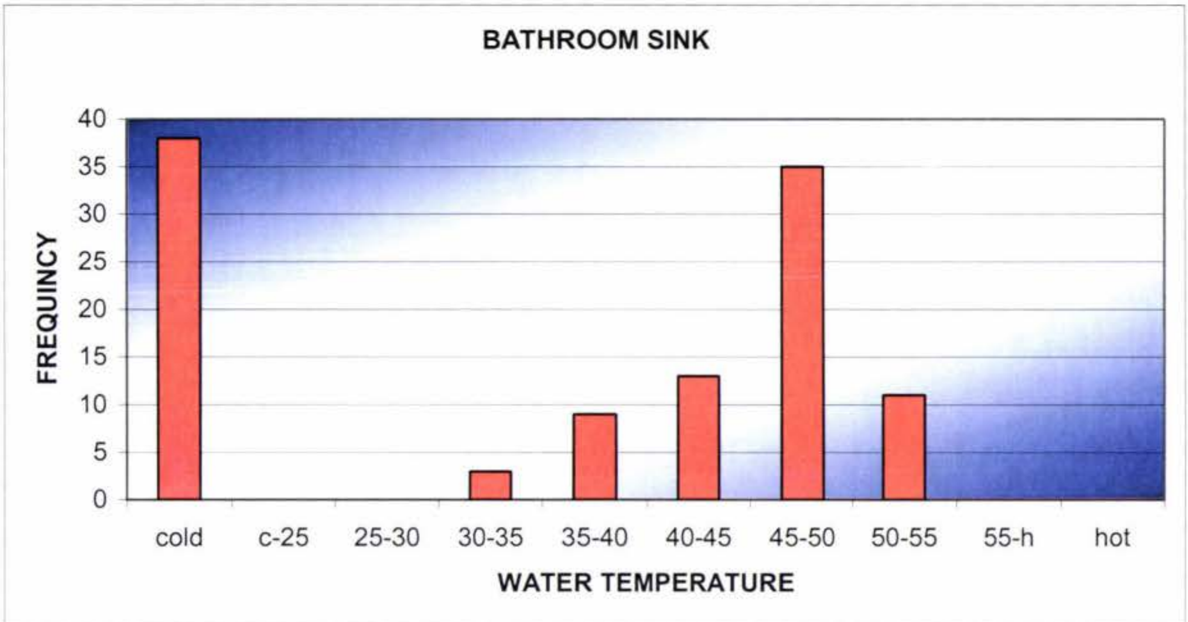


Figure 4-4 Frequency of water temperature use in bathroom sink over a three day period by 20 users

There is a cluster of data around the half flow mark and another cluster around the full flow mark. This suggests that users most commonly use either of these two settings when using their bathroom sinks.

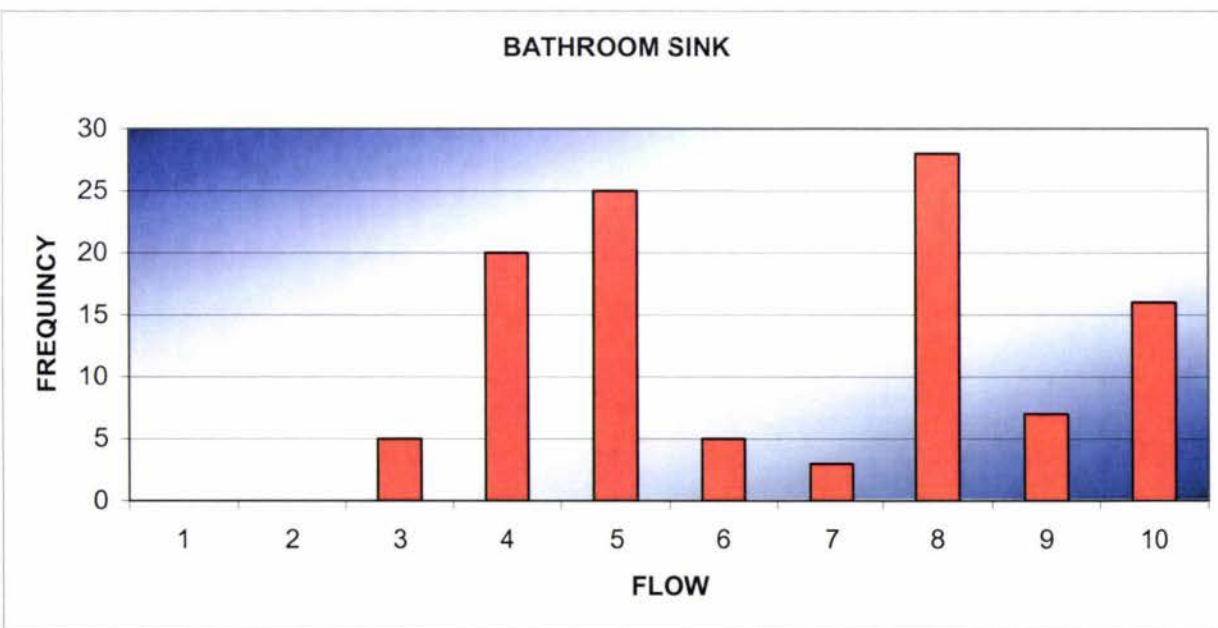


Figure 4-5 Frequency of water flow used in bathroom sinks by 20 users over a three day period. The flow numbers along the bottom represent a continuum. 10 represents full flow, 5 half flow and 1 minimum flow.

4.2.1.3.3 Showers

Findings with regard to the frequency of water temperatures used in showers within this study are shown in Figure 4-6.

- Users all showered within the temperature range 25-45 degrees.

Individuals suggested that the temperature they showered under varied a little depending on activities they had performed before hand, weather conditions and times of day. They also suggested that often they found themselves increasing the temperature slightly as their shower progressed.

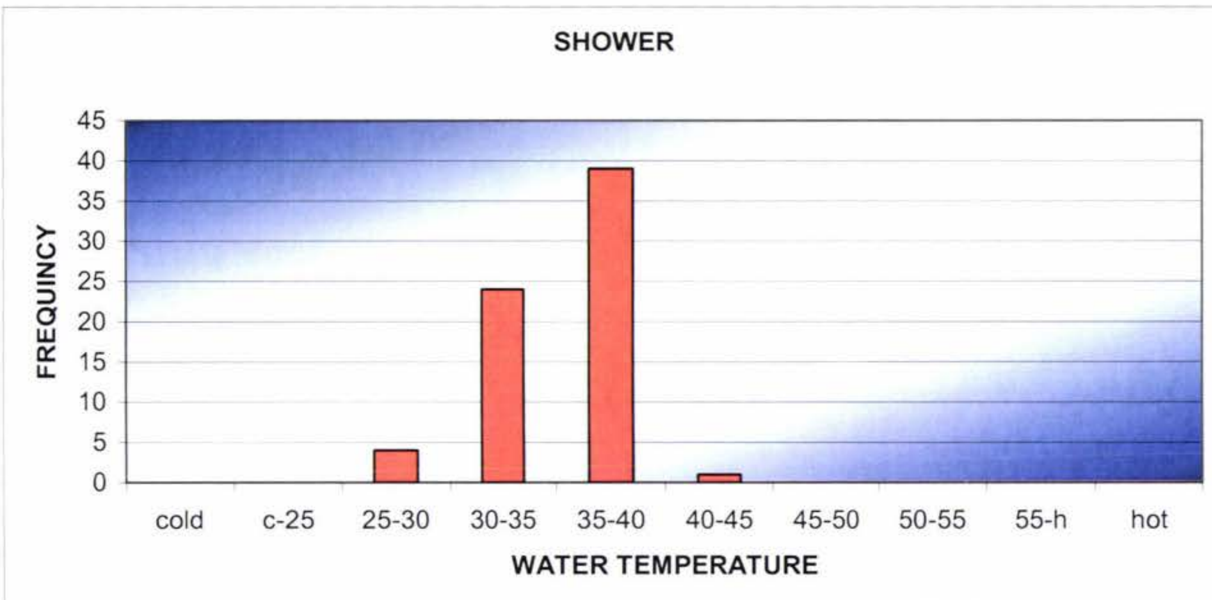


Figure 4-6 Frequency of water temperature use in showers over a three day period by 20 users

4.2.1.3.4 Bath

Figure 4-7 shows the frequency of water temperatures used in the bath. Findings are presented and discussed below.

- Bath temperatures ranged between 25 and 35 degrees Celsius.

One of the respondents used the bath to bathe a young child. She stated that the water needed to be a fairly precise temperature for this activity.

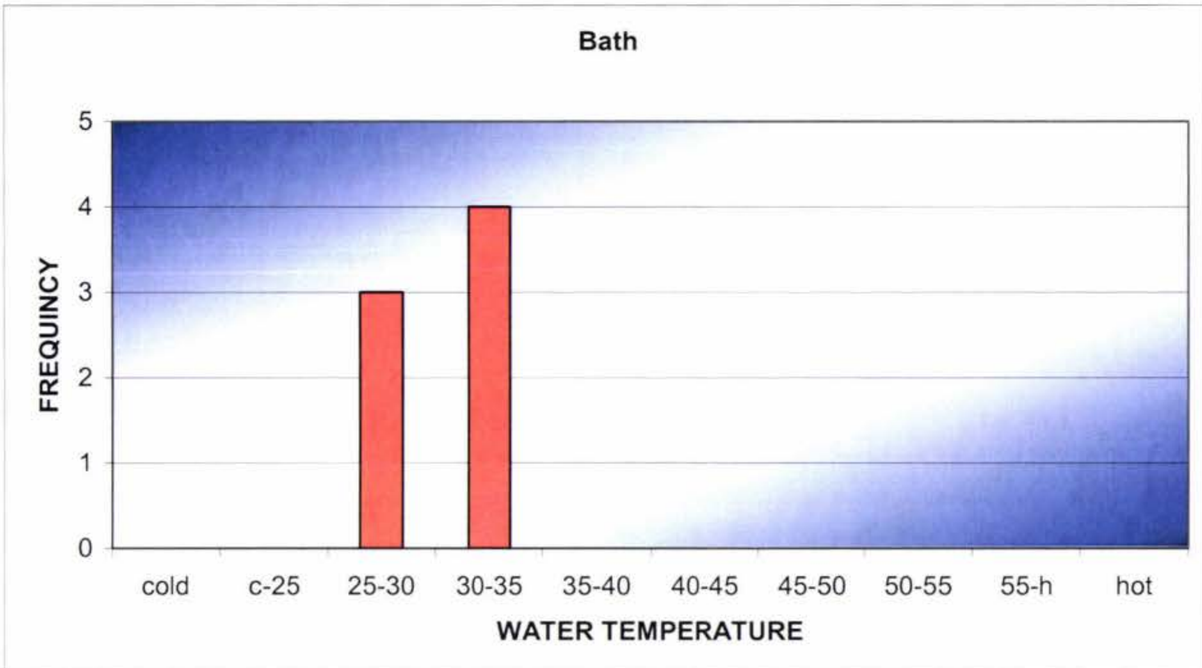


Figure 4-7 Frequency of water temperature use in baths over a three day period by 20 users

It was recognised at the end of this research phase that possible interface solutions for each of the facilities (sink, bath and shower) could differ dramatically. The company specified at this stage, that they would like to focus the design of the interface and concentrate on designing a desirable solution to replace conventional tap and faucets designed for sinks. Alternative interface solutions for showers and baths could be designed once the product idea had been sold to an interested party. Proof and demonstration that the idea worked was all that was required from this case study.

4.2.2 Customer Needs Statements

All of the statements made by consumers with regard to the product were turned into customer needs statements and put into relevant groups. This was done using the guidelines posted by Ulrich and Eppinger (1995) and outlined in section 3.2.2.3. The needs statements are represented in Table 4-1. Some of the needs identified relate solely to the interface. The other needs identified relate to the entire electronically operated water control system. They affected the development of both the valve and user interface systems. The primary needs are highlighted with their associated secondary needs below them.

Table 4-1 Consumer needs statements resulting from consumer research.

No.	Need	
1	The EOWCS	Is usable by people with the wide range of abilities
2	The interface	Provides line of sight to output or display
3	The interface	Can be located so outputs are readable from varying heights
4	The interface	Allows Users to reach the controls
5	The interface	Can be located so that it can be reached by users in wheel chairs
6	The interface	Can be located so that it can be reached by users who have limited reach
7	The interface	Can be located so that it can be operated with the least change in body position
8	The interface	Allows users to physically operate controls
9	The interface	Requires the minimum amount of force to operate controls
10	The interface	Has adequate space between controls
11	The interface	Requires minimum amount of actions to perform desired function
12	The interface	Only requires one action at a time to activate controls
13	The interface	Can be used with left or right hand
14	The interface	Can be used with mouth sticks
15	The interface	Has large controls
16	The interface	Allows users to hear auditory output clearly enough
17	The interface	Provides a volume adjustment
18	The interface	Provides auditory feedback at a strong mid-low frequency components
19	The interface	Allows users to see visual output clearly enough
20	The interface	Provides letters and symbols which are as large as possible/practical
21	The interface	Provides high contrast between text, graphics and the background
22	The interface	Has minimal glare
23	The interface	Allows users to find the controls if they cannot see them
24	The interface	Has controls which are varied in size, most important largest
25	The interface	Has controls which are varied in shape
26	The interface	Has controls which are varied in texture
27	The interface	Has shapes which are associated with their function
28	The interface	Is logical and easy to understand
29	The interface	Has tactile boundaries to controls
30	The interface	Allows users to determine the status setting of controls if they cannot see them
31	The interface	Provides multi sensory indication of the separate divisions, positions and levels of the controls
32	The interface	Provides multi sensory indication of the control position
33	The interface	Allows users to understand the output (visual, auditory, other)
34	The interface	Has simple displays
35	The interface	Represents information in as many forms as possible
36	The interface	Can understand how to use controls
37	The interface	Has the least amount of controls as possible
38	The interface	Is familiar
39	The interface	Is simple
40	The interface	Is intuitive
41	The EOWCS	Allows users to turn water flow on and off
42	The EOWCS	Allows users to adjust the water temperature
43	The EOWCS	Reaches the desired temperature as quickly as possible
44	The EOWCS	Allows users to reach the most frequently used water temperatures easily
45	The EOWCS	Can maintain the desired water temperature despite system fluctuations

No.	Need	
46	The EOWCS	Allows users to adjust the water flow
47	The EOWCS	Allows users to reach the most frequently used water flows easily
48	The EOWCS	Can maintain the desired water flow despite system fluctuations
49	The EOWCS	Is aesthetically pleasing
50	The EOWCS	Fits into the surrounding environment
51	The EOWCS	Is easy to install
52	The EOWCS	Can be installed on any existing or new facility
53	The EOWCS	Requires minimal plumbing on installation
54	The EOWCS	Can be used with any water supply system
55	The EOWCS	Is reliable
56	The EOWCS	Is waterproof
57	The EOWCS	Can withstand knocks
58	The EOWCS	Requires little maintain ace
59	The EOWCS	Prevents dripping from the faucet
60	The EOWCS	Can operate in a power cut
61	The EOWCS	Is priced competitively with existing tap and faucet systems
62	The EOWCS	Is very easy to clean
63	The EOWCS	Has easy to clean surfaces
64	The EOWCS	Is safe to use
65	The EOWCS	Can prevent users form overflowing the facility it is attached to
66	The EOWCS	Has no sharp corners
67	The EOWCS	Can prevent users from being scolded

4.2.3 Hierarchal Definition of Needs

The methodology outlined in section 3.2.2.4 was used to obtain the needs hierarchy. Ten consumers from each market group were asked to rank the needs for importance. The values obtained for each market group were then averaged and importance values for each market group obtained. The importance rankings for each group have been included in Table 4-2. It was recognised that each of the usability needs would be rated as very important to people who had the particular impairment the need addressed. For this reason they are all considered as very important and have been combined into one need for simplicity sake. Consumers are asked to rank the importance of each need based on the following five-point scale:

1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it.
3. Feature would be nice to have, but is not necessary.
4. Feature is highly desirable, but I would consider a product with out it.

5. Feature is critical. I would not consider a product without this feature.

No.	Need		Rank	
1	**The EOWCS**	**Is usable by people with the wide range of abilities**	5	2
41	**The EOWCS**	**Allows users to turn water flow on and off**	5	5
42	**The EOWCS**	**Allows users to adjust the water temperature**	5	5
43	The EOWCS	Reaches the desired temperature as quickly as possible	5	5
44	The EOWCS	Allows users to reach the most frequently used water temperatures easily	4	4
45	**The EOWCS**	**Can maintain the desired water temperature despite system fluctuations**	5	5
46	**The EOWCS**	**Allows users to adjust the water flow**	4	5
47	The EOWCS	Allows users to reach the most frequently used water flows easily	3	2
48	**The EOWCS**	**Can maintain the desired water flow despite system fluctuations**	3	3
49	**The EOWCS**	**Is aesthetically pleasing**	5	5
50	**The EOWCS**	**Fits into the surrounding environment**	4	5
51	**The EOWCS**	**Is easy to install**	4	5
52	**The EOWCS**	**Can be installed on any existing or new facility**	3	3
53	**The EOWCS**	**Requires minimal plumbing on installation**	2	4
54	**The EOWCS**	**Can be used with any water supply system**	5	5
55	**The EOWCS**	**Is reliable**	5	5
56	The EOWCS	Is waterproof	5	5
57	The EOWCS	Can withstand knocks	4	5
58	The EOWCS	Requires little maintain ace	5	5
59	The EOWCS	Prevents dripping from the faucet	5	5
60	The EOWCS	Can operate in a power cut	4	3
61	**The EOWCS**	**Is priced competitively with existing tap and faucet systems**	3	5
62	**The EOWCS**	Is very easy to clean	4	4
63	The EOWCS	Has easy to clean surfaces	4	5
64	**The EOWCS**	**Is safe to use**	5	5
65	**The EOWCS**	**Can prevent users form overflowing the facility it is attached to**	5	2
66	**The EOWCS**	Has no sharp corners	5	2
67	**The EOWCS**	**Can prevent users from being scolded**	5	3

Table 4-2 user needs statements. A combination of both market groups. The orange column represents the importance rankings put on each need by special needs users (MG-1) and the blue column represents the importance ranking put on each need by able-bodied users (MG-2). The re highlight indicates needs that the user felt was unexpected or exciting.

Figure 4-8 shows the comparison between the importance of needs for each market group. As can be seen from Figure 4-8, both market groups put similar importance on a majority of the identified needs. Need 1 clearly is one which has a major difference in importance. The reason for this is apparent. Users with special needs, who may have problems using existing systems, feel it is imperative that this product be developed so that they can use it. Unless able-bodied users are directly associated with somebody who is less capable or able, then the need for the product to accommodate the needs of the less able, is neglected. Needs 65, 66 and 67 registered far less importance for special needs users (MG-1). Users however did see needs 65 and 67 as being unique or unexpected along with need 45.

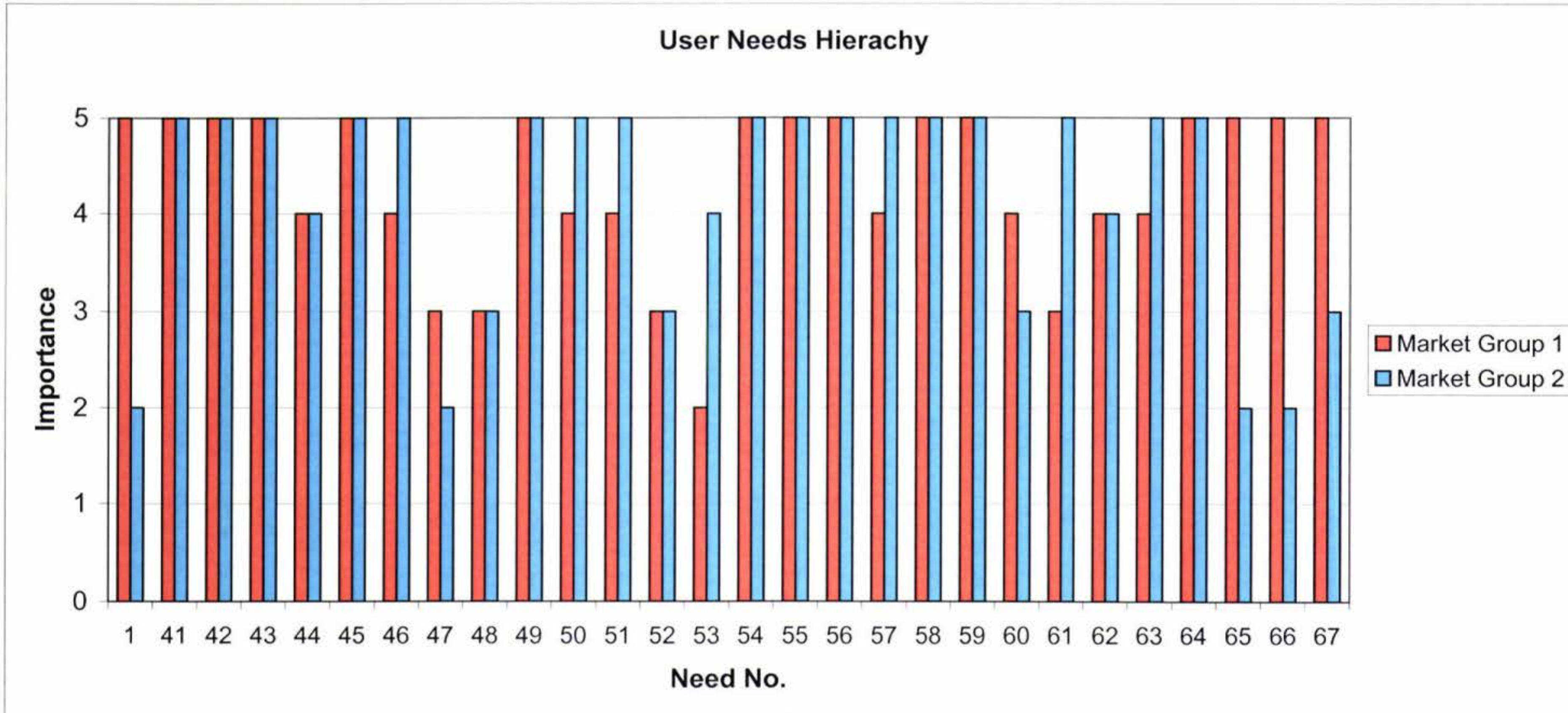


Figure 4-8 Comparison of importance of needs between market groups 1 and 2. The need number relates to figure 4-1. An importance of 1 means the feature is undesirable and the consumer would not consider a product with this feature and five means the feature is critical and the consumer would not consider a product without it

4.3 IDEA REFINEMENT

The product searches undertaken identified many possible solutions for controlling the interface. From these, numerous concepts were developed. These have been included as thumbnails in Appendix 1.

These concepts were then put through an initial screening process based on the criteria outlined in section 3.2.3. This resulted in five different interface styles, which the company could potentially develop with the technical assistance, monetary funding and time available. The concepts are shown below in Figure 4-9 as a series of storyboards.

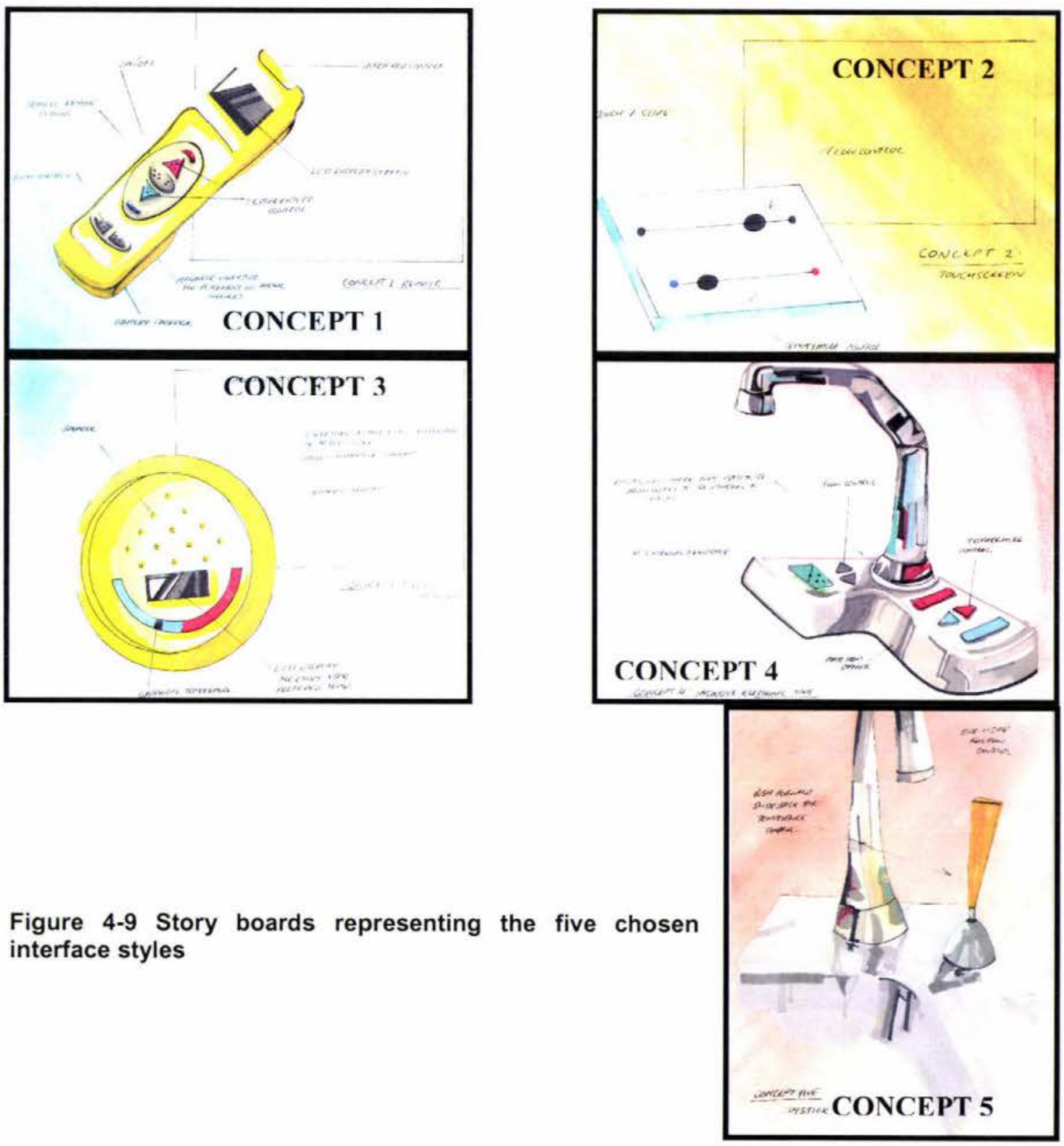


Figure 4-9 Story boards representing the five chosen interface styles

The methodology outlined in section 3.2.3 was followed to understand which of the five concepts was both usable and desirable. The results from this research have been summarised in Table 4-4.

	Usable			Desirable		
	yes	maybe	no	yes	maybe	no
concept 1 (remote control)	55	8	8	14	12	45
concept 2 (touch screen)	62	7	2	50	8	13
concept 3 (voice activated)	56	9	6	19	11	41
concept 4 (key pad)	64	6	1	58	9	4
concept 5 (joy stick)	64	5	2	44	11	16

Table 4-3 Summary of the results from survey undertaken upon five concepts to determine which one was usable and desirable.

Of the five concepts, two, four and five were considered to be the style that the most consumers could use. The only real variance between the concepts was the number of people who potentially could not use them.

Concept four stands out as being the concept that most users would want to use, with only four users stating that they would not want to use it.

4.3.1 Initial Needs and Specifications

The needs identified in section 4.2.2 related to the entire product. These needs and further needs identified throughout the idea refinement stage were tabulated in Table 4-4, to represent the needs relating to the user interface. Some of the needs affect very specific areas or aspects of the interface. These major areas were identified and have been shown in Figure 4-10. These major areas form the concept architecture, and were used to focus the concept development stage. Each of the needs shown in Table 4-4 has been categorised into one or more relevant areas. The initial specifications relating the needs have been included in Table 4-5.

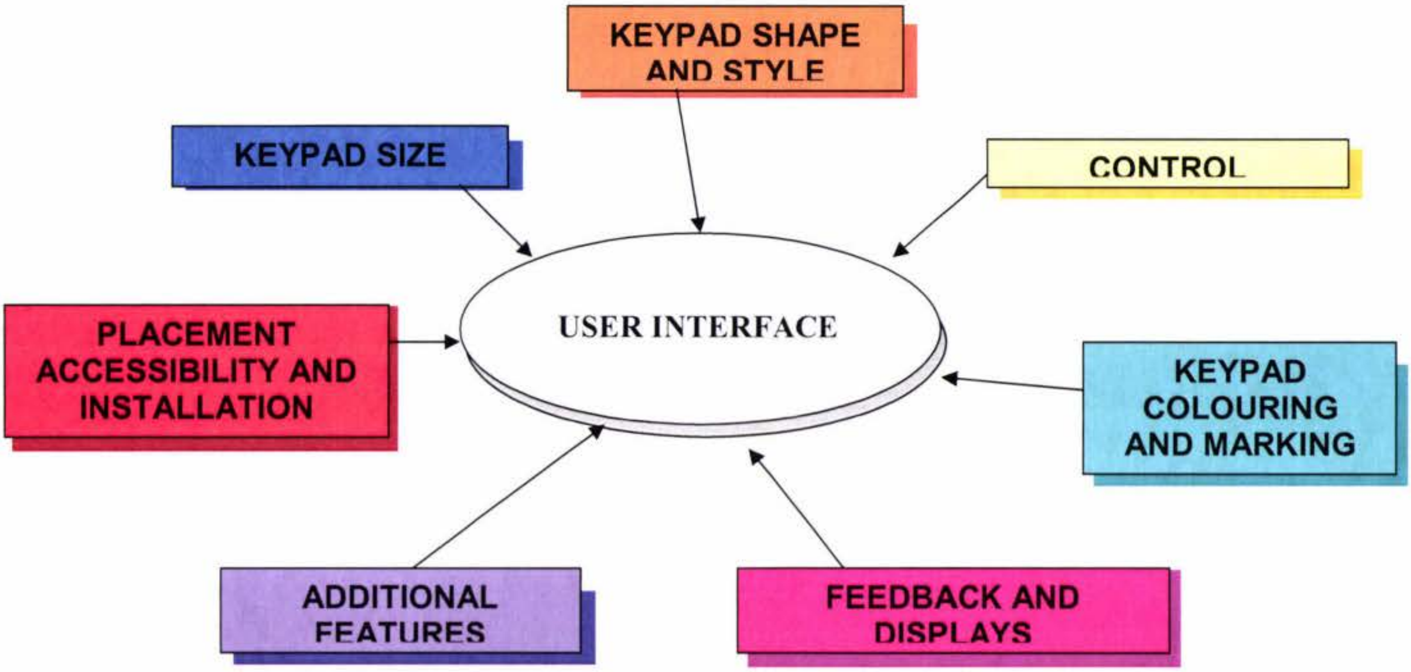


Figure 4-10 Interface concept structure outlining the major areas with which the user needs can be categorised under

No.	Need		Rank	
1	**The Keypad**	**Is usable by people with the widest range of abilities as possible**	5	2
2	The Keypad	Can be located so outputs are readable from varying heights		
3	*The Keypad*	*Has easy to reach controls*	5	4
4	The Keypad	Can be located so that it can be reached by users in wheel chairs		
5	The Keypad	Can be located so that it can be reached by users who have limited reach		
6	The Keypad	Can be located so that it can be operated with the least change in body position		
7	*The Keypad*	*Has buttons which the user can physically operate*	5	5
8	The Keypad	Requires the minimum amount of force to operate buttons	5	5
9	The Keypad	Has adequate space between buttons		
10	The Keypad	Requires minimum amount of actions to perform desired function		
11	The Keypad	Only requires one action at a time to activate buttons		
12	The Keypad	Can be used with left or right hand	5	5
13	The Keypad	Can be used with mouth sticks		
14	The Keypad	Has large buttons		
15	*The Keypad*	*Has auditory feedback the user can hear clearly*	5	2
16	The Keypad	Provides a volume adjustment for any auditory feedback		
17	The Keypad	Provides auditory feedback at a strong mid-low frequency components		
18	*The Keypad*	*Has visual feedback the user can see clearly*	5	3
19	The Keypad	Provides letters and symbols which are as large as possible/practical		
20	The Keypad	Provides high contrast between text, graphics and the background		
21	The Keypad	Has minimal glare		
22	*The Keypad*	*Has buttons which are easy to locate*	4	4
23	The Keypad	Has buttons which are varied in size, most important largest	4	4
24	The Keypad	Has buttons which are varied in shape	4	4
25	The Keypad	Has buttons which are varied in texture	4	
26	The Keypad	Has shapes which are associated with their function		
27	The Keypad	Is logical and easy to understand		
28	The Keypad	Has tactile boundaries to buttons		
29	*The Keypad*	*Has buttons which allow users to identify that they have been activated*	4	4
30	The Keypad	Provides multi sensory indication of the separate divisions, positions and levels of the		

No.	Need		Rank	
		buttons		
31	The Keypad	Provides multi sensory indication of the button position		
32	The Keypad	Provides indication of control activation		
33	*The Keypad*	*Has a easy to understand display*	3	3
34	The Keypad	Has simple displays		
35	The Keypad	Represents information in as many forms as possible		
36	*The Keypad*	*Has easy to understand controls*	5	5
37	The Keypad	Has the least amount of buttons as possible	4	4
38	The Keypad	Looks familiar	3	5
39	The Keypad	Looks simple	5	4
40	The Keypad	Is intuitive	4	5
41	**The Keypad**	**Allows the user to turn the flow on and off**	5	5
42	**The Keypad**	**Allows the user to control adjust the water to their desired temperature**	5	5
43	The Keypad	Allows users to reach there desire temperature with the least amount of buttons as possible		
44	The Keypad	Allows easy access to the most commonly used water temperatures		
45	**The Keypad**	**Allows the user to control the flow of water**	4	5
46	**The Keypad**	**Is aesthetically pleasing**	4	4
47	**The Keypad**	**Is easy to install**	3	4
48	**The keypad**	**Can be installed on any surface**	4	5
49	**The keypad**	**Is reliable**	5	5
50	The keypad	Is waterproof	5	5
51	The keypad	Can with stand knocks	4	5
52	The keypad	Requires little maintenance	4	5
53	**The keypad**	**Is very easy to clean**	4	4
54	**The keypad**	**Can prevent users from accidental scolding themselves**	4	3

Table 4-4 All of the user needs relating to the keypad

Table 4-5 Initial Specifications

Metric No.	Need Nos.	Specification	Units	Ideal Value
1	42	Temperature Range	°C	18-60
2	44	Most used temperatures	°C	18 40-50
3	43	Other required temperatures	°C	45 60
4	42,43,44	Temperature Accuracy	°C	3-5
5	45	Number of Flows required	#	3-5
6	45	Most Commonly used Flows	L/min	7 10
7	1-40	Button sizes	mm	60>20
8	1-40	Button separation	mm	120>10
9	1-40	Operating Force	oz	10-20
10	1-40	Installation height	m	
11	1-40	Button travel distance	mm	5-22
12	1-40	Button location	plane	Horizontal
13	1-40	Activation delay	sec	1-2

4.4 CONCEPT DEVELOPMENT

The user needs and idea refinement phases of the development resulted in a set of user needs which reflected the attributes and features that the users felt should be incorporated into the product. The needs were split into specific areas, which formed the basic concept architecture and are shown in Figure 4.9. This architecture was used to structure the concept development stage. It should be noted that the areas identified are not independent of each other. Decisions made in one area may have a very large influence on other areas. It should also be noted that the areas weren't developed in a sequential fashion; there was a lot of overlapping and iteration between areas. For structural purposes, this section has been split into the seven main areas identified. They have been arranged in a general sequential order which best represents the stage in this phase of the project that each area was addressed.

The design methodology outlined in Section 3.2.4 was followed. Each of the seven major areas of development have been split into two sections. The first explores the development of each development area, addressing the needs identified and paying special attention to the usability aspects. Special needs users (MG-1) influenced these usability aspects, and any design decisions made which affect usability involved direct influence from users who were affected the most. The second section explored the effect these design decisions had upon users from (MG-2) and in some cases involved extra development of the concepts to accommodate the needs of able-bodied users (MG-2).

4.4.1 Control

A very influential part of the development related to how, exactly, the keypad allowed the user to control the water temperature, water flow and turn the water on and off. The way this was done would affect such things as the style, possible layouts, shapes and sizes of the buttons and keypad. The user needs that relate to this part of the development and the importance of each need have been included in Table 4-6.

Table 4-6 User needs relating to the buttons, which will be used to control, flow and water temperature along with the identified importance of each need.

No.		Need	Imp.	
10	The Keypad	Requires minimum amount of actions to perform desired function	5	5
11	The Keypad	Only requires one action at a time to activate buttons	5	5
12	The Keypad	Can be used with left or right hand	5	5
13	The Keypad	Can be used with mouth sticks	5	5
27	The Keypad	Is logical and easy to understand	4	4
31	The Keypad	Provides multi sensory indication of the button position	4	4
32	The Keypad	Provides indication of control activation	4	4
36	*The Keypad*	*Has easy to understand controls*	5	5
37	The Keypad	Has the least amount of buttons as possible	4	4
38	The Keypad	Looks familiar	3	5
39	The Keypad	Looks simple	5	4
40	The Keypad	Is intuitive	4	5
41	***The Keypad***	***Allows the user to turn the flow on and off***	*5*	*5*
42	***The Keypad***	***Allows the user to control adjust the water to their desired temperature***	5	5
43	The Keypad	Allows users to reach there desire temperature with the least amount of buttons as possible		
44	The Keypad	Allows easy access to the most commonly used water temperatures		
45	**The Keypad**	**Allows the user to control the flow of water**	4	5

It can be seen from this table that users would like a very simple easy to understand control system. The needs suggest that accuracy of control is not as important as ease of control.

4.4.1.1 Temperature and Flow Control

A range of concepts were developed which outlined the possible ways the temperature and flow could be controlled - these have been included below in Table 4-7. Each of the concepts were analysed internally and externally, and the problems and benefits of each were discussed. The combination of temperature and flow controls was also explored. The discussions revolved around the needs identified in Table 4-6. A summary of the general comments and feelings has been included below. This table also identifies the expected outcomes and a summary of the general customer comments relating to each control concept.

Table 4-7 Concept descriptions for flow and temperature control of the interface

TEMPERATURE CONTROL
Concept 1 – NUMERIC KEYPAD The Keypad provides users with a set of numeric numbers, which allows the user to input their desired temperature. Numbers 2, 3, 4 and 5 will be the initial input number to represent 20°C, 30°C, 40°C and 50°C. From here any number can be input to reach the desired temperature. **Expected Outcomes** 1) The user can reach their desired temperature very quickly. 2) Precise temperatures control any temperature between 20 and 61 degrees. 3) Familiar same layout as a telephone keypad 4) Require learning from the user to understand what temperatures physically felt like 5) Nine buttons for temperature control could potentially result in a large interface **Summary of Customer Comments** 1) Over complicated. Would probably only use three or four temperatures anyway so no need for so many choices 2) Although it would look like a telephone keypad its not intuitive to use it to control temperature 3) The device would require some training.
Concept 2 – PRESET BUTTONS The users are given a number of presets, which allow them to activate those temperatures. It was suggested that the preset temperatures be the most commonly used temperatures cold, warm (45°C), and hot (61°C). **Expected Outcomes** 1) Easy to get the most commonly used settings 2) Minimal amount of buttons 3) Very limiting on the temperatures that are available **Summary of Customer Comments** 1) Would be wonderful if the presets were the temperatures you wanted to use otherwise it could be quite frustrating 2) Very simple especially if buttons were well labelled
Concept 3 – UP DOWN BUTTONS The water comes on at a default temperature and is controlled from that point using up and down keys. **Expected Outcomes** 1) Familiar and similar to existing temperature controls on washing machines 2) Minimal amount of buttons 3) Can achieve a wide range of temperatures depending upon the step setting

4) Take a long time to get to desired temperature if step intervals were too small
5) Most commonly used temperatures are not readily available

Summary of Customer Comments
1) Seems like a logical way to control temperature
2) Could get annoying if you wanted to reach a temperature on either end of the scale

Concept 4 – COMBINATION UP DOWN AND PRESETS

Expected Outcomes
1) Familiar and similar to existing temperature controls on washing machines
2) Minimal amount of buttons
3) Can achieve a wide range of temperatures depending upon the step setting
4) Easy to get the most commonly used settings

Summary of Customer Comments
1) Best of both worlds easy access to commonly used temperatures while still having the ability to vary temperatures if required.

FLOW CONTROL

Concept 1- CYCLE

One button which cycles through the three required flows

Expected Outcomes
1) Minimal Buttons
2) Cycle through all flows to achieve required one

Summary of Customer Comments
1) Will make the keypad very minimalistic

Concept 2 – UP DOWN BUTTONS

The water comes on at a default flow rate and can be increased or decreased with the up and down buttons.

Expected Outcomes
1) Can get to desired temperature quickly

Summary of Customer Comments
1) Easy to understand and comprehend
2) Good that it can go both up and down

4.4.1.2 Discussion, Testing and Outcomes

After comparing each concept against the needs identified, it was decided that a combination preset and up/down temperature control and up/down flow control offered the greatest benefits and ease of control to users. The temperature presets were advised to be straight cold (approx. 18°C), medium hot (45°C) and straight hot (61°C). A survey of users confirmed the decision for this combination of controls, with eighteen out of twenty-one respondents opting for this particular combination. Also investigated in the questionnaire was the relationship between temperature stepping intervals and temperature accuracy. Respondents were given a choice of 5°C, 4°C, 3°C, 2°C or 1°C, stepping intervals, which would result in three, four, five, eight or fifteen steps respectively between medium hot and straight hot. Fifteen out of the twenty-one respondents said, given the choice, they would opt for 3°C accuracy, resulting in five steps between medium hot and straight hot.

4.4.2 Placement Accessibility and Installation

Placement and accessibility is a usability issue, which greatly affects special needs users from market group 1. Many impairments affect the movements and range of motion of people and hence can potentially make facilities hard to access. The user needs, which relate to these issues are shown in Table 4-8.

Table 4-8 User needs relating to placement and installation of the keypad

No.	Need		Imp.	
2	The Keypad	Can be located so outputs are readable from varying heights		
3	*The Keypad*	*Has easy to reach controls*	5	4
4	The Keypad	Can be located so that it can be reached by users in wheel chairs		
5	The Keypad	Can be located so that it can be reached by users who have limited reach		
6	The Keypad	Can be located so that it can be operated with the least change in body position		
12	The Keypad	Can be used with left or right hand	5	5
47	**The Keypad**	**Is easy to install**	3	4
48	**The keypad**	**Can be installed on any surface**	4	5

The needs basically imply that users need to be able to install the interface on any surface, in any orientation. There is a constraining need however which is that the keypad needs to be electronically connected to the valve in order to control it. It was assumed at the beginning of the development that the interface would be hard wired into the valve. The possible ways this could be done were explored extensively. Some obvious problems arose from having the keypad hardwired.

- An orifice would have to be cut into the installation surface to allow the wiring to be connected to the valve. Some surfaces such as marble or granite would make this a difficult task and could require professionals for installation.
- Placement of the keypad on surfaces, which are not directly accessible to the valve such as a wall, would require professional help for installation.
- Once installed the keypad would be there permanently unless the installation orifice could be patched.

It became obvious that hard wiring the interface was not a desirable solution. The problem was discussed with the engineer who was in charge of the development of the electronics. The discussion resulted in a proposal for an interface, which was wireless and connected to the valve via radio signals. Doing this resulted in a number of outcomes.

- The interface could be installed on any surface
- With the right attachment method the interface could be made removable and would result in no permanent damage to installation surface.
- The interface could be used as remote control if desired.
- The keypad would be powered by batteries and therefore require a little bit of maintenance. It was predicted that the batteries would last for a minimum of six months.
- The batteries and internal electronics put small size limitations on the keypad.

The proposal of a wireless keypad was taken back to special needs users (MG-1). The consumer's saw the benefits of having a wireless interface straight away. However a number of queries relating to the batteries and the effect that having these would have upon the interface were raised. The needs were very similar to those voiced regarding the remote control concept and focused mainly upon the access and maintenance involved in ensuring a power source was available. These needs are shown in Table 4-9.

Table 4-9 User needs relating to a battery-operated keypad.

No.		Need
1	**The Keypad**	**Is battery operated**
2	*The keypad*	*Provides easy access to the batteries for changing*
3	*The Keypad*	*Facilitates orientation and insertion of batteries*
4	The Keypad	Has a guidance system which ensures correct placement of batteries
5	The keypad	Clearly marks the insertion point both visually and tactilely
6	*The Keypad*	*Facilitates the removal of batteries*
7	The keypad	Allows the batteries to be removed with minimal force
8	The Keypad	Provides indication when batteries are getting close to needing changing

Designs to include these needs were investigated at a later stage of the development after style and control issues were resolved.

4.4.2.1 Effect on able-bodied users – Market group 2

Able-bodied consumers from (MG-2) were interviewed to understand what effect this design decision had upon the desirability of this product to them. All users felt the design change to be beneficial. It simplified installation and increased the flexibility of interface placement. Questions were raised about the reliability of the electronic systems. Needs were also specified relating to the changing and removal of batteries, however all were covered by the consumer needs identified in Table 4-9.

4.4.3 Feedback and Displays

Section 4.3.1 outlined all the functions the interface needed to perform. Namely water on/off, temperature control and flow control. These three functions could all potentially be displayed to the user in a tactile, visual or auditory form if required. Section 4.4.2 also identified feedback and display issues which resulted from the incorporation of a battery. The needs relating to this aspect of the design are shown in Table 4-10.

Table 4-10 Needs relating to the feedback and display of the user interface

No.		Need	Imp.	
15	*The Keypad*	*Has auditory feedback the user can hear clearly*	5	2
16	The Keypad	Provides a volume adjustment for any auditory feedback		
17	The Keypad	Provides auditory feedback at a strong mid-low frequency components		
18	*The Keypad*	*Has visual feedback the user can see clearly*	5	3

No.	Need		Imp.	
19	The Keypad	Provides letters and symbols which are as large as possible/practical		
20	The Keypad	Provides high contrast between text, graphics and the background		
29	*The Keypad*	*Has buttons which allow users to identify that they have been activated*	4	4
30	The Keypad	Provides multi sensory indication of the separate divisions, positions and levels of the buttons		
31	The Keypad	Provides multi sensory indication of the button position		
32	The Keypad	Provides indication of control activation		
33	*The Keypad*	*Has a easy to understand display*	3	3
34	The Keypad	Has simple displays		
35	The Keypad	Represents information in as many forms as possible		
8	The Keypad	Provides indication when batteries are getting close to needing changing		

The needs shown in Table 4-10 were used to facilitate discussions with special needs users (MG-1). The discussions firstly focused on when feedback or displays could be required. The three types of feedback auditory, visual and tactile were explored to see what benefits each would offer. Alternative and existing feedback methods were explored. Table 4-11 summarises the discussions pertaining to the situations when feedback could be required and discussions all possible feedback options for each situation. The table indicates the

Table 4-11 Summary of situations were feedback could be beneficial, the types of feedback and how they could be implemented. Yellow indicates the chosen implementation and blue indicates implementations under consideration.

Situation	Type of Feedback	Implementation
On/Off Control	Auditory	- Beep - Could say on or off - Sound of water coming on
	Visual	- Display which showed "flow on" such as an LED - Could see the water come on and go off
	Tactile	- Tactile button which pushes in for on and pops out for off
Temperature Up/Down	Auditory	- Beep - Could indicate a temperature
	Visual	- Could change the colour of the water using LED - Temperature Display
	Tactile	- Buttons could get hotter or colder
Flow Up/Down	Auditory	- Beep - Sound of increased flow
	Visual	- See the change of flow - Display showing change of flow
	Tactile	
Button pushed	Auditory	- Beep

Situation	Type of Feedback	Implementation
	Visual	- Button lights up
	Tactile	- Button with tactile feedback
Battery Low	Auditory	- Beep when buttons pushed and battery low - Command telling "battery Low"
	Visual	- Light indicating battery low
	Tactile	

No concrete decision to include a temperature display resulted from discussion. Further investigation into the option was there for undertaken. The electronics engineer was consulted to understand what options where available to display temperature on the interface. Two realistic options were identified and have been summarised below:

Numeric display – A numeric display represents the temperature in number form. For example if the water temperature was forty-five degrees the numeric display reads 45.

LED graph – An LED graph would indicate the approximate water temperature on a

scale between cold and hot. The graph would be made up of LED's progressing in colour to represent the shift from hot to cold.

These visual display options were incorporated in a number of concepts and discussed with both consumers and the company. The pros and cons of a temperature display have been outlined below.

Pro's	Con's
Help prevent scalding	Draw a lot of battery power
Understanding of temperatures changes being made	Take up valuable room on the interface which could result in over complication
Identification tool for finding desired temperature	

A review of the needs and their importance identified the cons to be of higher priority than the pros. The decision was made not to incorporate a temperature display. However, preventing scalding was a desirable outcome. It was decided that if the preset buttons (cold and 45ºC) were used to turn the water on and neither of these were hot enough to cause scalding, then any adjustments made from these points could be accounted for by the user, nullifying the need for a display.

4.4.3.1 Effect on able-bodied users – Market group 2

Able-bodied consumers from market group 2 were interviewed to understand what effect these design decision had upon the desirability of this product to them.

Able-bodied users could see no negative effects of the inclusion of these feedback options. Discussions relating to the inclusion of a temperature display resulted in an agreement that a temperature display was not necessary.

4.4.4 Keypad Shape and Style

The needs and importance of each need relating to the Keypad shape and style are included in Table 4-12. These needs were used to guide the development.

Table 4-12 User needs relating to the keypad shape and style

No.	Need		Imp.	
7	*The Keypad*	*Has buttons which the user can physically operate*	5	5
8	The Keypad	Requires the minimum amount of force to operate buttons	5	5
13	The Keypad	Can be used with mouth sticks		
14	The Keypad	Has large buttons		
22	*The Keypad*	*Has buttons which are easy to locate*	4	4
23	The Keypad	Has buttons which are varied in size, most important largest	4	4
24	The Keypad	Has buttons which are varied in shape	4	4
26	The Keypad	Has shapes which are associated with their function		
38	The Keypad	Looks familiar	3	5
39	The Keypad	Looks simple	5	4
46	**The Keypad**	**Is aesthetically pleasing**	4	4

The identification of the particular controls that were to be included in the interface led on to the generation of concepts, which represented different solutions for the overall aesthetics of the interface.

The company investigated the concepts internally and four concepts were chosen for further investigation and development. These concepts were then put through a second phase of concept generation and numerous more concepts based around these concepts were generated. Influences were taken from existing kitchenware; tap ware; kitchen appliances; remote controls and new technologies such as cell phones. These concepts have been included in Appendix 1. The concepts were put through another iteration of development, which involved consultation with both potential users and directors from the sponsor company. The four concepts were modelled using the CAD program SolidWorks, these are shown in Figure 4-11. The models

Figure 4-11 Interface style concepts

depicted keypad shapes, button layouts and possible colour solutions for each of the four concepts.

4.4.5 Keypad Size

The keypad size was dependant on a number of factors. The first is the constraints put upon it by the physical size of the electronics, which are needed to operate it. The second was the constraints related to button size and button separation. Obviously, the bigger the buttons were and the greater the separation between them, then the bigger the interface would need to be. These two issues were raised by special needs users (MG-1) and are represented along with other needs relating to the keypad size in Table 4-13

No.	Need		Imp	
9	The Keypad	Has adequate space between buttons		
13	The Keypad	Can be used with mouth sticks		
14	The Keypad	Has large buttons		
18	*The Keypad*	*Has visual feedback the user can see clearly*	5	3
22	*The Keypad*	*Has buttons which are easy to locate*	4	4
23	The Keypad	Has buttons which are varied in size, most important largest	4	4
38	The Keypad	Looks familiar	3	5
39	The Keypad	Looks simple	5	4

Table 4-13 Needs relating to keypad size

The first of the two constraints was the electronic components, which needed to be incorporated into the interface. Guidelines on these components sizes were provided by the electronics engineer and included:

- Two AAA batteries. (Each battery measures 43mm x ø10mm)
- Between six and eight switches depending upon the final number of buttons incorporated. (range from 3.5mm^2 up to 7mm^2)
- Between 30mm^2 and 40mm^2 of circuit board.

The second constraint on interface size was the button size and separation. The bigger the button, the easier it was to use by people with special needs, however, the bigger the resulting keypad will be. Similarly, the greater the space between buttons the less chance there is of accidentally pressing the wrong button; however, this will increase the overall size of the keypad. A number of sources were identified in

Chapter 2, which provided guidelines for designing interfaces for use by people with special needs. The guidelines provided suggestions for appropriate button sizes, and spacing distances between buttons. These were:

- Button size 1.0-6.0 inches diameter or square.
- Spacing 0.5-2.0 inches between buttons.

The guidelines suggested that the closer a product is made to the higher end of the guidelines the more users it will accommodate. These guidelines have a large range of variance. It was decided at this stage to take the guidelines along with the product concepts identified in section 4.4.4 to special needs users (MG-1), to identify which limits satisfied their usability and desirability issues.

4.4.5.1 Analysis of size and spacing issues with Special needs users – Market Group 1

A focus group was set up to resolve sizing and spacing issues. The sizing and spacing issues were predominantly raised by users who suffered from physical and visual impairments and for this reason the focus group comprised of individuals who could best associate with people with these needs. Included in this group were occupational therapists that had worked with people who had a large range of disabilities, and Field Officers from both the Foundation for the Blind and the Arthritis Foundation who worked with individuals living with these impairments. It also included two participants who had physical impairments.

Participants were given drawings of the proposed four concepts shown in Figure 4-11. The suggested design guidelines were then outlined. A general discussion within the group was undertaken to gather their opinions on both the concepts and guidelines and the effect that these would have on special needs users.

The focus group ended with participants working in a team to outline concepts with sizes and layouts, which were felt to be usable by all parties represented in the group.

4.4.5.1.1 Discussions and Outcomes

The initial discussion of concepts raised a few issues associated with concept 1. A comment was made, which suggested that the concept "looks too similar to a computer game remote". This comment led to further discussion pointing out possible problems with the dual levels of control, specifying that some special needs users may find that concept too hard to comprehend and access. A third issue was raised stating that it could potentially be hard to clean. A positive response was given towards the other three concepts. Potential could be seen in their simplicity.

The discussions relating to sizing and spacing issues provided both verification of assumptions and the introduction of some new knowledge. It substantiated that larger button sizes and greater separation mainly helped users who were physically impaired, and also made products easier to use for people who had visual impairments. This was because it enabled the size of labelling and indicator markings to be increased because of increased button size. Users who had neuromuscular disorders, which limit their fine motor skills, have trouble controlling precision movements, hence, the larger the button, the more likely they are to hit it, instead of its neighbour. Similarly, people with skeletal impairments would have more options, in terms of the body parts they can use for pushing buttons, with an increase in button size. It was also registered that spacing between buttons could be reduced with an increase in button size.

Earlier consumer research suggested that using larger sizes for the more commonly used buttons and differentiating shapes of buttons would be a very useful way of suggesting differences in their operation. For example, using arrows for temperature up and down portrays the purpose of the button. This was verified throughout discussions and shown in the generation of concepts.

The group outlined concepts, which specified button and keypad sizes that were thought to accommodate the most users. The sketches and drawings were then turned into pictorial sketches and eventually CAD drawings. Figure 4-12 below shows each of the concepts along with a scale to offer some perspective on relative size. The red measuring rod shown alongside the concepts is 200mm long and is shown full size below.

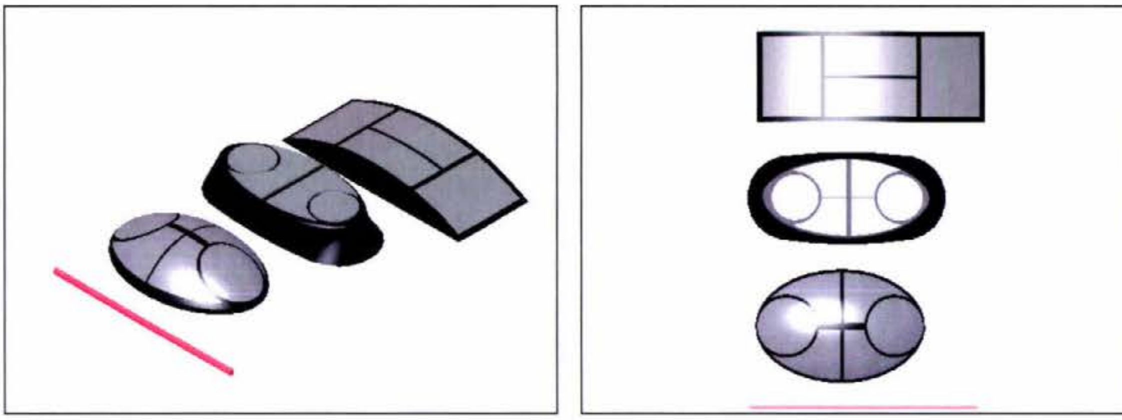


Figure 4-12 Concepts portraying keypad and button sizes resulting from special needs focus group

4.4.5.2 Effect on Able-bodied users – Market Group 2

The concepts outlined in section 4.4.4, Figure 4-11, along with the sizes and layouts for each that were identified by the special needs market, were taken to both able body consumers and kitchen and bathroom retailers. The groups were asked to comment on the concepts, the sizes and layout, developed by the other market group. Ten able-bodied users and seven retailers were identified to offer insight.

4.4.5.2.1 Discussion and Outcomes

Able-bodied users (MG-2), agreed with the special needs market in showing their disinterest in concept one. It was felt that it would be "too hard to clean" and looked quite high tech. This negative feedback provided enough concern to warrant the discontinuation of the development of concept one. Users from this market group also disliked concept three. It was stated that "It did not look organic enough", and "didn't fit in a kitchen environment". As a result Concept 3 was left out of the size analysis. The retailers, in particular, showed very high interest in concepts two and four.

When shown representations of the sizes that special needs consumers had identified, it became immediately clear that there was conflict between the opinions of the two groups. Retailer comments included things such as "consumers want products that are minimalistic, smaller is better", " this is far too big and intrusive" and "take up, too much needed bench space". These comments were discussed and agreed with by the able bodied users (MG-2).

Retailers were asked to outline some sizes of interface that they thought would be desirable to consumers. These were then transformed into product concepts, which are represented below in figure 4-13.

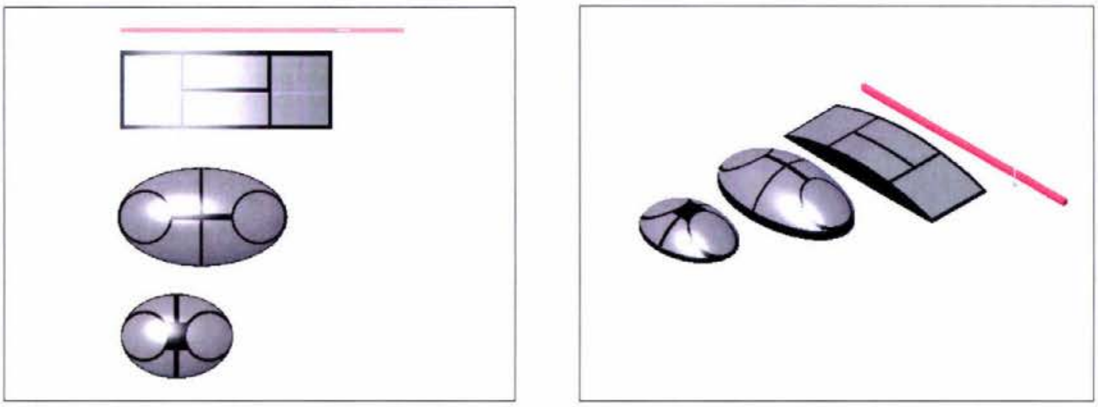


Figure 4-13 Concepts portraying keypad and button sizes as specified by users and retailers from market group 2

4.4.6 Keypad Colouring and Markings

The keypad and button markings had a number of influences on the overall design of the interface. The keypad markings and colouring not only had a major effect on the overall aesthetics of the interface but also were very important when considering the overall usability of the interface to users who was visually and cognitively impaired.

As pointed out in the identification of needs section, the functional use of colours and markings was most important to people with sensory and cognitive needs. As such consumer research was undertaken to develop concepts, which improved the usability of the interface through the use of colour and markings for people with special needs.

4.4.6.1 Analysis of colouring and marking issues with special needs users – Market group 1

The focus group that was used to explore sizing and spacing issues was also used to explore colouring and marking issues as well.

The group was given the range of concepts identified as a result of the development carried out in section 4.4.4. The were asked to discuss possible colouring and marking styles and solutions that would allow the greatest number of users with the widest range of abilities to use the interface. The solutions obtained were then portrayed in a number of pictorials on different interface styles.

4.4.6.1.1 Discussion and Outcomes

The focus group discussed the different people who may benefit from the use of colours and markings as functional parts of the design.

Fully blind users - would only benefit from the use of markings, as they would not be able to see the colours. Fully blind users would first need to able to identify where the buttons were. It was suggested that the best ways of doing this was either to raise the buttons themselves or incorporate a raised edge around the buttons, which would determine each buttons boundary.

Once the user had found the button they would then need to determine what function it was the button performed. The use of different shapes and sizes of buttons, identified from the development in sections 4.4.4 and 4.4.5 was identified as being good way to allow blind user to differentiate between buttons. The large buttons showed that they were the most important. The other buttons, shaped as they were, could indicate up and down. However it was still necessary for users to understand what it was that the button actually controlled. Texture was also discussed, and texturing with Braille was the obvious solution for marking hot and cold; however, it was pointed out that only a small number of blind people could actually read Braille. Instead it was suggested that simple symbols such as one dot for hot and two dots for cold could be used to differentiate between the two buttons. These markings could also be used to indicate hotter or colder on the up down button and would allow consistency in the markings.

Partially blind users - would benefit from both the colours used and markings used. A majority of visually impaired people have only minor impairments. It was suggested that these people would benefit the greatest from a smart use of colour. Colour combinations were discussed. The Foundation for the Blind Field Officers suggested a number of guidelines, which were applied.

Cognitive impairments -would benefit from both colours and symbols. Users with these impairments have trouble remembering new instructions. For this reason it was recommended to use colours that have always been associated with hot and cold (red and Blue). It was also suggested to keep the markings as simple as possible so that there was little opportunity for confusion.

A general colouring guide was developed and appropriate markings suggested. These were incorporated in a number of concept drawings shown in Figure 4-14.

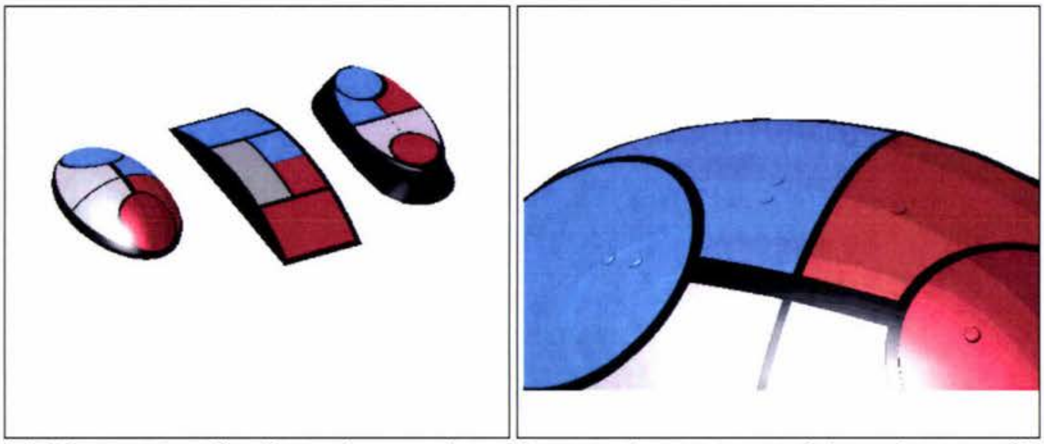


Figure 4-14 Concepts reflecting colour and marking requirements special needs users (MG-1)

4.4.6.2 Effect on Able-bodied Users – Market Group 2

The concepts developed by the special needs focus group where taken to a number of able-bodied users and retailers. The outcome was an obvious distaste for the colouring used in the design. Users and retailers offered many different alternative suggestions. These suggestions, along with research into current kitchen appliances, were used to develop a number of alternative colouring solutions.

A survey of the three concepts: two, three and four identified in Figure 4-11, section 4.4.4 was undertaken to determine which concept was the most desirable to able-bodied users and retailers. Forty individuals were asked to consider all three concepts. The concepts included the three styles of interface still in development stages, which were coloured in varying ways. Respondents were asked to pick their favourite coloured concept from each of the styles. The survey aimed to identify which styles were desirable as well as identifying which colourings were desirable. A few of the colouring styles have been included in Figure 4-15 as an example, with all the concepts included in Appendix 1.

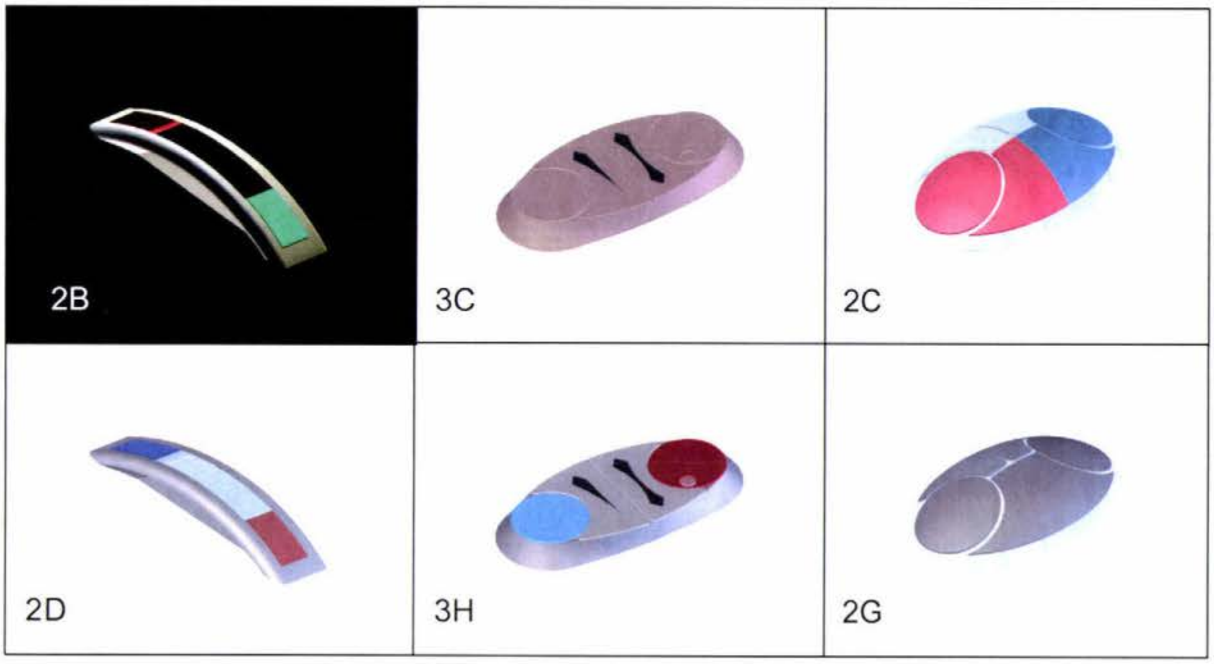


Figure 4-15 Example concepts portraying different colouring options

The results were tabulated and shown in Table 4-14. Concept 2H and concept 4F were regarded as considerably more desirable than any of the other concepts. These two concepts are shown below in Figure 4-16.

Concept 2		Concept 3		Concept 4	
A	10	A	10	A	15
B	12.5	B	27.5	B	0
C	2.5	C	5	C	12.5
D	10	D	17.5	D	0
E	2.5	E	22.5	E	0
F	5	F	2.5	F	45
G	12.5	G	0	G	27.5
H	45	H	15		

Table 4-14 Results of survey regarding preferred keypad colouring

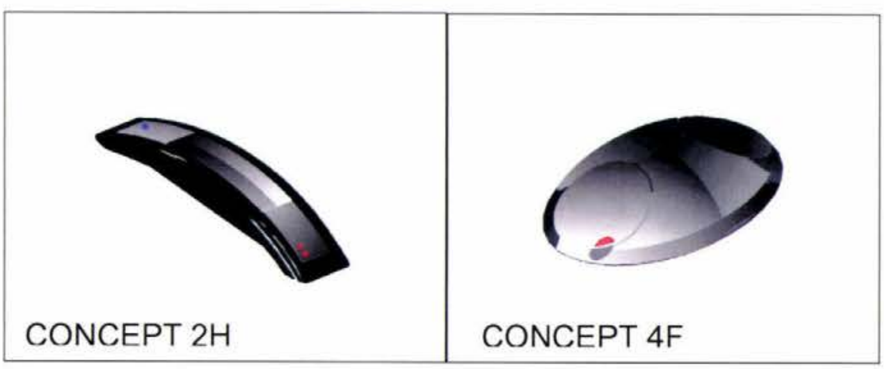


Figure 4-16 Concepts portrayed as the most desirable by able-bodied users (MG-2)

4.4.7 Additional Requirements

The additional requirements for the keypad included issues such as reliability, water protection, and safety issues. Most of these issues were addressed in later stages of the development with the exception of some safety aspects.

Users remarked on circumstances where young kids, the elderly and people with special needs had scalded themselves using facilities. Retirement homes also registered the fact that the water in these facilities is not allowed to be above 45°C.

A number of solutions were considered which would allow users to run the keypad in safety mode.

1. A button was provided that would allow the user to preset their desired maximum temperature. A user could run the water at a temperature they wished the maximum temperature to be at. While running the water they would hold the preset button down for a period of time, which would be long enough not to create an accident - say 10 seconds - and would then set the maximum temperature.

2. The electronic system was designed in such a way that all the control parameters could be adjusted from a Laptop computer. This means that the maximum temperature setting can be adjusted from a laptop. This however needed to be done on purchase of the product or through a technician who came to your home.

Solution 1 was thought to be a better option because it allowed users the option of setting their own maximum temperature. The idea was discussed with users from all market groups. It was received as a good idea however it raised concerns that it may overcomplicate the interface and add a button that potentially would never be used. The idea was very well received by elderly users and retirement homes.

The design question posed was how to allow users to set a maximum hot water temperature that would prevent them from scalding themselves with out adding any extra buttons. A very good solution to the problem was found after pondering the problem for some time. It was decided that instead of allowing users to set any maximum hot water temperature they were given a choice between two maximum hot water temperatures 61°C and 45°C. Users could switch from one to the other by holding down the 45°C preset for 15 seconds. This amount of time would mean that it could only be done intentionally. It was considered that a light should be placed on the interface that indicated when the interface was being used in safety mode, however on speculation and discussion with users it was felt that this was not necessary. Users either, would, or would not, use this mode. They would not switch between modes.

4.5 OUTCOMES AND CONCLUSIONS

Two major conflicts in the opinions of the two market groups, identified throughout the development, led to the need for two different sets of concepts. The two different sets of concepts were based on the same style of interface, had the same mode of operation, and included the same features; however, they also differed in a number of ways. They were different sizes and had different colourings. The reason for this was the sizes and colourings established by special needs users, (MG-1) were found to be undesirable by able-bodied users (MG-2).

Concept group A reflected the needs of special needs users (MG-1). The sizes and colourings were developed for usability purposes. Concept group B was developed to reflect the desires of able-bodied users (MG-2). The sizes and colourings were developed for desirability purposes. All six concepts are shown below in Figure 4-17.

The two major conflicts are an indication that design decisions relating to the usability of a product can in fact affect the desirability of the product to other potential users. This suggests that the design decisions made relating to the usability of the product could have had negative impacts on the financial success of the product.

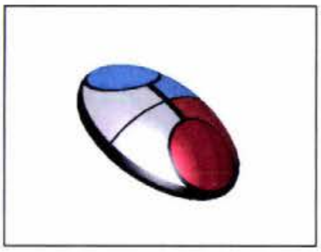
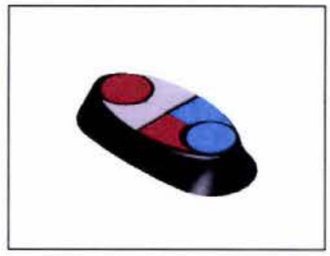
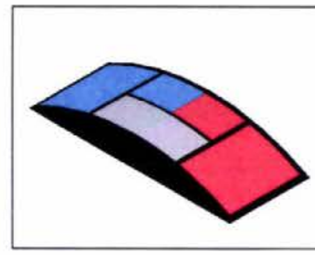
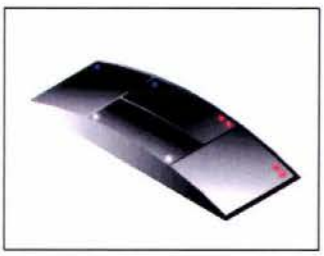
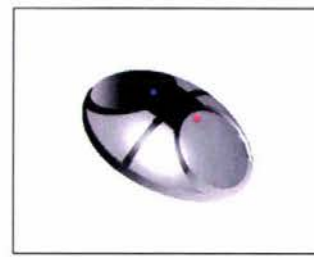
CONCEPT GROUP A		
		
CONCEPT A	CONCEPT B	CONCEPT C
CONCEPT GROUP B		
		
CONCEPT D	CONCEPT E	CONCEPT F

Figure 4-17 All six concepts resulting from the development

The different concepts, which resulted from this conflict, were explored further and will be discussed in the next chapter. An in depth consumer analysis of the concepts explored which concepts all users find most usable and which concepts all users find most desirable. Differences between market groups were explored. The intention was to come up with a compromise, which would resolve the conflicts identified in this chapter, to allow for the continued development of an interface, which was both usable to users with the widest range of impairments as possible, and desirable to the greatest number of potential users.

CHAPTER 5

CONSUMER TESTING AND REFINMENT OF THE USER INTERFACE

5.1 INTRODUCTION

This chapter covered the back end development of the user interface. The usability and desirability conflicts identified in chapter four were resolved through detailed concept testing. The results of this testing were then used to refocus the development and resolve outstanding design problems in the Concept Refinement stage. The process followed is outlined in Figure 5-1, which was also used to structure this chapter.

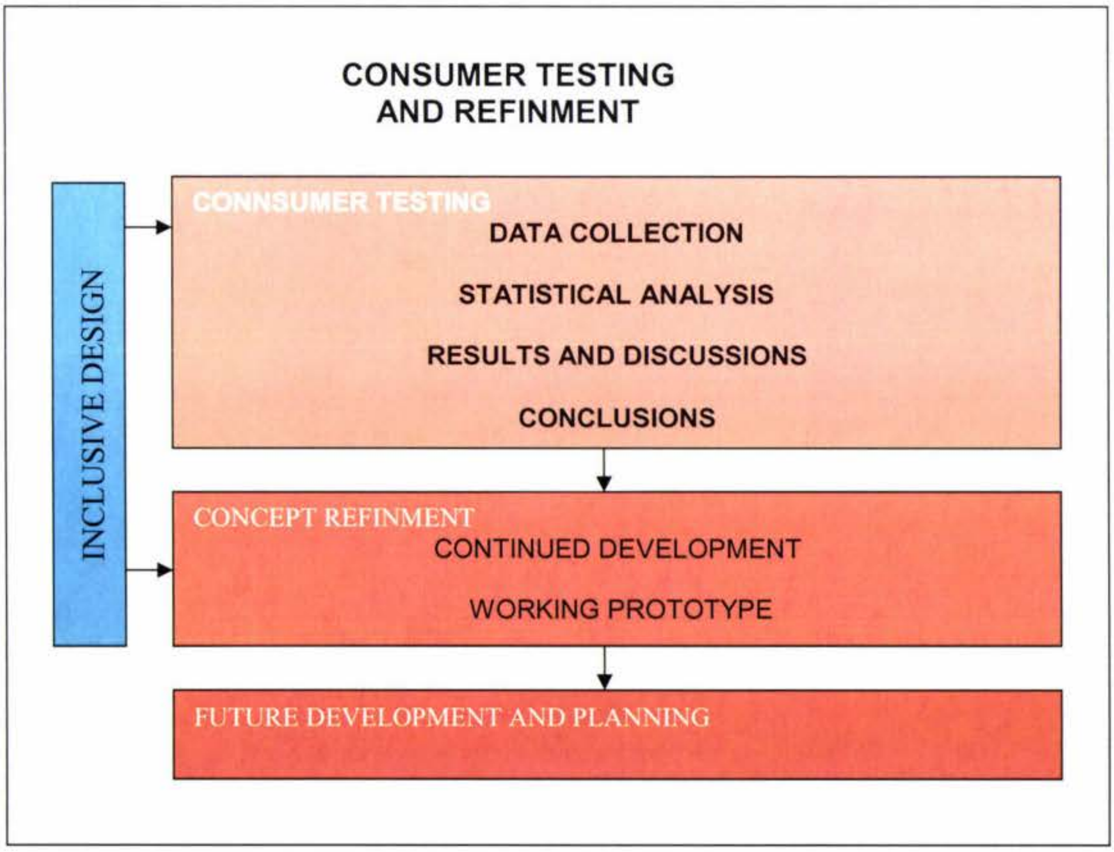


Figure 5-1 Development process used in the consumer testing and refinement stages

5.2 CONSUMER TESTING

The previous stages of development resulted in two separate sets of concepts each reflecting the needs of one of the two market groups. It was proposed that detailed consumer testing be undertaken to verify the design decisions made and offer information, which may help resolve the conflicts raised, leading to a single solution which is both usable and desirable. The information gained was also used to understand the research objective, which was: To understand what effect design decisions, which affect the usability of a product, have upon the desirability of the product to all users. A methodology was established and has been outlined in chapter 3, section 3.2.5, to answer the following questions:

1. How usable/desirable did users find each of the six concepts? It is necessary to understand both how usable/desirable users perceived each of the six concepts overall but also how usable/desirable they were perceived relative to each other. For example concept six may be perceived as less usable than concept four however it is still perceived as adequately usable overall. This allowed the two concept groups to be compared for usability/desirability.

2. What factors influence users perception of usability/desirability? Knowing this helped verify the design decisions made and offer information on what aspects of the design could be compromised if need be. Users were given a choice of factors. These factors were identified as being different between the two sets of concepts and relevant to either its usability or desirability. The two sets of factors are shown in Table 5-1 below.

USABILITY	DESIRABILITY
Interface/Button size	Interface usability
Interface markings button shape	Interface style
Interface/Button colour	Interface colouring/markings
Interface style	Interface/Button size
Other	Other

Table 5-1 Choices given to users representing influential factors in users usability and desirability decisions.

3. Did knowledge of the drivers behind design decisions influence people's perception of the concepts? This information helped to understand what effect

informing potential consumers about design for inclusion had upon their opinions of the usability or desirability of these products.

5.2.1 Consumer Groups

The sample group from market group 1 was split into three segments. The first two segments represented the groups who benefited the most from the points of conflict identified throughout the development, and the third segment represented a sample of the entire special needs market. The first segment consisted of thirteen people and included individuals whose only impairment was visual. This is because it was the colour scheme identified by visually impaired users as being most usable, that was disliked by able-bodied users. The second segment consisted of eight people and included users whose only impairment was physical. This was because the physically impaired benefited the most from a larger keypad and button size, which were disliked by able-bodied users. The third segment consisted of forty-one people who suffered from a range of impairments. Users were identified using the methodology outlined in section 4.2.1.

The sample group from market group 2 consisted of thirty-two able bodied people. These individuals were approached at random and asked to participate in the survey.

Numbers were generated to identify which segment different respondents fitted into without jeopardising the respondent's privacy. The letter B was used to represent visually impaired users, C used to represent physically impaired users, M to represent other users from Market Group 1 and A to represent users from Market Group 2.

5.2.2 Prototypes

Six aesthetic prototypes were developed which represented the concepts identified at the end of the development phase. The concepts replicated the sizes and colourings of each concept however were non-working models. Each concept was labelled to allow analysis. Pictures of prototypes with corresponding labels are shown in Figure 5-2. A display unit was also designed to eventually house the working prototype and to present concepts to potential users. Photos of this are also presented in Figure 5-2.

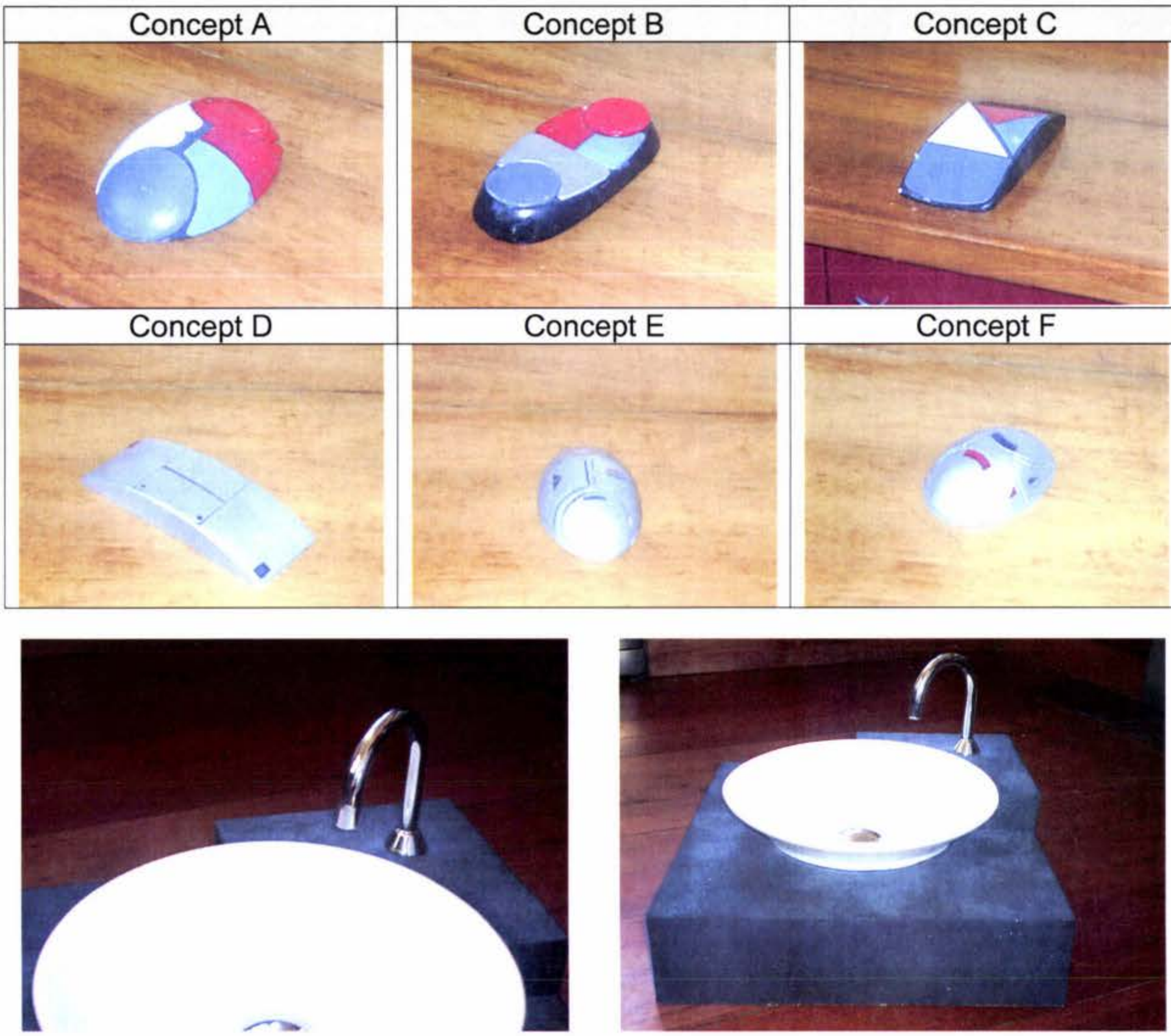


Figure 5-2 Prototype concepts used for consumer testing

5.2.3 Data Collection and Analysis

The methodology outlined in section 3.2.5 required users to consider the six prototypes for both usability and desirability and fill out the questionnaire included in Appendix 2.

Question one required the user to mark their perception of the usability of each of the concepts, on a given Likard scale, shown in Figure 5-3. The concept labels A-F were used to mark each one. The scale was marked with phrases to represent the users' perceptions of usability.

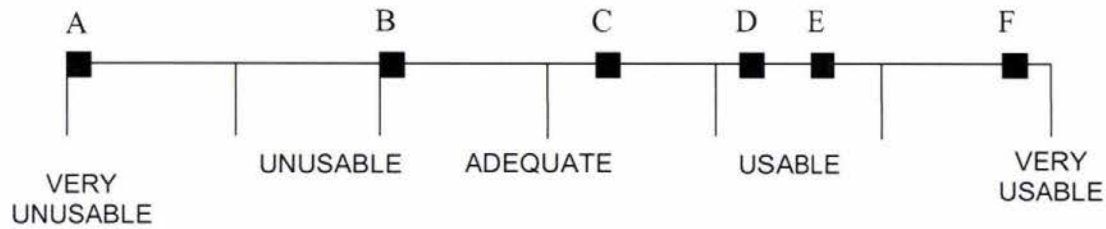


Figure 5-3 Usability scale used in consumer testing of prototypes

The scale was assigned with numeric values ranging from –6 to 6, which allowed the perceptions to be quantified. In the example shown in figure 5-3 the concepts were assigned the following values, A:(-6), B:(-2), C:(0.8), D:(2.5), E:(3.2), F:(5.8). In this way quantitative values for the perceived usability of the six concepts from each respondent were obtained and tabulated.

Question two asked users to identify the factors, which influenced their usability decisions. Users were able to select more than one option. The number of times a factor was acknowledged as being influential was tabulated.

Questions three and four were exactly the same as one and two but related to the desirability of the interface. They were also analysed in the same way.

Question five informed users of the intention of each concept and its design background and then asked how this affected the usability or desirability of each concept.

5.2.3.1 Statistical Tests

The data collected was analysed statistically. An ANOVA statistical test was used to determine if there was a considerable difference in the perceived usability or desirability of the six concepts. ANOVA is short for Analysis of Variance. The ANOVA analysis is used to compare numerous data sets. In this case the data sets represent each market group's perception of either the usability or desirability of each of the six concepts. The test firstly analyses each data set individually obtaining an average and a variance for each set. The average variance within data sets (WG) was then compared with the variance between data sets (BG), this value was called the *F* value and was a ratio WG:BG. An *F* value of 1 indicated that the variance between groups and within groups was exactly the same. If the *F* value was higher than one, it meant that the variance between groups was higher than the variance within groups.

The analysis then used this fact to obtain a critical value, which indicated an *F* value that groups that are similar would fall within 95% of the time. It was concluded that obtaining an *F* value outside this critical value, indicated that there was a significant difference between the means obtained for each data set. The problem is that the ANOVA analysis doesn't pin point, which data groups there is a significant difference between. Common sense however, was used to compare means and a fairly accurate guess was made as to which combinations of products were significantly different from the others. Table 5-2 provides an example of the output generated by running the ANOVA analysis. The output data is split into two tables. The first is the summary table. The summary table consists of the following information. The *Groups* column shows the data sets, which were analysed with the ANOVA analysis. In this particular case the data sets being analysed were concepts A, B, C, D, E and F. The *Count* represents the number of data points in each particular set. The *Average* shows the average of each particular data set, and the *Variance* column represents the variance of each data set.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A	32	128.8	4.025	3.656774
B	32	135.8	4.24375	1.587702
C	32	128.7	4.021875	2.914667
D	32	110.3	3.446875	3.235474
E	32	77.9	2.434375	6.621038
F	32	72.7	2.271875	9.307248

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	118.2798	5	23.65596	5.194754	0.000173	2.262674
Within Groups	847.01	186	4.553817			
Total	965.2898	191				

Table 5-2 Example of the output produced from an ANOVA analysis

The 2nd table, ANOVA table provides the results of the analysis. This table shows data for two sources of variation; the variation *Between Groups* and the variation *Within Groups*. The *SS (Sum of Squares)* and *df (degrees of freedom)* were used to obtain a *MS (mean squares value)* both between and within groups. The ratio of these two values gave the *F* value, which was then compared to the *F-crit (F critical* *value)* as discussed previously. If the F value was considerably higher than the F critical value it was concluded that 95% of the time, users, would indicate a difference between concepts with regard to the factor being studied (usability or desirability). Entire ANOVA printouts are included in Appendix 2. Values in summary and ANOVA tables are quoted and referred to in the following sections.

This statistical data was used to verify design decisions made throughout the concept development stage. The statistics represented how usable and how desirable each of the six concepts were to all potential users of the product. The results demonstrated the effectiveness of the development process followed.

5.2.4 Results and Discussion

This section provides and discusses the results of the consumer testing. The results have been portrayed under two major headings: Usability Results and Desirability Results.

5.2.4.1 Usability

Figure 5-4 represents the average perception of the usability of each of the six concepts as viewed by special needs users (MG-1). able-bodied users (MG-2) and the entire sample market.

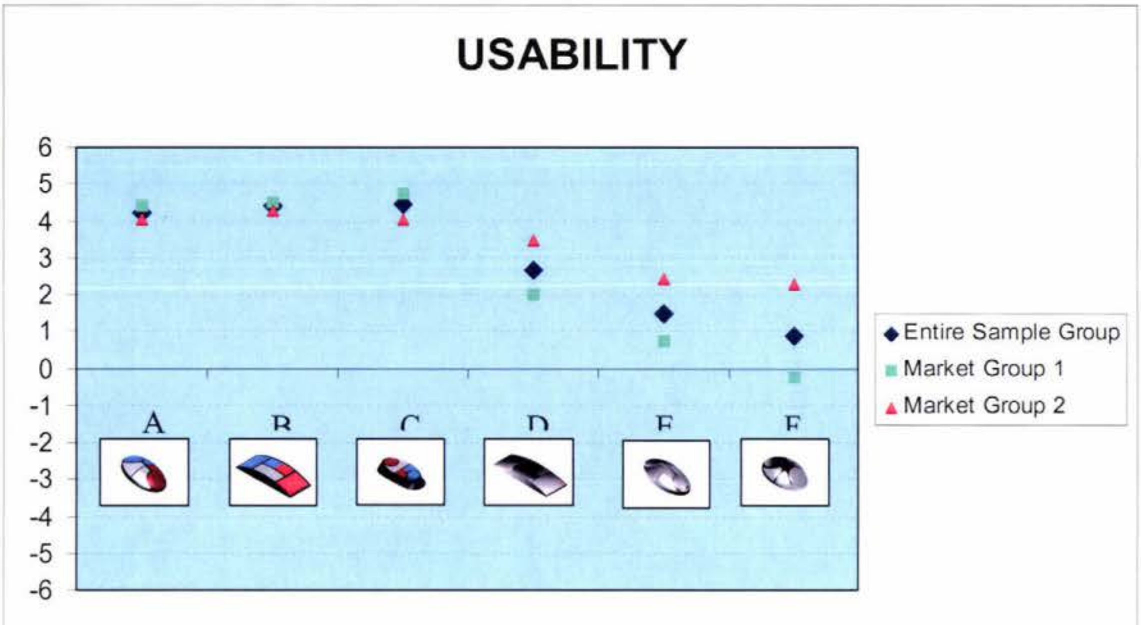


Figure 5-4 Average perception of the usability of the six concepts

Special needs users (MG-1) on average considered concept A to be more than usable averaging 4.4 on the usability scale. Concepts B and C were also considered to be more than usable with similar usability values of 4.5 and 4.7 respectively. Concept D had an average value of 2 on the usability scale. A value of 2 suggests that the concept is considered more than adequate in terms of usability. Concepts E and F had average values of 0.7 and –0.3, which indicated the concepts were adequately usable. Figure 5-5 below shows the six concepts in order of usability as perceived by Special needs users (MG-1).

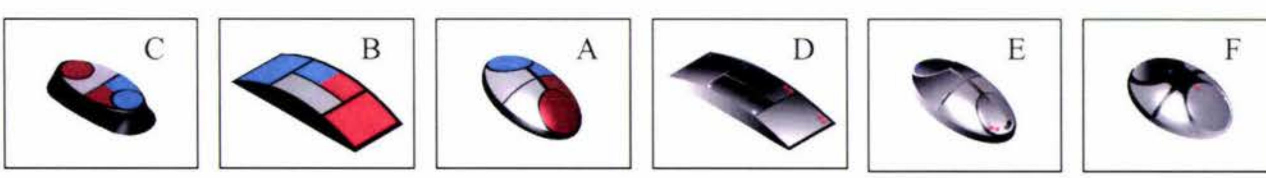


Figure 5-5 Concepts in order of usability as perceived by Special needs users (MG-1)

Able-bodied users (MG-2) followed a very similar trend to special needs users (MG-1) with concepts A, B and C all registering close to an average of 4 on the usability scale. The actual values were 4, 4.2 and 4 respectively. Concept D again was considered slightly less usable than A, B or C however an average value of 3.5 suggested the concept was considered usable. Concepts E and F had average values of 2.4 and 2.3, which also suggested that on average the concepts were considered usable.

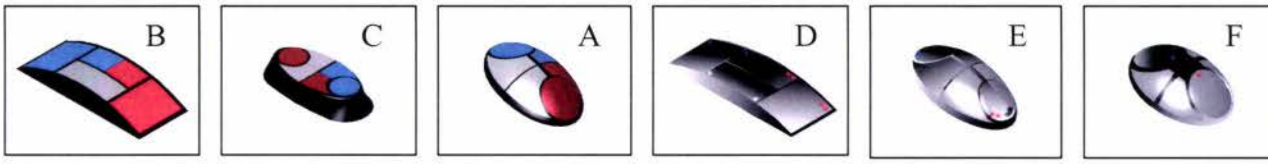


Figure 5-6 Concepts in order of usability as perceived by Able-bodied users (MG-2)

These results show that on average users from both market groups found concepts A, B and C to be more usable than concepts D, E and F. This indicates that design decisions made to make concepts A, B and C more usable achieved this objective. All six concepts where on average perceived as more than adequately usable

The remainder of this section describes the usability data in greater detail, looking at each market group and relevant segments of market group 1.

5.2.4.1.1 Special Needs Users - Market Group 1

As stated previously the special needs market was split into three separate segments for analysis. These three segments were analysed separately.

Users with only visual impairments

Figure 5-7 graphically represents each respondent's (with only visual impairments) perception of usability for each of the six concepts. The larger red dots indicate the average perception of usability for each concept from this group of respondents. Visually impaired users found Concepts A, B and C to all be very usable with average usability ratings of 4.8, 4.7 and 5 respectively. 100% of respondents found concepts A, B and C to be more than adequately usable. Concepts D, E and F were all found to be progressively unusable with usability ratings of 0.9, -0.5 and -1.5. Negative numbers suggest that concepts E and F were on average considered slightly unusable. Although it could not be proven statistically, observation while testing showed that respondents with increasingly severe levels of impairment, found concepts D, E and F increasingly harder to use.

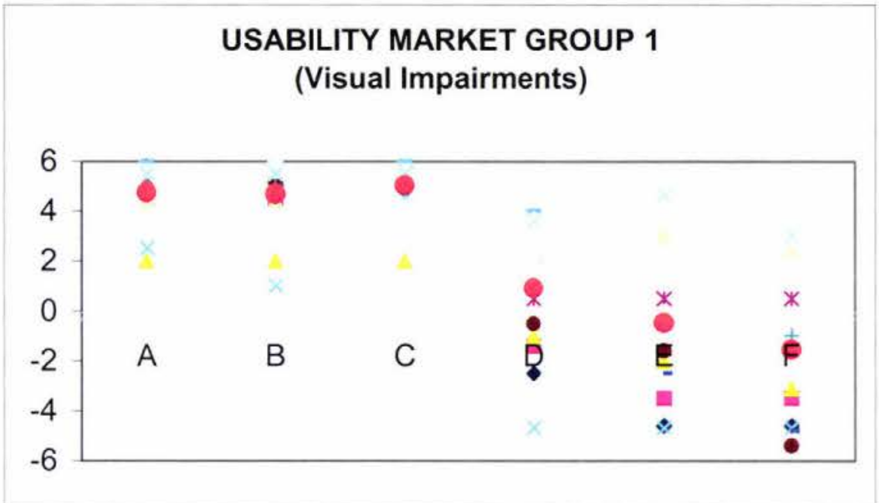


Figure 5-7 Plot of all visually impaired respondents measure of usability, showing the variability within concepts

The ANOVA analysis results showed that there was a significant difference in usability between concepts. The F value of 22.1 was significantly larger then the F critical value of 2.34. Concepts A, B and C were considered definitively more usable to visually impaired users than concepts D, E and F.

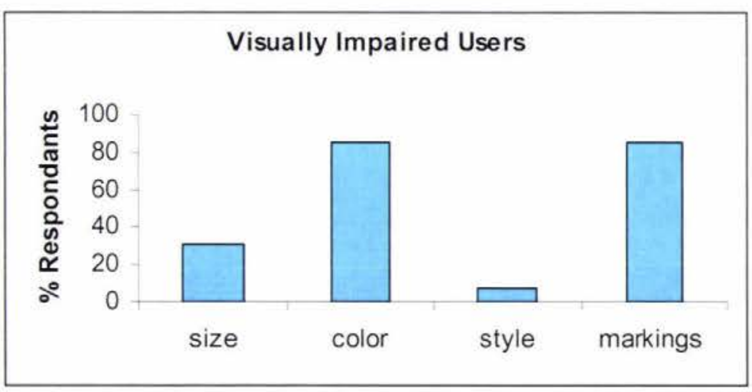


Figure 5-8 Reasons stated by the visually impaired market, which influenced the usability measure

Figure 5-8 showed that colour and markings were the major influences upon usability to the visually impaired market, with 84% of users indicating each as an influence. This meant that the colouring and marking on concepts A, B and C made these concepts more usable to respondents with visual impairments.

Users with only physical impairments

Figure 5-9 graphically represents each respondent's (with only physical impairments) perception of usability for each of the six concepts. The larger red dots indicate the average perception of usability for each concept from this group of respondents. Physically impaired users found Concepts A, B and C to all be very usable with average usability ratings of 4.6, 5.2 and 5.2 respectively. Concepts D, E and F were all found to be progressively unusable with usability ratings of 3.9, 2.5 and 1.8. The lowest usability rating of 1.8 for concept F was still considered more than adequately usable. It should be noted that all respondents bar one found all concepts to be more than adequately usable. The low response, which has been circled in figure 5-9, was observed to have been indicated by a user with particularly severe physical impairments. The smaller size of concepts E and F made it more difficult for the user to manipulate.

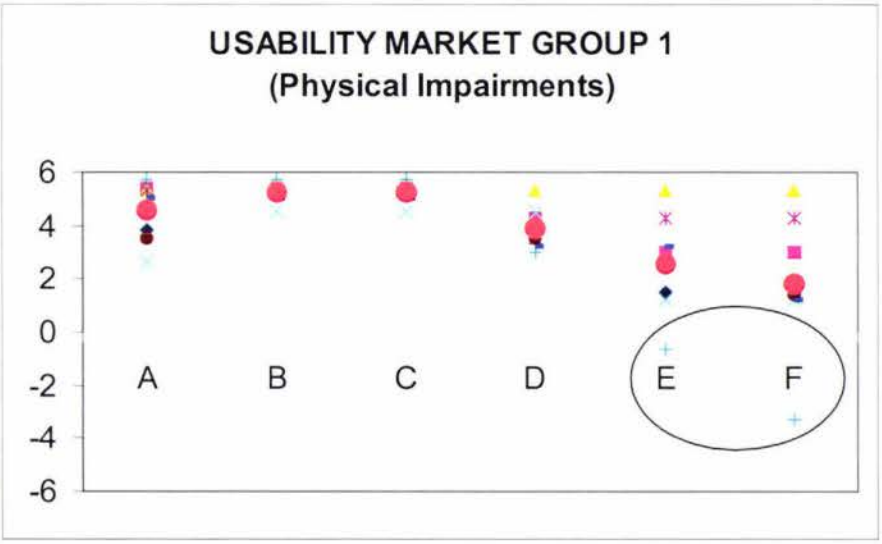


Figure 5-9 Plot of all physically impaired respondents measure of usability, showing the variability within concepts

The ANOVA analysis results showed that there was a significant difference in usability between concepts. The F value of 7.88 was significantly larger then the F critical value of 2.43. The high averages and very low variance values for concepts B and C indicated that these concepts could be considered more usable than concepts E and F, which had considerably, lower averages. The variances of perceptions of usability for concepts A, D, E and F prevented any statements being made based on the ANOVA analysis as it relied on a 95% confidence level.

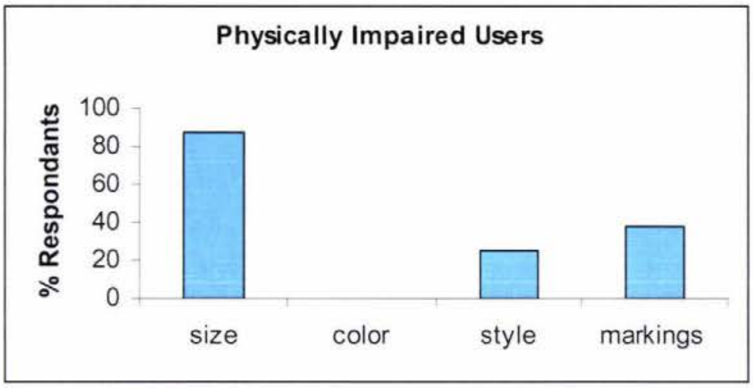


Figure 5-10 Reasons stated by the physically impaired market, which influenced usability measure

Figure 5-10 showed the contribution of factors, which influenced respondent's usability decisions. It was apparent that size was the major influence upon usability to the physically impaired market as indicated by 86% of the respondents. Larger concepts where considered easier to use. Markings and style were both indicated as contributing factors to the usability decisions.

Users with general special needs (including visual and physical impairments in conjunction with other impairments)

Figure 5-11 shows that there is a wide range of variance between perceptions of users towards usability within this market group. On average concepts A, B and C with usability ratings of 4.1, 4 and 4.4 were considered more usable than concepts D, E and F which had usability ratings of 2, 0.8 and –0.3.

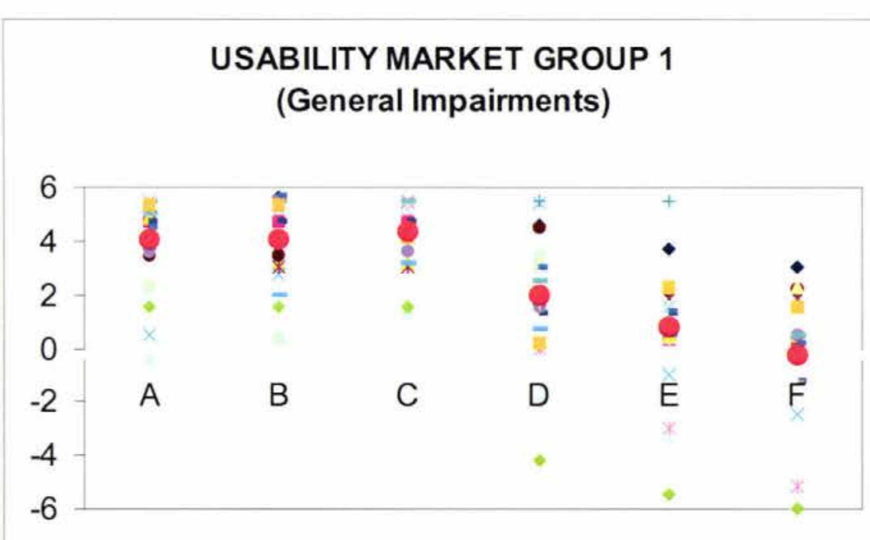


Figure 5-11 Plot of all impaired respondents measure of usability, showing the variability with in concepts

The ANOVA analysis results showed that there was a significant difference in usability between concepts. The F value of 40.31 was significantly larger then the F critical value of 2.25. From looking at the mean values, it was predicted that this comparison could only be used between concept D and F, with D being considerably more usable than F.

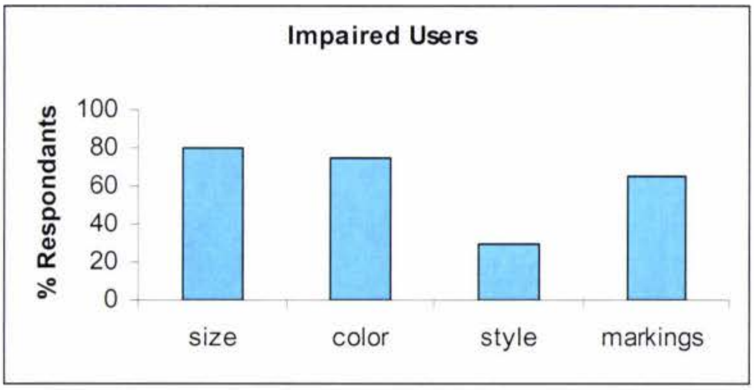


Figure 5-12 Reasons stated by the general special needs market, which influenced usability measure

Figure 5-12 shows that colour, size and markings are all relevant reasons for users opinions on usability. This was determined to be due to the wide variation in impairments. Some users suffer from multiple impairments including physical and visual ones.

5.2.4.1.2 Able-bodied users – Market Group 2

Figure 5-13 indicates that able-bodied consumers felt that all concepts were more than usable. There was not a large difference between averages for each concept with usability ratings of 4, 4.2, 4, 3.4, 2.4, 2.3 sequentially. This was also demonstrated by the ANOVA analysis with an F value of 5.19 and an F-critical value of 2.26 suggesting that there was a small difference between some concepts but not a significant one.

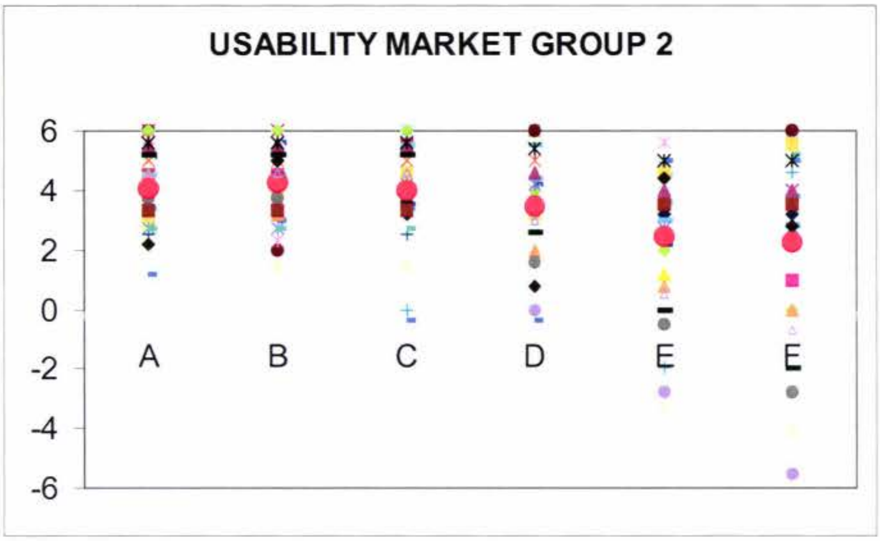


Figure 5-13 Plot of all able-bodied users (MG-2) respondents measure of usability, showing the variability with in concepts

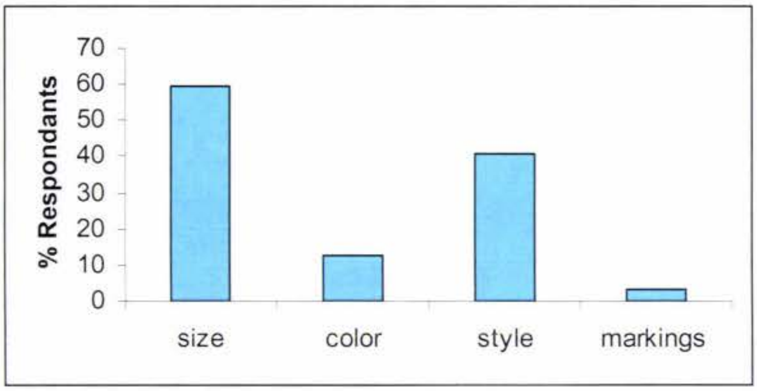


Figure 5-14 Reasons stated by able bodied market, which influenced usability measure

Figure 5-14 represented the reasons, which influenced usability. It can be seen that 59% of respondents stated keypad size was an influential factor in their usability decision. This was followed by style, which 41% of respondents stated as being an influential factor. Colour and Markings were considered minor influences, accounting for 13% and 3% respectively. This indicated that special needs users (MG-1) recognised that the larger size of concepts A, B and C did, in fact make them easier to use.

5.2.4.2 Desirability

Figure 5-15 represented the average perception of the desirability of each of the six concepts as viewed by special needs users (MG-1), able-bodied users (MG-2) and the entire sample market.

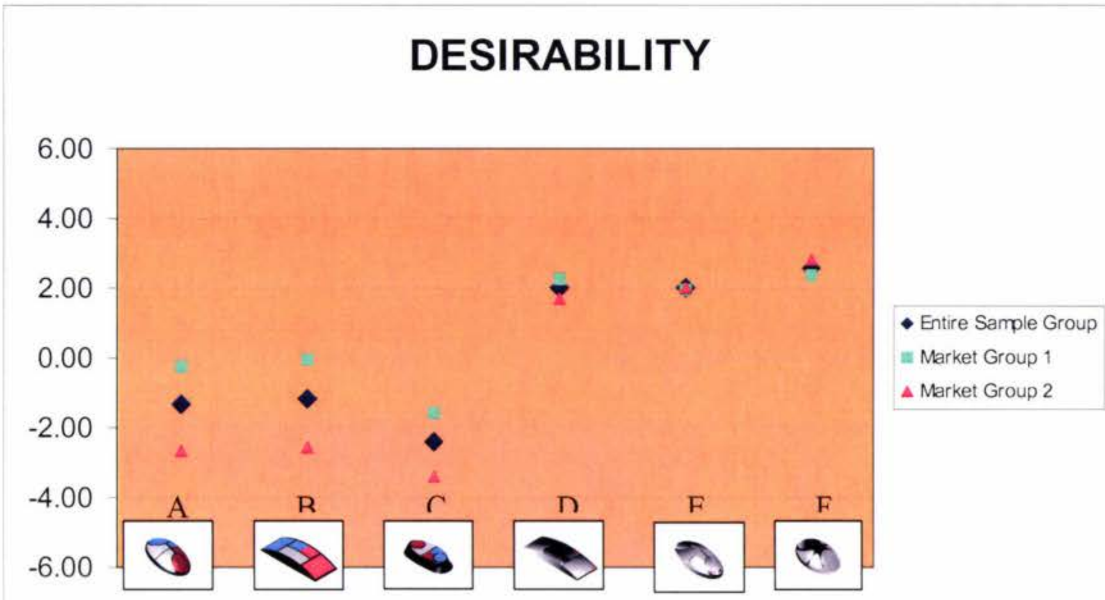


Figure 5-15 Average perception of the desirability of the six concepts

Special needs users (MG-1), on average considered concepts D, E and F to be the most desirable with average desirability ratings of 2.3, 2 and 2,4 respectively. These values reflect that these three concepts were found to be desirable. Concepts A, and B were both found to be adequate in terms of desirability with desirability ratings of –0.3 and –0.1. On average concept C was found to be the least desirable with a desirability rating of –1.6.

Figure 5-16 Concepts in order of desirability as perceived by special needs users (MG-1)

Able-bodied users (MG-2) followed a very similar trend to special needs users (MG-1), with concepts D, E and F registering basically the same desirability values. Concepts A, B and C were considered less desirable by able-bodied users (MG-2) than special needs users (MG-1), registering desirability ratings of –2.7, -2.6 and –3.4.

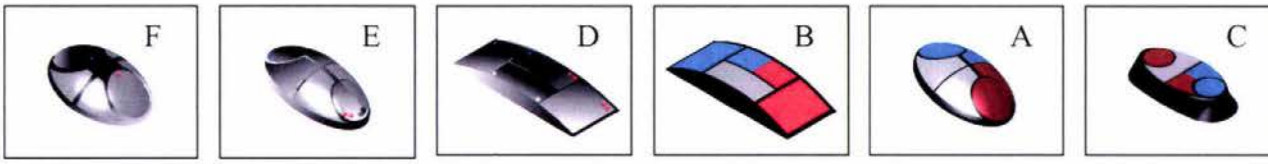


Figure 5-17 Concepts in order of desirability as perceived by Able-bodied users (MG-2)

These results show that, on average, users from both market groups found concepts D, E and F to be more desirable than concepts A, B and C. This indicates that design decisions made to make concepts D, E and F more desirable to able-bodied users (MG-2) also were portrayed as more desirable to special needs users (MG-1).

The remainder of this section will investigate the desirability data in greater detail, looking at each market group and relevant segments of market group 1.

5.2.4.2.1 Special needs users - Market Group 1

As stated previously the special needs market was split into three separate segments for analysis. These three segments will also be analysed separately.

Users with only visual impairments

Figure 5-18 shows that visually impaired consumers felt all concepts were close to adequate in terms of desirability. The high variance within concepts represented in Figure 5-18 shows the diversity within the visually impaired market.

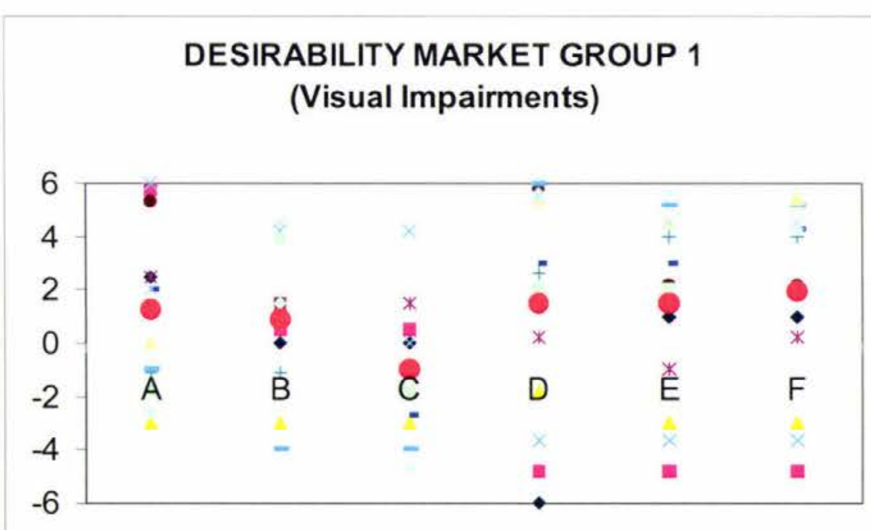


Figure 5-18 Plot of all visually impaired respondents measure of desirability, showing the variability with in concepts

The ANOVA analysis results show that there was no significant difference in desirability between concepts. The F value of 1.34 was less than the F critical value of 2.33. This meant that no real distinction could be made between the concepts.

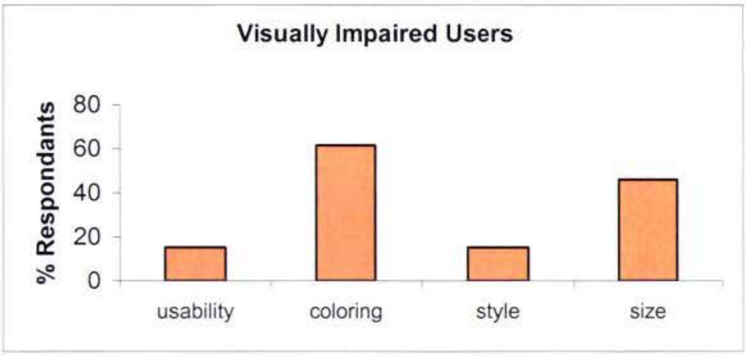


Figure 5-19 Reasons stated by the visually impaired market, which influenced desirability measure

Figure 5-19 shows that colouring and size were the most influential factor in users, opinions of desirability of the concepts. Because of the high variance in perceptions of desirability within concepts it was hard to make a distinction as to which factors made what concepts desirable. For example, was the colouring on concepts A, B and C more desirable than the colouring on concepts D, E and F, and vice versa?

For this reason the data was broken up further, looking at the individual factors that influenced the desirability the most. Size and colouring were looked at individually, graphically representing each, to show which concepts were preferred because of that particular factor.

Colouring and Markings

Figure 5-20 shows the responses from each respondent in the visually impaired market segment of market group 1 who indicated colouring and markings as an influence upon their desirability decisions. A majority of the respondents trended from low desirability ratings for concepts A, B and C up to higher desirability ratings for concepts D, E and F. A few respondents preferred the colouring and markings of concepts A, B and C, however, these were observed to be respondents with particularly severe impairments.

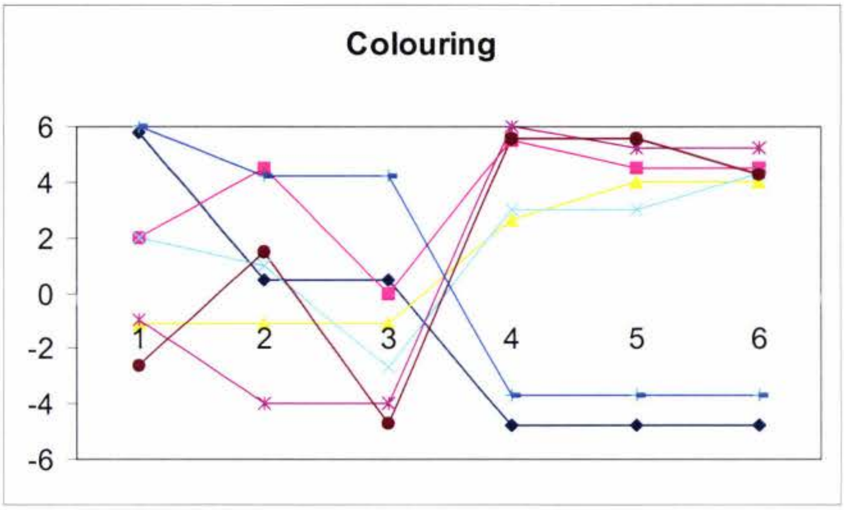


Figure 5-20 Visually Impaired respondents who stated colouring as the major influence

Size

Interestingly, all visually impaired respondents, who stated size as the influencing factor, preferred the smaller concepts of D, E and F. This is shown below in Figure 5-21.

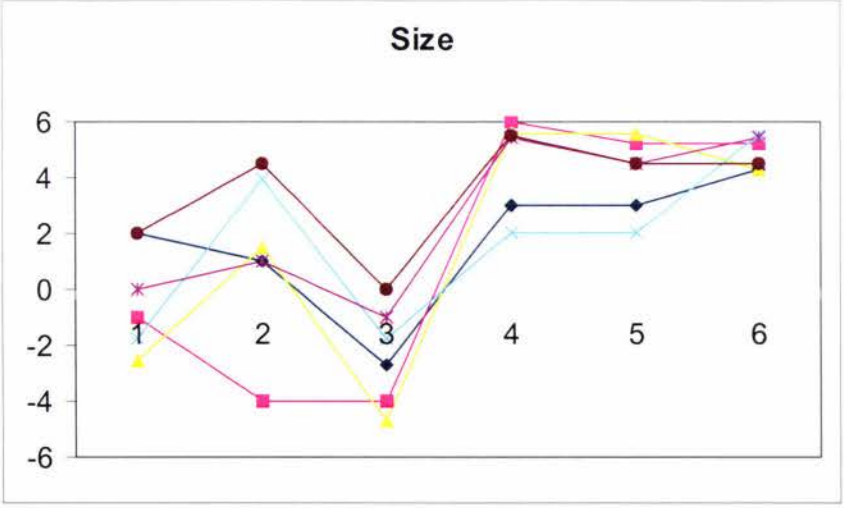


Figure 5-21 Visually Impaired respondents who stated Size as the major influence

Users with only physical impairments

The results portrayed in Figure 5-22 suggest that users found concepts D, E and F more desirable than concepts A, B and C. The ANOVA analysis agreed with this statement. The F value of 15.15 was significantly larger then the F critical value of 2.43. From looking at the data values it was predicted that Concept C was the most desirable with E and F being considerably more desirable than A, B or C.3

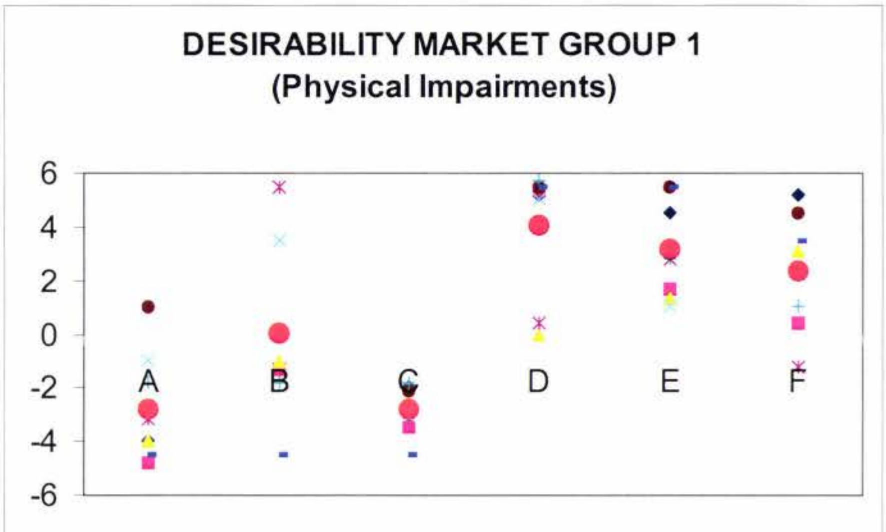


Figure 5-22 Plot of all physically impaired respondents measure of desirability, showing the variability within concepts

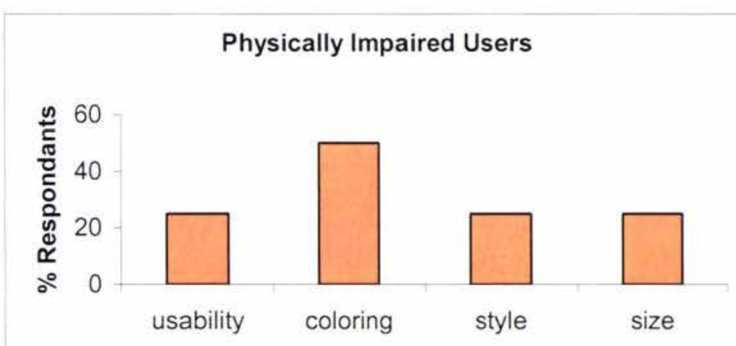


Figure 5-23 Reasons stated by the physically impaired market, which influenced usability measure

It is apparent from Figure 5-23 that colourings were the major influences upon desirability to the physically impaired market. This suggested that the colouring of Concepts D, E and F made them more desirable than Concepts A, B and C

Users with general special needs (including visual and physical impairments in conjunction with other impairments)

Figure 5-24 shows there was a wide range of variation within concept groups. This was attributed to the varying impairments and levels of ability. The ANOVA analysis results showed that there was a significant difference in desirability between concepts. The F value of 7.27 was significantly larger then the F critical value of 2.29. From looking at the mean values it was predicted that Concepts D, E and F were considered to be more desirable than Concept C.

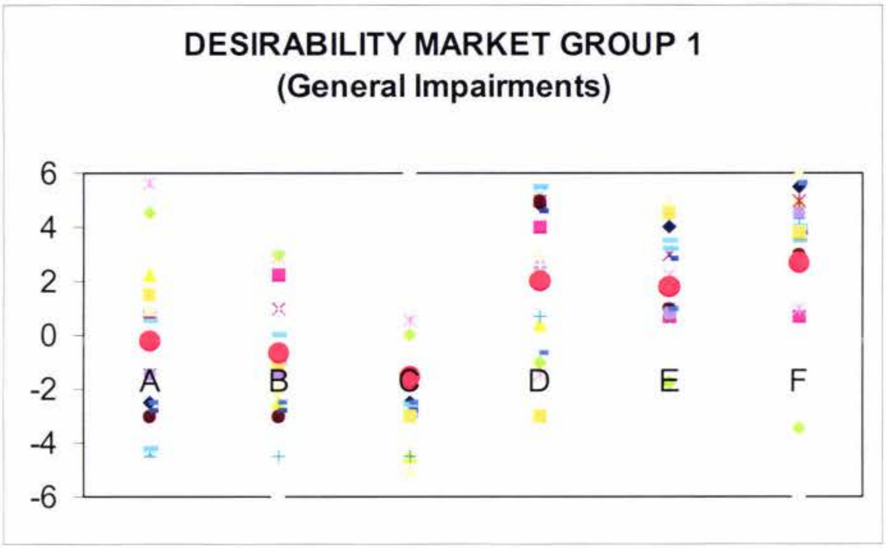


Figure 5-24 Plot of all impaired respondents measure of desirability, showing the variability with in concepts

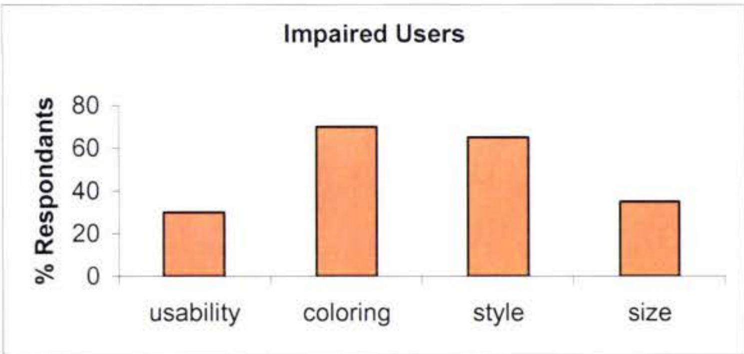


Figure 5-25 Reasons stated by the general special needs market, which influenced usability measure

Figure 5-25 showed that colouring and markings and style were the most contributing factors to desirability decisions by this market group. However, size and usability both also contributed significantly.

5.2.4.2.2 Able-bodied users – Market Group 2

Figure 5-26 showed that Concepts D, E and F were on average considered more desirable than Concepts A, B and C. Although, there was a wide range of variance within concepts the trend between concepts (an example of this trend shown with the purple data points) indicated that, in a majority of cases, users found Concepts D, E and F more desirable.

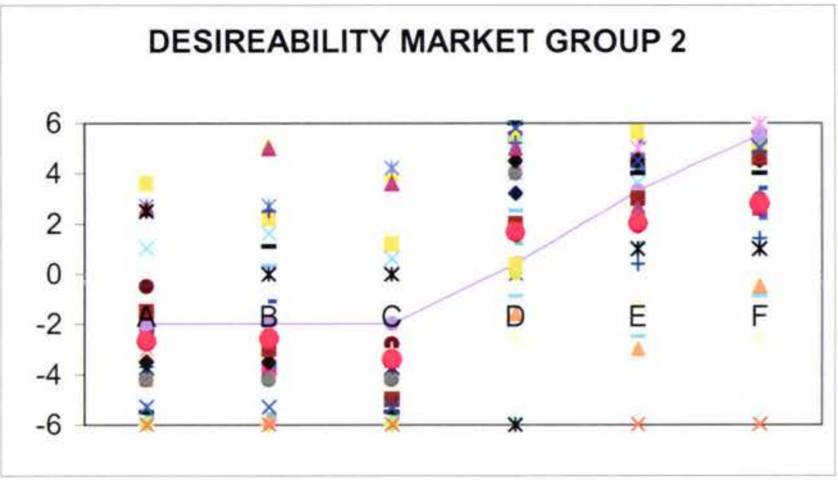


Figure 5-26 Plot of all able bodied respondents measure of desirability, showing the variability with in concepts

The ANOVA analysis showed that there was a significant difference in desirability between concepts. The F value of 24.0 was significantly larger than the F-critical value of 2.26. It was derived that this again indicated Concepts D, E and F were more desirable than Concepts A, B and C.

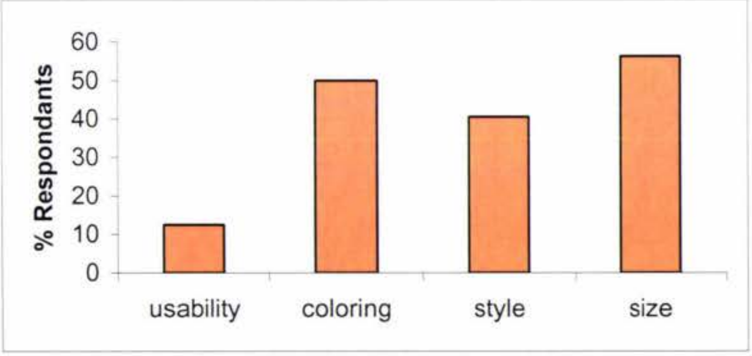


Figure 5-27 Reasons stated by Able-bodied users (MG-2), which influenced desirability measures

Figure 5-27 shows the main influences on able-bodied consumers (MG-2) choices, in terms of desirability, were: size, and colouring and markings. These were points of conflict identified throughout the development and represent the main differences between Concepts A, B, C and D, E, F. Style was also considered a fairly important influence; showing that able bodied consumers preferred the dome shaped styles of A, E and F over the others.

5.2.4.3 Understanding

It was interesting to note that making consumers aware of the reasons behind differences in concepts did not affect their judgment. Only two consumers out of the seventy-two survey opted to change their perceptions on usability and desirability once they understood the philosophies behind the concepts development. This did not provide enough data to justify an analysis. In both cases however, the decision was made to change desirability opinions by able-bodied user, because they were aware that there was a possibility that someone with special needs may need to use the facility in their household.

5.2.5 Conclusions

The concepts developed to incorporate the special needs market, A, B and C were recognised as being the most usable by all markets. 100% of respondents from both market groups recognised these concepts as being more than adequately usable. Reasons for this were very similar to findings in the development phase. The colouring and markings made the concepts easier to use by people with visual impairments and the size of the interfaces and buttons made the concepts easier to use by people with physical disabilities. All other users also noted that these concepts were easier to use because of these two reasons. The concepts adapted for the able bodied market, D, E and F were found to be more than adequate in most situations in terms of usability, and only being found unusable by people with severe levels of impairment.

Concepts A, B and C were found to be the least desirable by all market groups. Visually impaired users preferred the size of Concepts D, E and F and in some cases preferred the colouring of Concepts D, E and F. As just stated however the more severely visually impaired users found these concepts harder to use and as a result found Concepts A, B and C more desirable. Physically impaired users liked the colouring of Concepts D, E and F.

It was also concluded that users didn't take into consideration the overall needs of a population when considering the usability or desirability of products unless directly affected themselves. The two scenarios where user's changed their opinions, were both from respondents who had siblings with impairments. In most situations informing users of the design theories behind each concept did not affect feelings towards the concepts usability or desirability in any way.

This testing suggested that design decisions made to influence the usability of products could potentially have a negative effect by decreasing the desirability of the product to other potential users. This in turn will have a negative effect upon company objectives to make as much money as possible. Therefore usability alterations, which theoretically will make the product usable by a wider group of people and hence increase a potential market size could also affect the desirability of that product, having an inverse affect upon the market size. Because of this, it is very important to asses any design decision with a varying range of users to understand the usability and desirability effects the design decision may have.

The statistical analysis shows that the design process followed was effective in identifying features, which would improve the usability of the interface to special needs users, (MG-1). The design approach followed was also effective in identifying the features which users without severe impairments, found to be desirable that were being compromised by changes to usability.

5.3 CONCEPT REFINEMENT

The conclusions drawn from the concept-testing phase allowed the concept focus to be refined. There was a far greater difference in the perceptions of desirability between the concepts than there was between the perceptions of usability of the six concepts. For this reason, Concepts D, E and F, which proved to be the most desirable concepts, were adapted and refined to make them more usable.

Visually impaired users were the only market segment who did not find Concepts D, E and F distinctly more desirable than Concepts A, B and C. The recognised reason for this was the colouring and markings present on Concepts A, B and C, which made them usable to these respondents. It is these factors that the refinement focused on

5.3.1 Keypad Style

One of the initial objectives was to identify a single interface style that was usable and desirable. Two styles of interface were still under developed; the long rectangular style of interface D and the elliptical dome of interfaces E and F. No real distinction was obvious from the concept testing between the two styles of concept. For this reason the two styles were taken to a number of retailers of kitchen and bathroom equipment. The two styles were discussed in depth with all retailers. Concept D's rectangular profile was described as "unrefined". The elliptical dome on the other hand was seen as "very finished", "quite sleek" and "organic". There was an overwhelming agreement that the style Concepts E and F portrayed, showed far greater potential than Concept D. The differences between Concepts E and F were only slight. The dome of Concept F is less pronounced than that of Concept E, the ellipse is rounder and the entire keypad slightly smaller. It is this shape that was preferred between the two. It was commented that it looked "simpler", "would merge into the surroundings better", "flow with the bench top" and "would suit the minimalistic trends which were becoming popular". It was decided that the smaller profile of Concept F would be used for future development and refinement, with the electronic components being used as a constraint for the size.

5.3.2 Keypad Colouring and Markings

Colour and markings were attributed as a major influence on the usability of the interfaces. These two factors were outlined in the concept-testing phase as limiting the desirability of the chosen concept to visually impaired users. However the metallic colour scheme of the chosen concept was also outlined in the concept-testing phase as attributing to the desirability of the concept to non-visually impaired users. The problem posed therefore is how to increase the usability of this interface concept without compromising the metallic colour scheme.

Concept drawings of the interface along with a prototype were taken into the National Foundation for the Blind. The problem was proposed to a group of field officers whose job is to make homes more usable for people with visual impairments.

They agreed that this concept was much more aesthetically pleasing than the ones they had originally helped to develop. They suggested a number of things, which would make the product more usable to people with visual impairments. These were as follows.

- Increase the size of the colour indications. This should accommodate most users who have slight to medium visual impairments.
- Add the markings previously discussed into this solution. Making it easier to use by people with severe visual impairments.
- Making sure that there is tactile definition between buttons. Again making it easier for people with severe impairments to use.

A number of concepts were generated which had increased amounts of colour in the interface. These were given to over forty respondents from both market groups and asked to evaluate. All users identified a clear solution shown in Figure 5-28.

The recommendations regarding inclusion of markings on the buttons to enable definition between hot and cold, and inclusion of tactile definition between buttons were included in the interface concept design.

5.3.3 Keypad Control

Figure 5-28 outlines the button layout for the keypad interface to be used. Each of the buttons was labelled with a number, which was used as a label in the discussion of the control of the interface.

1) Cold water On/Off
2) 45°C preset On/Off
3) Temperature down
4) Temperature up
5) Flow up
6) Flow down

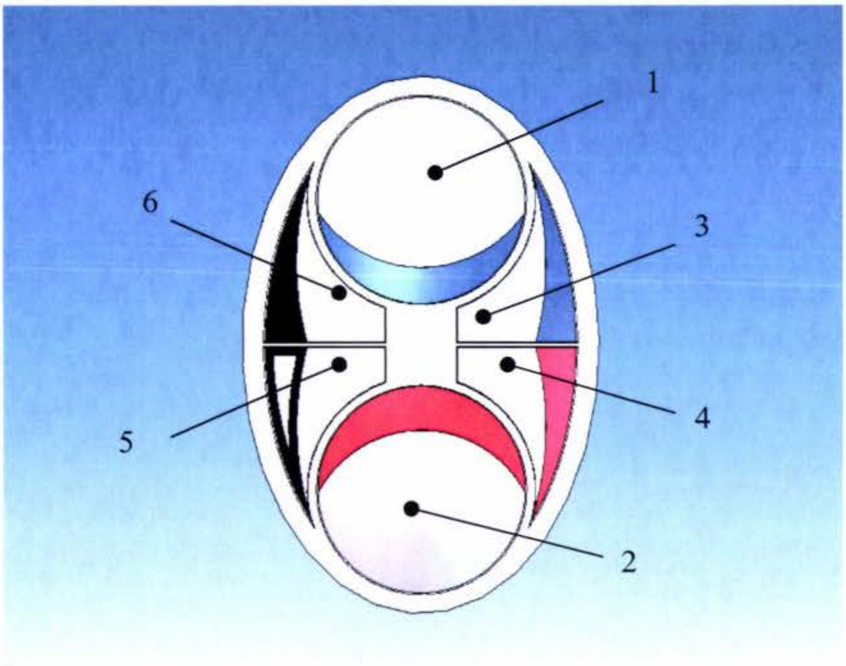


Figure 5-28 keypad interface with button labels

5.3.3.1 Turning the faucet on and off

Single pressing either button 1 or button 2 will turn the faucet on. Pressing the same button again will turn the water off.

5.3.3.2 Temperature Control

A temperature scale is shown in Figure 5-29. This represents the temperature range that the user can reach. Buttons 1 and 2 have been placed on the scale to represent their corresponding preset temperatures. Button 1 was set at cold and button 2 was set at 45°C. Buttons 3 and 4 were temperature down and temperature up respectively. They allowed the temperature to move up and down the temperature scale from the starting points provided by buttons 1 and 2. A single press of button 3 moved down the temperature scale one place, and similarly a single push of button 4 moved the pointer up the temperature scale one place. The temperature scale was developed as a result of the user testing performed in section 4.1.1.3.

It should be noted that if button 1 was used to turn the water on then the water temperature was approximately 20°C. If the user wished then to switch quickly to a hotter temperature while the tap was still running they pressed button 2 which changed the water temperature to 45°C. In order to turn the tap off the user simply tapped button 2 again.

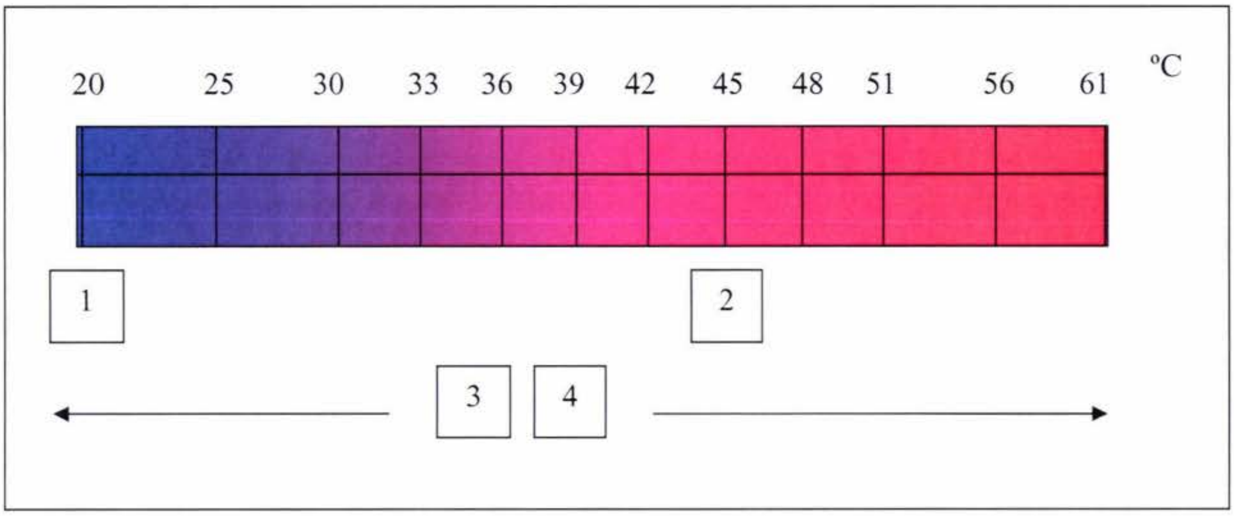


Figure 5-29 representation of the temperatures which can be reached with temperature controls.

Using this system the user was never any further than four taps of a button from their desired temperature.

Holding down buttons 3 and 4 to decrease and increase temperatures continuously along the scale was decided against due to the need for consumers to physically feel the implications of their actions. Holding the buttons down gave the user no idea of how much they had adjusted the temperature. Consideration was given to a display showing the current temperature setting. However, this was traded for simplicity of the interface. It was felt that it overcomplicated the design.

5.3.3.3 Flow control

The water automatically came on at a default medium flow. The target flow rate was 7L/min, however this varied depending upon the water pressure of the system it was installed in. The flow was either increased or decreased with the use of buttons 5 and 6. The maximum desired flow was approximately 9 L/min and the minimum was 2.5 L/min. Again this varied depending upon the system it was installed in.

5.3.3.4 Safety controls

Users had the option of setting their maximum hot water temperature to 45°C as pointed out in section 4.3.7. The user simply had to hold the preset hot temperature button down for 15 seconds. This amount of time was adequate to ensure that the activation into safety mode was done on purpose.

5.3.4 Interface Prototype

The interface prototype was designed using three components: base, shell and buttons. The final working interface prototype was shown in states of disassembly, in Figure 5-29. The prototype does not reflect the final colour scheme identified through the research. Problems were associated with colouring the interface in a manner that looked professional and complete.

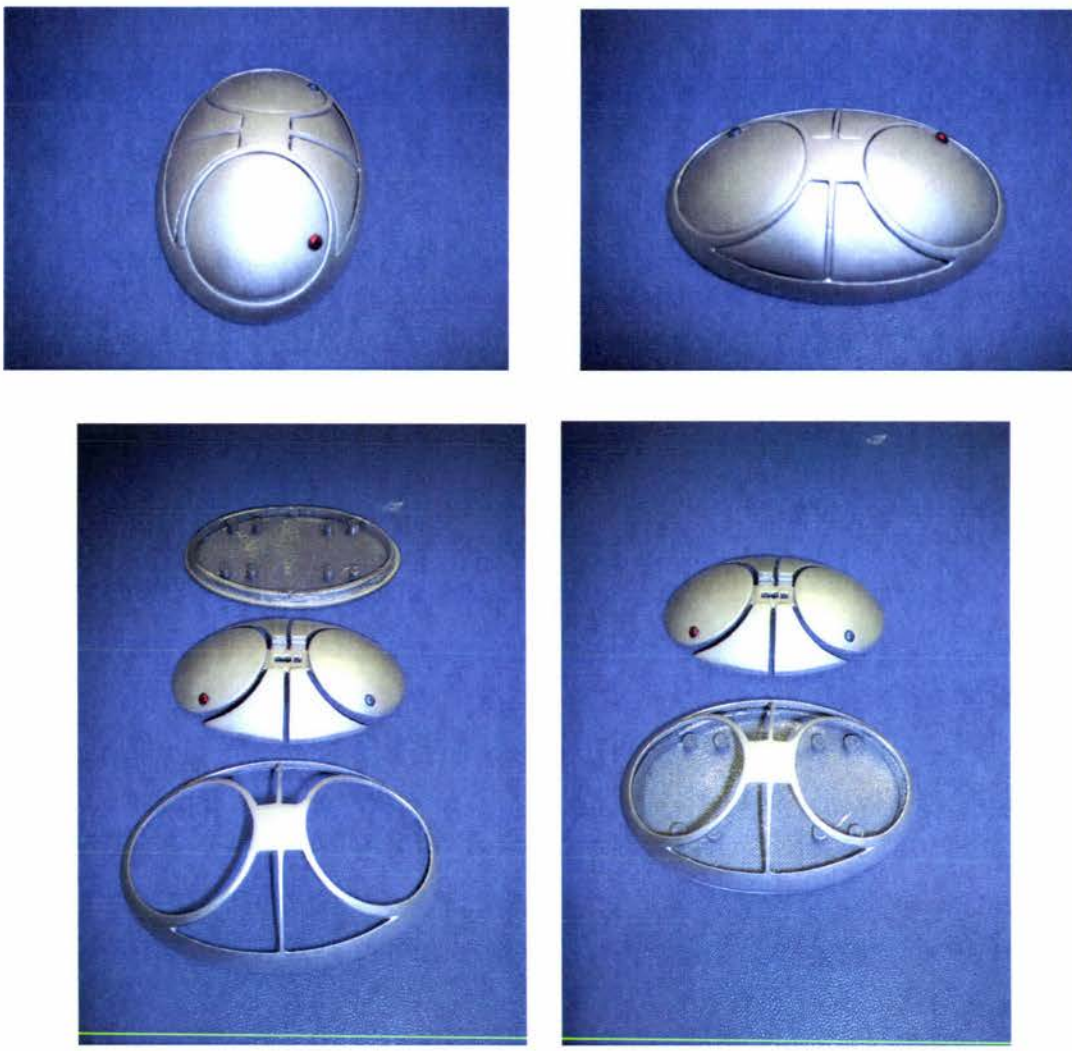


Figure 5-30 Working Interface Prototype

5.3.5 Final Interface User Testing

Users tested the final interface, to investigate how usable and desirable it was. A similar testing methodology to the one identified in section 3.2.5 was followed. The final working prototype and an aesthetic prototype were taken to users from both market groups who were asked to identify the concepts perceived usability and the concepts perceived desirability. Users were required to mark on a usability scale (previously shown in figure 5-3) their perception of the usability of the concept. Users were then asked to mark on a desirability scale (same as figure 5-3 except with desirability criteria), their perception of the desirability of the concept. Fifty users in all from a mixture of both market groups took part in the testing. The results are shown in figure 5-31.

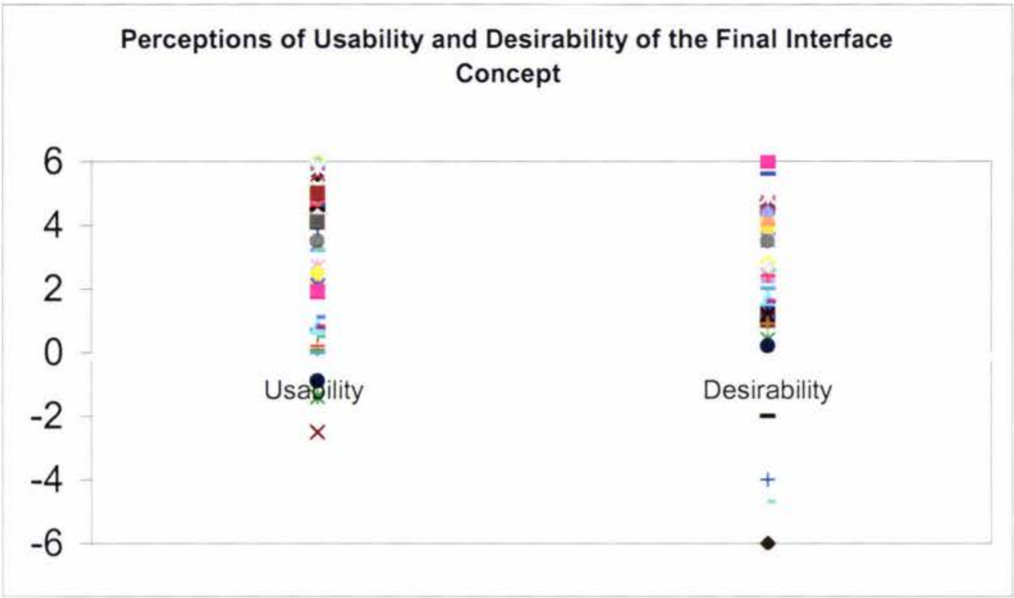


Figure 5-31 Perceptions of usability and desirability for the final interface concept

96% users found the concept to be more than adequately usable. 92% of users found the concept more than adequately desirable. These results indicate that the final concept can be considered usable by people with a wide range of impairments and desirable to a majority of all potential users.

5.4 FUTURE DEVELOPMENT AND PLANNING

The interface was handed over to the electronics engineer to install the appropriate electronics into the interface. This interface was used as a demonstration and display piece to help sell the idea to companies interested in the product.

Other interface designs for showers and baths not included in the scope of this project have been developed to a concept stage and will be incorporated as intellectual property into the package sold to external companies.

CHAPTER 6

VALVE SYSTEM DEVELOPMENT

6.1 INTRODUCTION

The process identified in figure 6-1 will be followed to develop the valve system. The stages in this process have also been used to structure this chapter.

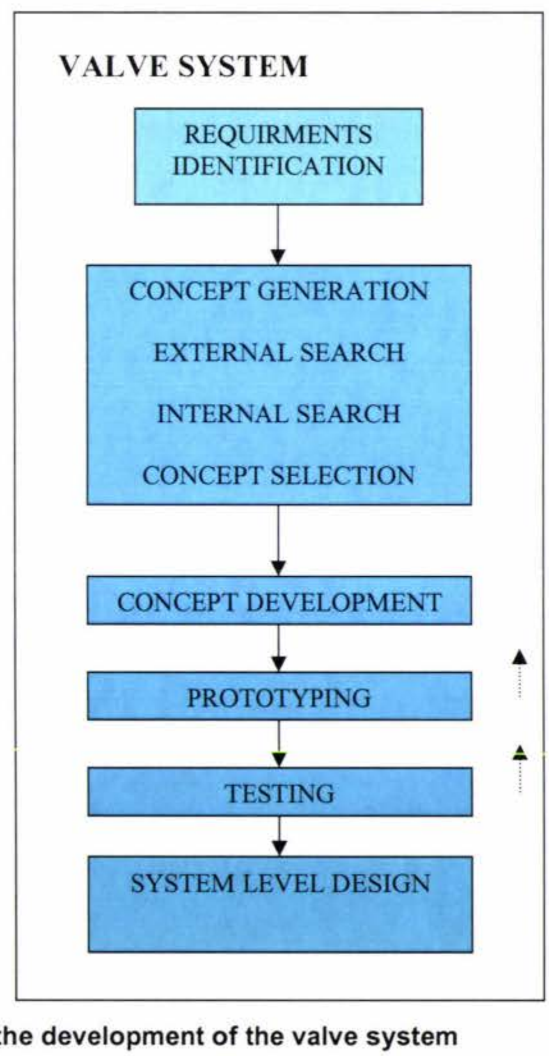


Figure 6-1 Process for the development of the valve system

6.2 REQUIREMENT IDENTIFICATION

The methodology outlined in section 3.3.1 was used to identify the requirements, which guided the development of the valve system. As stated the requirements were gained from three sources. These three resources included; the user - whose needs where gained through consumer research, the initial prototype which provided a physical object, which users could use and comment upon, and the sponsor company, who outlined guidelines they wished to be met.

6.2.1 User Needs

The user needs identified in section 3.2.2.3 not only influenced the user interface but also affected the valve system. The needs identified in section 4.1 relating to the electronically operated water control system (EOWCS) were redefined to relate solely to the valve system. These are shown in Table 6-1. The light blue shading represents the primary needs, with their associated secondary needs included below them.

Table 6-1 Valve requirements identified from the user needs

No.		Need
1	**The Valve**	**Can turn the water flow on and off**
2	The Valve	Allows users to adjust the water temperature
3	The Valve	Allows users to adjust the water temperature before the water is turned on
4	The Valve	Allows users to adjust the water temperature while the water is running
5	The Valve	Reaches the users desired temperature as quickly as possible
6	The Valve	Can reach the most frequently used temperatures easily
7	The Valve	Can maintain the desired water temperature despite system fluctuations
8	The Valve	Can respond quickly to changes in the inlet water temperature
9	The Valve	Has the capability to reach all required water temperatures
10	**The Valve**	**Can adjust the water flow rates on the outlet**
11	The Valve	Can control the flow to all those desired by he user
12	**The Valve**	**Can maintain the desired flow despite system fluctuations**
13	**The Valve**	**Fits into the surrounding environment**
14	**The Valve**	**Is easy to install**
15	**The Valve**	**Can be installed on any existing or new facility**
16	**The Valve**	**Requires minimal plumbing on installation**
17	**The Valve**	**Can be used with any water supply system**
18	**The Valve**	**Is reliable**
19	**The Valve**	Is leak proof
20	**The Valve**	Can withstand knocks
21	**The Valve**	Requires no maintenance
22	**The Valve**	Prevents dripping from the faucet
23	**The Valve**	Can operate in a power cut

No.		Need
24	The Valve	Can be produced for a reasonable amount of money
25	The Valve	Provides numerous safety features
26	The Valve	Can prevent users from overflowing the facility it is attached to
27	The Valve	Can prevent users from being scolded

6.2.2 Initial Prototype

The initial prototype was tested by a number of consumers who identified a few major problems with the concept. These problems were turned into positive needs, which had to be met to avoid similar problems with future concepts.

The problems identified from the testing of the initial prototype were as follows.

1. The water pulsed out of the faucet. The valves pulsing on and off caused this. This could not be avoided unless perfect timing could be accomplished (meaning that the cold valve shut precisely as the hot valve opened, and only if the two streams were under exactly the same pressure).

2. The valves used made a lot of noise. Cheap on/off valves, such as the ones used, make a loud hammering noise when they open or closed. It was possible to purchase valves, which did not make as much noise however they cost a far greater amount of money.

3. The system was very large. The prototype took up an area of approximately 500mm x 300mm x900mm. Further development had minimised the design down to approximately 150mm x 150mm x 300mm, however, there were concerns that this was still too large.

4. Control time. It took the unit approximately seven seconds to reach a desired temperature once changed. This amount of time was far too long, especially if the user was trying to feel the water temperature to understand what temperature it was.

The requirements, which differ from those identified in section 6.2.1, obtained from these findings are represented in Table 6-2..

No.	Need	
28	The valve	Is unobtrusive
29	The Valve	Can be installed conveniently out of sight
30	The Valve	Takes up minimal space
31	The valve	Is quiet
32	The valve	Provides a steady output of water

Table 6-2 Valve requirements identified from initial prototype

6.2.3 Company

Once the industrial sponsor backed the project they pointed out a number of key factors. The first point made was that the valve was the key to developing a financially successful product. As stated earlier, the company wished to develop this product further and then sell the idea to a potential manufacturer. A company who would potentially want to buy this product off of the sponsor company and manufacture it, would want proof that the valve system was reliable. It would not only have to allow users to control the temperature and flow accurately but also be almost invisible in doing so. This meant that it would have to be quiet and relatively small. It was also made clear that the valve system accounted for a majority of the product cost and would therefore have to be manufactured and assembled for a reasonable amount of money if the product was to compete in a similar price range to conventional tap and faucet systems.

The one major need identified by the company which has not already been covered is shown below in table 6.3.

No.	Need	
33	The valve	Incorporates Intellectual Property

Table 6-3 Valve requirements identified from the sponsor company

The company mentioned at this early stage, that the more standard components we use, the easier our valve design will be to copy by competitors. If given the opportunity to develop a completely new innovative valve solution, we should. Something of this nature would add far more value to the product and offer a very good focal point for on-selling of the product.

6.2.4 Initial Needs and Specifications

The entire list of user needs was shown in Table 6-4. The needs were ranked for importance following the methodology outlined in section 3.2.2.4. Both market groups were included in this activity however the results are shown as a combination of both market groups. The importance rankings range from 1 to 5 and were exactly the same as those used earlier.

No.		Need	Imp
1	*The Valve*	*Can turn the water flow on and off*	*5*
2	The Valve	Allows users to adjust the water temperature	5
3	The Valve	Allows users to adjust the water temperature before the water is turned on	4
4	The Valve	Allows users to adjust the water temperature while the water is running	5
5	The Valve	Reaches the users desired temperature as quickly as possible	5
6	The Valve	Can reach the most frequently used temperatures easily	4
7	The Valve	Can maintain the desired water temperature despite system fluctuations	5
8	The Valve	Can respond quickly to changes in the inlet water temperature	5
9	The Valve	Has the capability to reach all required water temperatures	5
10	*The Valve*	*Can adjust the water flow rates on the outlet*	*4*
11	The Valve	Can control the flow to all those desired by he user	5
12	The Valve	Can maintain the desired flow despite system fluctuations	3
13	*The Valve*	*Fits into the surrounding environment*	*4*
14	*The Valve*	*Is easy to install*	*3*
15	The Valve	Can be installed on any existing or new facility	4
16	The Valve	Requires minimal plumbing on installation	4
17	The Valve	Can be used with any water supply system	3
18	*The Valve*	*Is reliable*	*5*
19	The Valve	Is leak proof	5
20	The Valve	Can withstand knocks	3
21	The Valve	Requires no maintenance	4
22	The Valve	Prevents dripping from the faucet	5
23	The Valve	Can operate in a power cut	3
24	*The Valve*	*Can be produced for a reasonable amount of money*	*5*
25	*The Valve*	*Provides numerous safety features*	*3*
26	The Valve	Can prevent users from overflowing the facility it is attached to	3
27	The Valve	Can prevent users from being scolded	3
28	The Valve	Is unobtrusive	4
29	The Valve	Can be installed conveniently out of sight	4
30	The Valve	Takes up minimal space	4
31	The Valve	Is quiet	5
32	The Valve	Provides a steady output of water	4
33	The Valve	Incorporates Intellectual Property	4

Table 6-4 User Needs identified for the valve system along with the relative importance of each need. The needs highlighted in red were considered unexpected and exciting.

The results show that the valve's ability to control water temperature was a very important aspect. The valve needed to not only reach all required temperatures but also reach them as quickly as possible. Other needs, which were imperative to the success of the valve system, were; its ability to provide the water flows specified by the users, cost of production, and reliability.

The needs where turned into a set of initial specifications to guide the development. A list of the related metrics was shown in table. The table includes identified metrics along with ideal values for these metrics obtained from the initial requirement identification.

Metric No.	Need Nos.	Metric	Units	Ideal Value
1	1	Water on response time	s	>1
2	1	Water off response time	s	>1
3	2,3,4,5,6,7,8	Temperature change response time	s	>3
4	5,6,9	Maximum temperature	Deg	65
5	5,6,9	Minimum temperature	Deg	18
6	10,11,12	Minimum flow	L/min	2
7	10,11,12	Maximum flow	L/min	10
8	11,12	Number of flows	#	3
9	11	Flow step sequence	L/min	2
10	12	Flow response time	s	>3
11	6,9	Temperature steps	Deg C	1
12	17,19,22	Maximum operating pressure	Bar	10
13	14,31	Valve weight	g	500
14	14,16	Number of external sensors	#	0
18	14	Installation time	min	30
19	24	Production Cost	NZ$	200
20	28,29,30	Valve maximum dimensions	mm	150 x150x150
21	15,16,17	Attachment sizes	mm	15
22	18,22	Operating time without failure	yrs	10
23	31	Operating Noise	subj	quiet
24	33	Incorporates innovative designs	scale	5
25	26	Stops facility overflowing	scale	5
26	27	Temperature safety features	scale	5
27	32	Fluctuation in output flow	L/min	>0.5

Table 6-5 Initial specifications, outlining metrics along with their ideal values.

6.3 CONCEPT GENERATION

6.3.1 Concept Decomposition

The valve was a complex system. There were a number of major functions it must perform to meet the needs specified in the previous section. These have been shown in Figure 6-2 and include, on and off control, temperature control, flow control and level sensing.

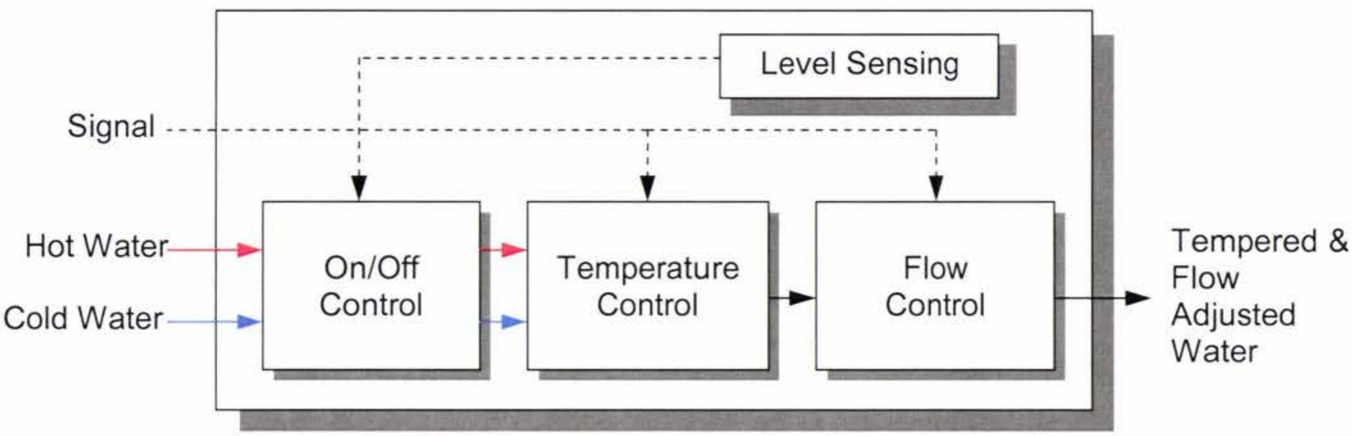


Figure 6-2 Function Diagram of the valve system showing the major sub functions.

Breaking the valve system up into its major sub functions simplified the design problem. The decision was made to focus upon the temperature and flow control functions first. It was felt that resolving these functions would partially resolve the on/off control. Level sensing was a separate entity and although considered an exciting need was not viewed as important as the other three vital functions. Searches were firstly conducted externally to identify existing products, which performed the required functions. Secondly concepts were generated internally addressing the temperature and flow control functions.

6.3.2 External Search

The external search focused on identifying products, which performed the required functions, temperature control, flow control on / off control and level sensing. The external search looked at both electronic and manually operated systems. The investigation resulted in a number of findings, which have been summarised below.

1. No electronically operated system was available, to control both temperature and flow in a single device.

2. No electronically operated domestic water temperature control devices were identified. However, there were numerous electronically operated industrial water temperature control devices. All industrial devices where designed to deal with much larger volumes of water than were required in this case. All were over engineered for this application, which resulted in a price tag too large to consider useful to this project. The principles behind their operation were however useful and were used as basic for the idea generation of internal concepts.

3. A number of electronically operated flow control devices were identified. These included proportional solenoid valves and electronically controlled ball, butterfly and gate valves. Devices were available from $60 NZ and up when purchasing in bulk.

4. Numerous electronically controlled on/off valves were identified. Devices were similar to the flow control devices, however simpler in nature and as a result much cheaper, with valves being available from as little as $9 NZ.

5. Existing manual shower and sink mixers performed the function of water and flow control in the same device. The devices used two directions of control to do this; forward and back for flow control and rotational movement for temperature control.

6. Numerous manual valves were available which performed temperature or flow control. These valves were commonly available and as a result were typically inexpensive, available for as little as $6 NZ.

7. Level sensors were readily available. They came in many forms, float, conductivity, proximity, capacitance and infrared.

This external search and the resulting conclusions led directly to one major concept idea, which could be approached in a number of ways. No existing electronically operated device, which controlled both temperature and flow, had been either designed for a similar application or within the desired price range to be useful. The alternative that was left from the external search was therefore to electronically control one, or a number, of the manual devices.

Concept 1 - An electronic controller for shower or sink mixers. Allowed both the control of temperature and flow in the single valve, however still required two axis of control for operation e.g. temperature rotational, flow forward and back.

Concept 2 - Electronically control a manual temperature control valve and a manual flow valve.

Concepts 1 and 2 involved electronically, controlling manual valves. As a result an extension of the external search was undertaken to identify possible electronic controllers. The findings from this search have been summarised below. For greater detail of this information refer to Appendix 3.

1. Stepper motors provide precise positioning and ease of use. They provide an accurate rotational movement to as precise as ½ a degree.
2. Synchronise motor were cheaper than stepper motors but do not have the same precise mode of operation.
3. Actuators provide precise linear control however generally work on water, air or pneumatic pressure.

6.3.3 Internal Search

The external search was originally undertaken to identify a product, which could adjust temperature and flow within a single device. Unfortunately none were identified. As a result, the internal search concentrated on generating product concepts that could adjust both temperature and flow. The sponsor company made it clear that this was the preferred path. Although riskier, it offered far greater financial benefits as a result of the related intellectual property and would make the idea much harder to copy by rival companies. A number of ideas were generated which reflected ways that both temperature and flow could be adjusted in a single device.

Concept 3 – A two-disk arrangement where the top disk controlled the flow and bottom disk controlled the temperature mixing.

Concept 4 – A two-stage valve. The first stage controlled the temperature using a wedge that changes the proportion of hot to cold water. The flow was controlled by the second stage, which incorporated an internal ball valve.

Concept 5 – A two-stage valve where a thermostatic heater controlled the temperature and the flow was controlled using a proportional opening.

Concept 6 – A single disk within a mixing chamber which controlled the temperature on the inlet and flow on the outlet. The disk was broken into six sections. Three of the sections incorporated flow-mixing cavities and the other three sections each incorporated different size outlet holes to control flow.

Concept 7 – A disk that moved along a cam to control temperature and flow.

6.3.4 Concept Selection

The concept selection methodology outlined in section 3.3.3 was used to make a choice on potential new concepts. Table 6.6 shows the concept selection matrix used. Concept 6 was identified as having the greatest potential. Further development concentrated on this concept.

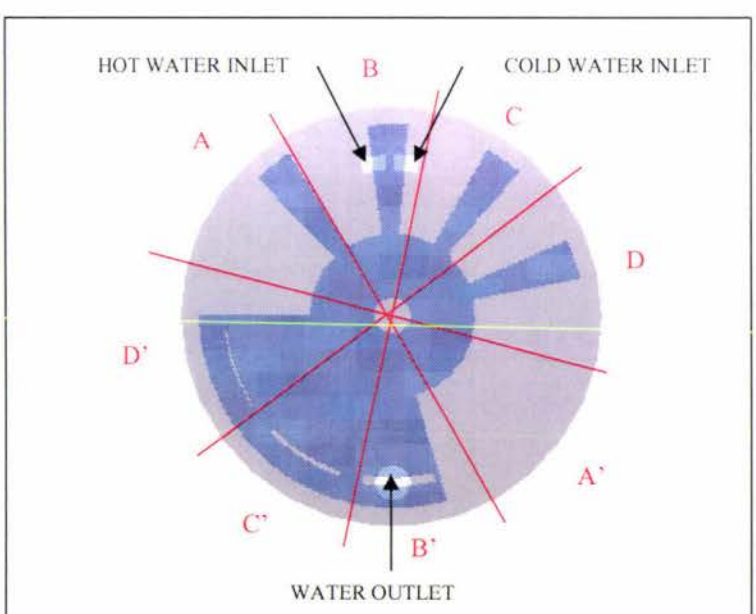
Table 6-6 Concept selection matrix

Criteria	Aim	Imp.	W.	Concept Ratings						
				1	2	3	4	5	6	7
Temperature Control										
-Accuracy	1 °C	5	0.1	5/0.5	4/0.4	5/0.5	5/0.5	4/0.4	5/0.5	5/0.5
-Response time	>3 seconds	5	0.1	5/0.5	4/0.4	5/0.5	5/0.5	1/0.1	5/0.5	5/0.5
-Range	18-70	5	0.1	5/0.5	5/0.4	5/0.5	5/0.5	5/0.5	5/0.5	5/0.5
Flow Control										
-Number of flows	3 different	4	0.08	5/0.4	5/0.4	5/0.4	5/0.4	5/0.4	5/0.4	5/0.4
Size	>150x150x 150mm	3	0.05	5/0.15	3/0.15	4/0.2	4/0.2	2/0.1	5/0.15	5/0.15
Controller										
-Complexity	Simple	4	0.08	1/0.08	2/0.16	1/0.08	2/0.16	1/0.08	4/0.32	1/0.08
-Potential production cost	>$100	4	0.08	2/0.16	2/0.16	2/0.16	2/0.16	1/0.08	5/0.4	3/0.24
-Knowledge availability	Readily	5	0.1	4/0.4	4/0.4	2/0.2	4/0.4	3/0.3	5/0.5	1/0.1

Criteria	Aim	Imp.	W.	Concept Ratings						
				1	2	3	4	5	6	7
Valve										
-Innovativeness	Innovative	5	0.1	1/0.1	1/0.1	4/0.4	4/0.4	4/0.4	5/0.5	5/0.5
-Ease of manufacturing	Easy	4	0.08	4/0.32	3/0.24	2/0.16	2/0.16	4/0.32	3/0.24	3/0.24
-Ease of installation	Easy	3	0.05	5/0.25	4/0.2	5/0.25	5/0.25	4/0.2	4/0.2	4/0.2
-Potential production cost	>$80	4	0.08	5/0.32	5/0.32	3/0.24	3/0.24	4/0.32	4/0.32	3/0.24
Σ		51	1.0	3.68	3.33	3.59	3.87	3.2	4.43	4.37

6.3.5 Concept Outline

The concept was made up of two main parts, a chamber and a disk. The chamber had two water inlets (hot and a cold) and one water outlet. The disk sat in the bottom of the chamber and was shaped so that when rotated it could; 1) Vary the size of the inlet holes thus altering the amount of hot and cold water entering the chamber and hence varying the temperature of mixed water inside the chamber. 2) Vary the size of the outlet hole thus altering the amount of mixed water leaving the chamber resulting in a change of flow. How exactly the disk achieved this was shown below.



For explanation purposes the disk shown would theoretically allow users four choices of flow rate and any temperature between the cold water supply temperature and the hot water supply temperature. The disk was broken into eight segments as shown by the red lines.

Segments A, B, C and D were used to control temperature and segments A', B', C' and D' were used to control flow. Rotating the solid sections of segments A, B, C and

D across the inlet holes changes the temperature. Doing this changes the ratio of hot to cold and thus changes the temperature. The segment could be rotated to allow any ration of hot to cold to be let in. When segment A was being used to control temperature segment A' was controlling the flow. When segment B was being used to control temperature segment B' was controlling the flow and so on. Altering the slot sizes in segments A', B', C' and D' altered the four available flows.

A stepper motor offered the greatest potential for flow. The precision and accuracy offered by stepper motors suited the application and need for fine accurate rotational movement perfectly. The decision was further validated by the use of Stepper motors to control industrial disk valves.

The disk was very reliant upon an extremely flat sealing surface being formed between the disk and the inlet and outlet holes. If this did not happen water would come in the inlets and flow under the disk, resulting in mixing of water that shouldn't be mixed.

This concept offered a number of benefits. It was using proven technology disk valves have been used for years. Secondly the use of disks made it adaptable. The disk shapes could be altered to correspond with different pressure systems and flow requirements.

6.3.6 Initial Specifications Refinement

The use of a stepper motor posted a number of considerations upon the design that needed to be considered even in the manual valve.

As stated previously stepper motors rotate in a finite number of steps. The number of steps determined how accurately the temperature could be controlled. For example a stepper motor that had 2-degree steps, allowed 45 different positions for the valve over a 90-degree temperature control segment. Therefore decreasing the step size also increased the accuracy of the valve. The second thing that was considered was operating torque. A motor was required that provided enough torque to turn the valve without fail.

Because of an increase in torque and decrease in step size, there was a significant increase in price. For this reason it was decided to outline some initial design specifications that the initial manual valve could be based upon. This gave some idea of the costing for the system but also gave a starting point to aim at in terms of design. Shown in Table 6-7 were the needs identified and the related specifications.

No.		Need	Imp
34	***The Valve***	***Can be controlled by a stepper motor***	***5***
35	The Valve	Can be rotated easily	5
36	The Valve	Operates in a number of finite steps	5

Metric No.	Need Nos.	Metric	Units	Ideal Value
28	1	Valve Rotational torque	Nm	>6.5
29	1	Control accuracy	Deg	1

Table 6-7 Newly identified needs and specifications

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6.4 CONCEPT DEVELOPMENT PROTOTYPING AND TESTING

A decision was made to firstly develop a manual valve and on proof of design begin to operate it with a stepper motor. The first iteration of development therefore was to develop a manually controlled valve that met the initial specifications identified, as best as possible

6.4.1 Manual Valve

The first point of development was to design the disk. An attempt was made to incorporated three flows, as the users stated they required in section 6.2.4. This meant breaking the disk into six segments.

The concept was modelled in SolidWorks as this made the rotating disk easier to envisage. Figure 6-3 shows the disk in its three-flow operating states: full flow, half flow and minimum flow.

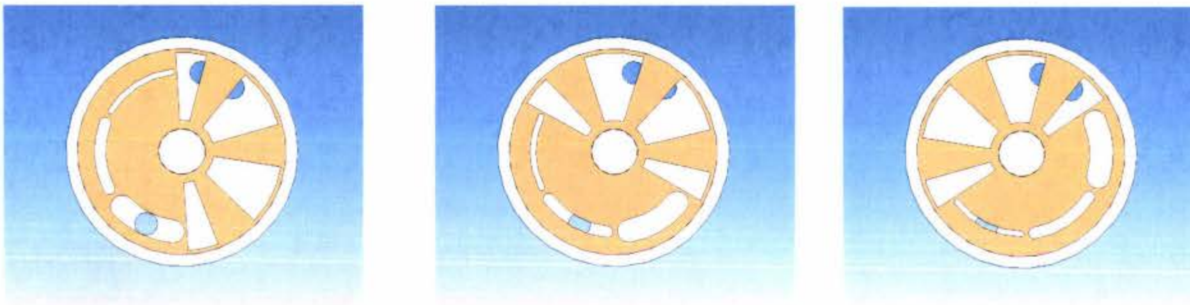


Figure 6-3 Shows the disk in its three flow operation states, full, half and minimum flows.

A problem was instantly recognised from this modelling and that was that the range of motion with which the temperature was being controlled was only about 30 degrees of movement. This meant that with a one-degree stepper motor or one degree of control accuracy there would only be thirty steps to control a temperature range between 20°C and 60°C. The initial specifications identified a 1°C temperature accuracy and similarly identified 1 degree of control accuracy. This meant that the maximum temperature change for 1 degree of rotation was 1°C, resulting in a minimum of forty degrees of rotation to achieve the temperature range desired. The required temperature profile was shown in Figure 6-4.

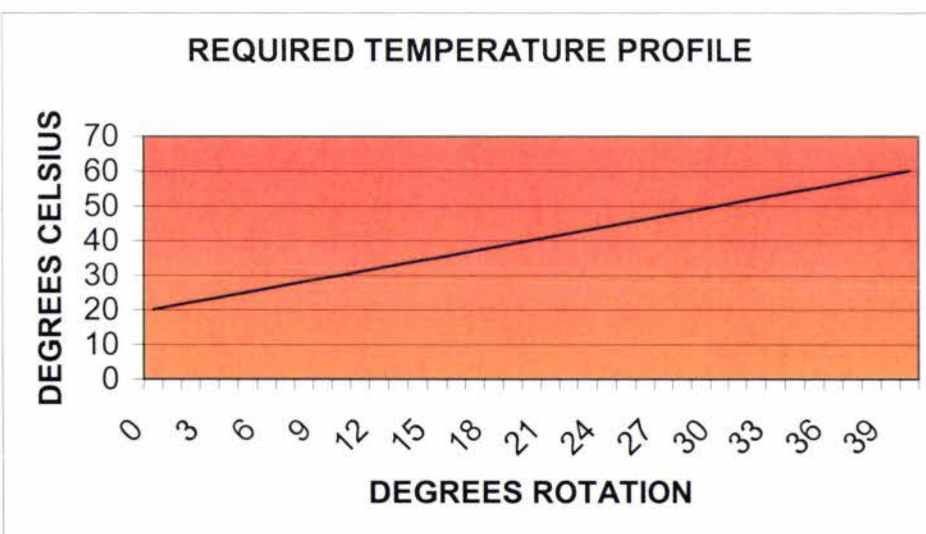


Figure 6-4 Required Temperature mixing Profile

It was recognised that adjusting a number of factors could alter the range of motion. The factors included disk cavity shape and size, inlet hole shape and size and placement, disk size and chamber size. These factors were all interrelated and were very dependant upon each other. As a starting point however cavity shape was chosen as a starting point for development. A range of concepts, were developed, initially changing the disk cavity shape and adjusting the other factors like inlet sizes and placement, and valve size, upon the requirements of the disk cavity. The disk, and specifically the cavities, (which control temperature and flow), are currently under patent application and for this reason have been left out of this body of literature. The potential disk shape and cavity shapes were explored using SolidWorks, modelling the disk and inlet holes in each position of rotation, to try and estimate the mixing profile that would result. This investigation lead to the identification of a cavity shape, which was hypothesised to offer a similar temperature profile to that shown in Figure 6-4.

The concept was developed further taking into consideration such things as: materials, sealing of the chamber, and facilities available for the building and testing of the prototype. The prototype was made in house. The facilities available meant that valve could be made out of either plastic or metal. It was thought that both would provide an adequate solution, however, it was recognised that plastic would be cheaper and easier to machine. If it worked, it also offered greater potential for manufacturing of mass quantities. The size of the solution limited the type of plastics, which could be used to prototype it. Nylon was chosen as it was cheap and easy to machine. An exploded view of the design was shown in Figure 6-5.

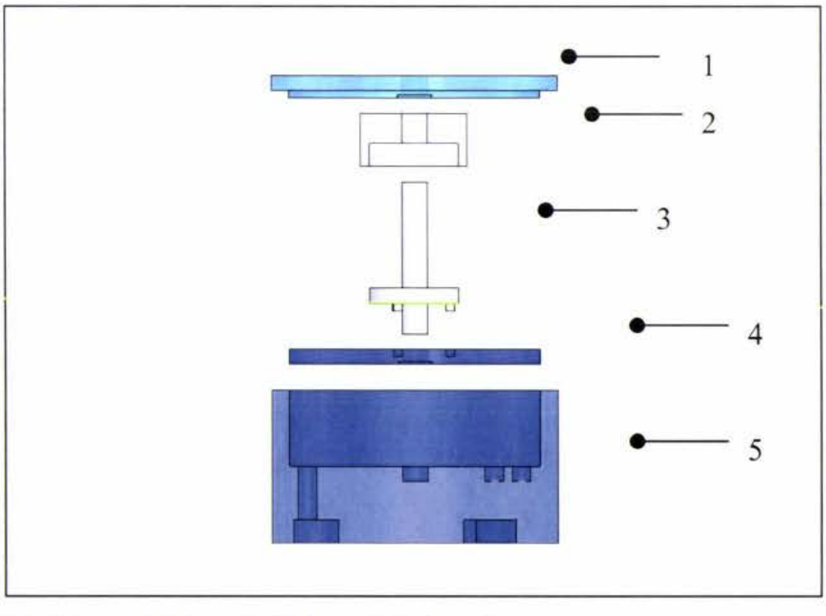


Figure 6-5 Design of concept to be prototyped

1. Lid – The lid sealed both the chamber and the shaft. An O-ring was used to seal the chamber and a radial seal was used to seal the shaft.

2. Spacer – The spacer put pressure on the disk ensuring a good sealing surface between disk and inlet and outlet holes.

3. Shaft – Provides the means of rotation. The shaft was fixed permanently to the disk and was driven by a motor.

4. Disk – Explained earlier

5. Chamber – Encompassed the hot and cold water inlets, a chamber for mixing and the an outlet for the water.

6.4.1.1 Prototype 1

The prototype was shown in Figure 6-6. It was represented in a number of stages of disassembly.

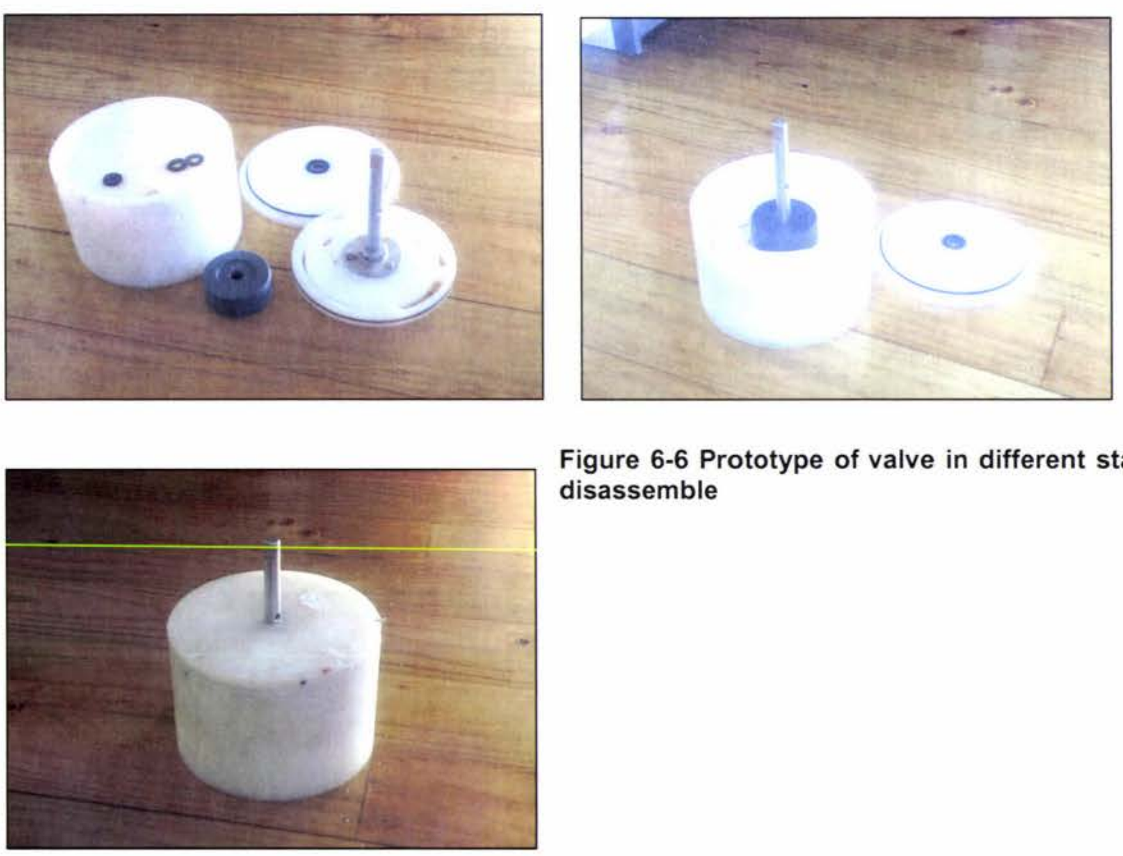


Figure 6-6 Prototype of valve in different stages of disassemble

Before the prototype could be tested to see how accurately it worked it needed to be tested to see if it would work at all. Table 6-8 provides a summary of the initial problems found and the resulting solutions and outcomes.

Table 6-8 Initial prototype problems solutions and resulting outcomes

Problem	Solution	Outcome
O-ring sealing the lid burst and water squirted out of the top	More screws to hold down the lid	The lid stayed sealed
Water flowed freely at a fairly constant temperature irrespective of the disks position due to too much pressure on the outside of the disk forcing it up and letting water flow beneath it.	A second spacer was added which would hold the outside of the disk against water pressure.	Still leaked was apparent the surfaces between disks were not perfectly flat
The surfaces between the disks were not perfectly flat	Bearing Grease	Still leaked did not form a good enough seal between inlets/outlets and disk
Not a good enough seal between chamber and disk	Seal precisely around the whole with o-rings so that the disk forms a seal with the inlet or outlet the same shape as that inlet or outlet	Sealed between the disk and chamber but made it very hard to turn disk. Pressure build up began to deform lid.
Deforming lid again began to leak	Lid held down with clamps	Stopped leaking

6.4.1.2 Testing Methodology

Once a working prototype was achieved, testing was undertaken to determine its accuracy of control. There were two things, which needed to be measured. 1) Its ability to control water temperature. 2) Its ability to control water flow.

A temperature thermocouple attached to an electronic thermometer was attached to the outlet of the valve. The valve was rotated in one-degree steps and the temperature recorded after each one-degree movement.

The output flow was measured using a flow meter attached to the outlet of the valve. The flow meter needed a minute of steady flow to calibrate the correct reading. For this reason it was decided to register the flow every five degrees. These tests were repeated over a number of input flows to determine the effect this had upon the valve.

The data was graphed showing degrees of rotation versus temperature and degrees of rotation versus flow. A graph was developed from Figure 6-4, which portrayed the ideal temperature and flow profiles for the entire disk. This was then used for comparison with the actual results. These are shown in Figure 6-7.

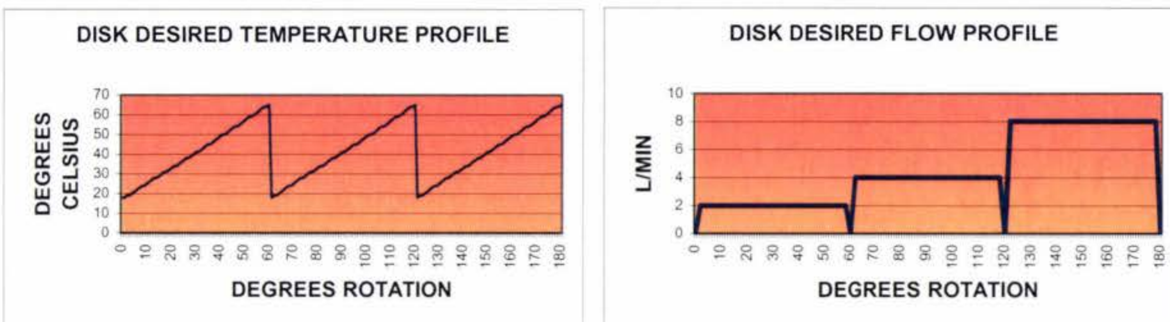


Figure 6-7 Ideal temperature and flow characteristics of the prototype valve

6.4.1.3 Results and Discussion

The temperature and flow profiles obtained from testing the valve are shown in Figures 6-8 to 6-11. The four graphs represent the four different inlet flows and hot to cold ratios that the valve was tested under.

The valve allowed the temperature to be altered between cold and hot temperatures however the temperature profiles obtained did not match the straight proportional line outlined in the desired profile shown in Figure 6-7. Instead the temperature changes appeared to be stepped, settling at certain water temperatures for prolonged intervals of the disk rotation. Testing conditions where the inlet flow ratios (ratio between hot and cold water inlet flows) were kept relatively close to 1:1, as in Figure 6-9 and Figure 6-11, resulted in a much more even distribution of temperature than testing conditions where the two flows differed considerably.

The graphs showed that no difference in flow characteristics was achieved. All graphs showed a maximum of approximately 12 L/min being reached, regardless of the size of the outlet cavity.

An important observation made was that the valve had a very slow reaction time to changes in disk position and hence the temperature. This was due to the very large mixing chamber.

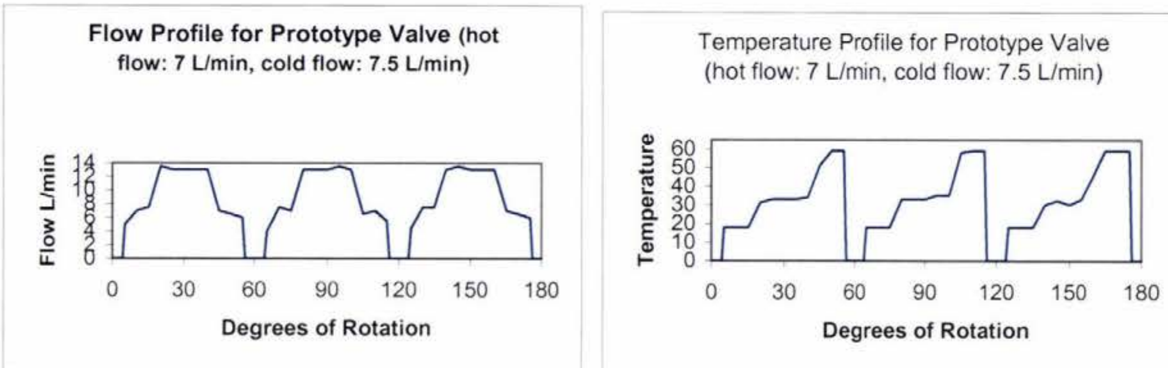


Figure 6-8 Graphs indicating temperature and flow profiles from the prototype testing of the valve. Inlet flow ratio of 1:1.6

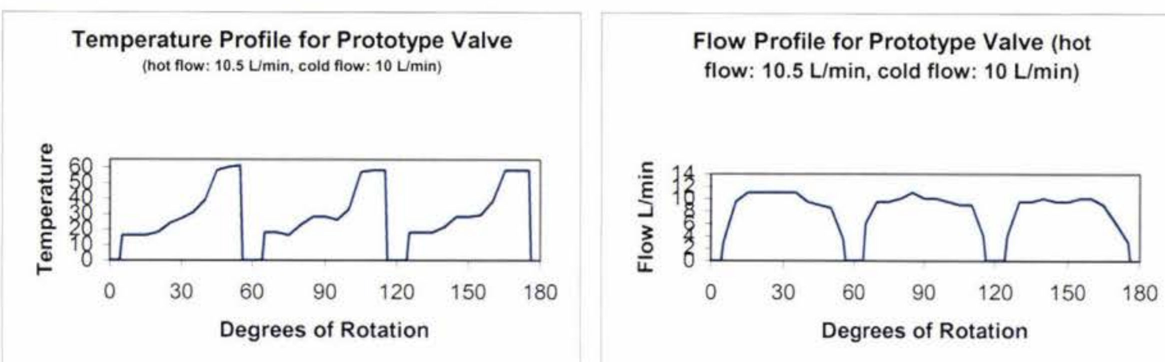


Figure 6-9 Graphs indicating temperature and flow profiles from the prototype testing of the valve. Inlet flow ratio of 1:1

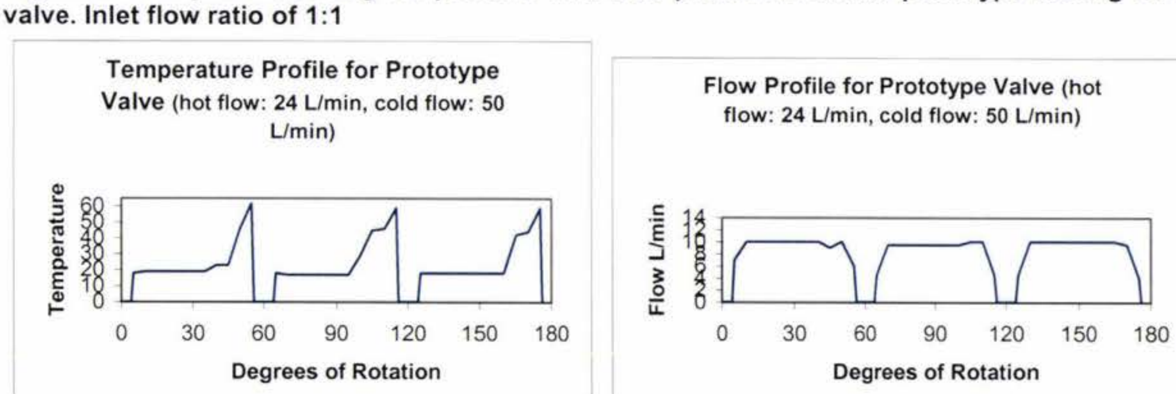


Figure 6-10 Graphs indicating temperature and flow profiles from the prototype testing of the valve. Inlet flow ratio of 1:2

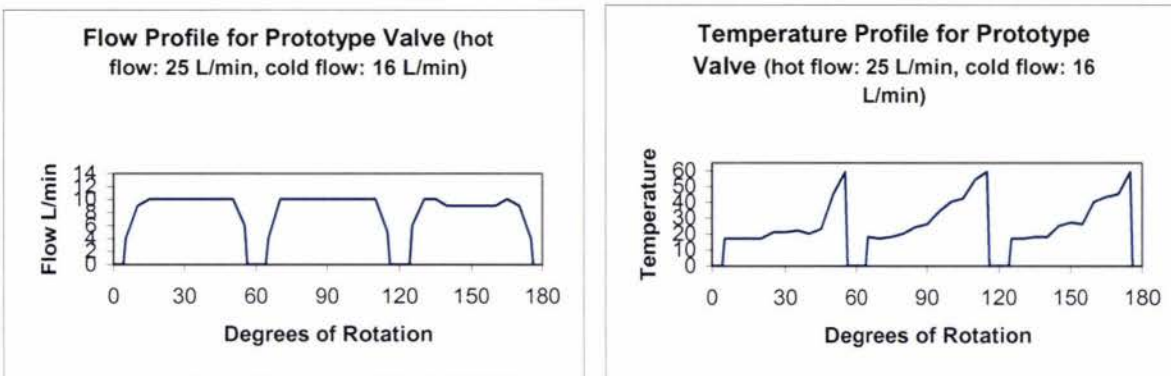


Figure 6-11 Graphs indicating temperature and flow profiles from the prototype testing of the valve. Inlet flow ratio of 4:3

Reasons behind the stepping pattern in the temperature profile were discussed and it was concluded that the pattern could be caused from turbulence created by the disk seals. The suggestion was that the seals on the inlet holes might provide enough movement to disturb the water and cause a turbulent effect on the water trying to enter the chamber. This effect was only be disturbed when the opening became large enough to allow a lot more water in. It was thought that this could be overcome by prototyping a new valve made out of a flatter material that would allow the two surfaces to seal without the need for rubber seals.

This failure to adjust flow was found to be caused by the solenoid valve used to turn the valve on and off. The orifice size of the solenoid valve was smaller than the smallest flow rate cavity, hence limiting the flow before the valve could. Later observation of the valve working showed that changing the outlet orifice size did change the flow, however, with this particular orifice size, the minimum flow achieved was around 25 litres per minute and ranging up to ~ 50 litres per minute.

6.4.1.4 Outcomes

The manual valve was measured against the initial specifications to identify areas that could be improved in the second iteration of development. Table 6.8 shows this comparison presenting the metric, units, which it was measured with, the ideal value and the achieved value.

Table 6-9 Comparison of initial prototype to initial specifications. Green ticks show where a specification has been achieved and a red cross shows where a specification has not been met.

Metric No.	Metric	Units	Ideal Value	Actual Value	Rating
1	Water on response time	s	>1	1	✓
2	Water off response time	s	>1	1	✓
3	Temperature change response time	s	>3	9	X
4	Maximum temperature	Deg C	65	55	X
5	Minimum temperature	Deg C	18	18	✓
6	Minimum flow	L/min	2	20	X
7	Maximum flow	L/min	10	~50	X
8	Number of flows	#	3	3	✓
9	Flow step sequence	L/min	2	20	X
10	Flow response	Deg	2	10	X
11	Temperature steps	Deg C	1	5-10	X
12	Maximum operating pressure	Bar	10	2	X
13	Valve weight	g	500	3000	X
14	Number of external sensors	#	0	N/A	
18	Installation time	min	30	N/A	
19	Production Cost	NZ$	200	N/A	
20	Valve dimensions	mm	150 x150x150	250 x 250 x 200	X
21	Attachment sizes	mm	15	N/A	
22	Operating time without failure	yrs	10	N/A	
23	Operating Noise	subj	quiet	quiet	✓
24	Incorporates innovative designs	scale	5	5	✓
25	Stops facility overflowing	scale	5	N/A	
26	Temperature safety features	scale	5	N/A	
27	Fluctuation in output flow	L/min	>0.5	>0.5	✓
28	Valve Rotational torque	Nm	>6.5	20	X
29	Control accuracy	Deg	1	5-10	X

The lack of green ticks showed that not a lot of the initial specifications were achieved with the initial prototype. This first iteration did however show that the concept was feasible; changing the proportions of hot to cold by varying inlet sizes, could control temperature, and changing the size of the of the outlet could change the flow.

A second iteration of development was undertaken with a number of objectives, identified from the downfalls of the initial prototype. These objectives were:

1. Develop a valve that had a higher operating pressure to ensure that it was leak proof.

2. Use materials that allowed a better seal between inlet ports, outlet port and the disk under the assumption that this would improve the temperature mixing profile.

3. Reduce the overall size of the valve.

4. Determine port sizes that would allow flow to be controlled at rates desired by the users, (2 –10 Litres).

6.4.2 Development of Valve 2

The development of valve 2 consisted of the following stages. It was first developed concentrating on the objectives identified from the initial valve. The valve was then prototyped and tested. These results were then reflected upon to guide future development.

6.4.2.1 Development

The four objectives identified from the initial valve development were used to structure the development. This section is broken into these four areas to explain the development.

6.4.2.1.1 Leak Proofing the Valve

The initial valve had various problems relating to the sealing of the valve. These were mainly associated with the lid and became very noticeable when the valve was closed. The initial valve was also made of nylon plastic, which distorted under pressure.

A number of ideas were discussed with the engineers who would be involved with the production of the second prototype. It was suggested that the best way to reduce leaking, especially under pressure was to make the valve out of a solid block of metal with a screw on lid. In order to make this idea feasible the size of the valve would need to be reduced.

6.4.2.1.2 Port Sizes

Existing sink mixers were pulled apart to get an idea of appropriate port sizes. The inlet ports used in these devices were no larger than 7mm long and 2mm wide, and the outlet ports ranged from 0.1mm to 5mm depending upon the flow. The intial prototype had circular 10mm inlet and outlet ports providing a much greater inlet and outlet flow than necessary. The realisation that port sizes could be reduced considerably led to the reduction of the valve size.

6.4.2.1.3 Valve Size

Reducing the port size brought about the realisation that the valve could be made smaller. There was however a major factor, which determined exactly how small the valve, could be made. This was the fact that the disk cavities still had to be cut using in house mills, as other manufacturing strategies such as injection moulding were too expensive to justify their use at this stage in the project. A secondary limiting factor was found to be inlet port shapes. The circular shapes used in the initial valve were predicted to have impending effects as the valve size decreased. This predicted effect was shown in Figure 6-12. It can be seen from this graph that as valve size and hence disk size decreased, then so did the operating range of the valve. Each temperature mixing segment of the valve took up to 60 degrees of the disks surface, assuming three flow rates were required as in this case. The circular ports begin to eat into much needed mixing valve space reducing the amount of each segment, which can actually be used. As a result a number of options were explored which investigated various inlet port sizes and shapes. These were modelled and tested using SolidWorks and resulted in port sizes and shapes, which both maximised as much of the available 60 degrees as possible and allowed the disk to be decreased to about 50% the size of the previous disk. Disk cavities to fit the inlet ports were modelled and discussed with the engineers who would cut them. Slight changes in size had to be made as a result to allow for the disk to be manufactured effectively. Reducing the size of the disk and valve opened up the option for the valve to be made from metal. At this stage it was decided that at least the casing would be made this way to allow for the screw on lid proposed earlier.

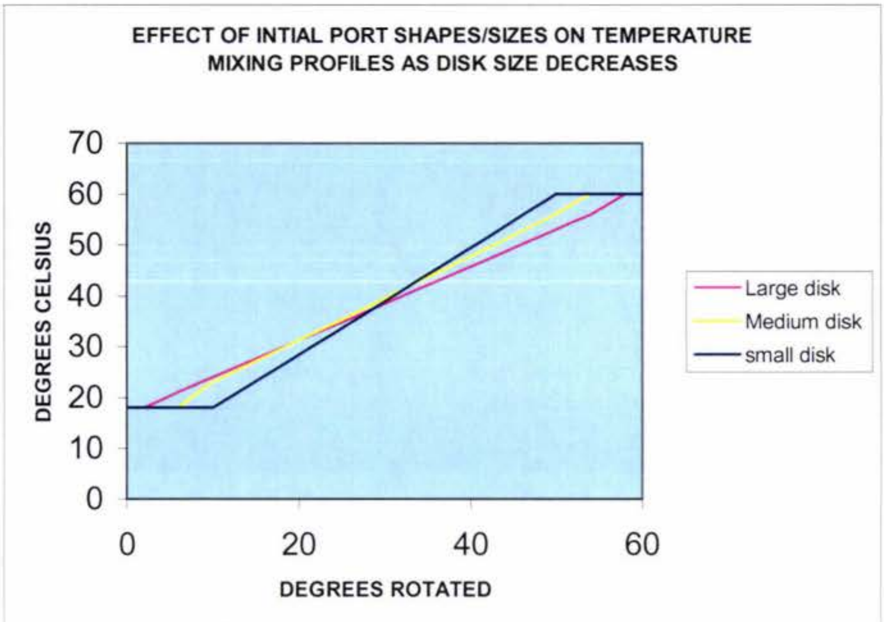


Figure 6-12 Effect the circular ports used in the first prototype had upon the temperature profile as the valve and hence the disk decreased in size. The profile represented one segment of the three temperature mixing parts of the valve.

6.4.2.1.4 Disk Seals

Sealing between the disk and the inlet and outlet ports caused problems within the initial design. When the surfaces were not precisely sealed leaking occurred under the disk surface and resulted in an unpredictable temperature mixing profile. O-ring seals were used on the initial prototype to form the seal between disk and port surface however this had a number of negative effects which were discussed earlier but included turbulent mixing effects and high compressive force on the disk resulting in a very high rotational torque required to turn the disk.

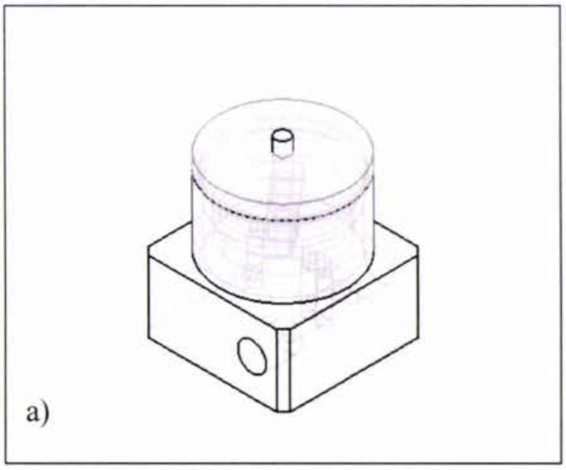
Existing disk valves were explored to identify how these problems had been overcome. It became apparent that the disk needed to sit within an internal chamber that was precision engineered. The internal chamber had a cavity exactly the same depth as the depth of the disk. Doing this allowed maximum force to be placed upon the internal chamber and sealed the inlet and outlet ports while still allowing the disk to rotate easily. This principle was used in the design of prototype two.

All disk valves are now using ceramic technology. The ceramic material used is very hard and can be moulded with a genuinely flat surface that is wear resistant. Ceramic disks are typically press moulded, which is an enormously expensive process when dealing in small quantities as required with this prototype. The decision was made to use a hard plastic instead of ceramic, which had good machining and finishing properties. Both the disk and internal chamber were made from this material.

6.4.2.1.5 Resulting Concept

Figure 6-13 includes CAD models representing the developed valve. The exploded views shown in c) and d) show the major components which make up the valve. View d) has the major components labelled 1-6, which are as follows:

1. Lid – sealed the valve and put pressure on the internal chamber
2. Lid/Mixing chamber for internal chamber – Provided pressure on the disk to form seal with the bottom of the internal chamber and transferred the force from the lid onto the bottom internal chamber to provide a seal between bottom internal chamber and valve body.
3. Shaft – disk driver.
4. Disk – Temperature and flow control.
5. Bottom of internal chamber – Formed a seal with the valve body and reduces the size of the inlet ports to minimise the pressure on the disk.
6. Valve body – Provides attachments for inlet and outlet ports.


a)


b)

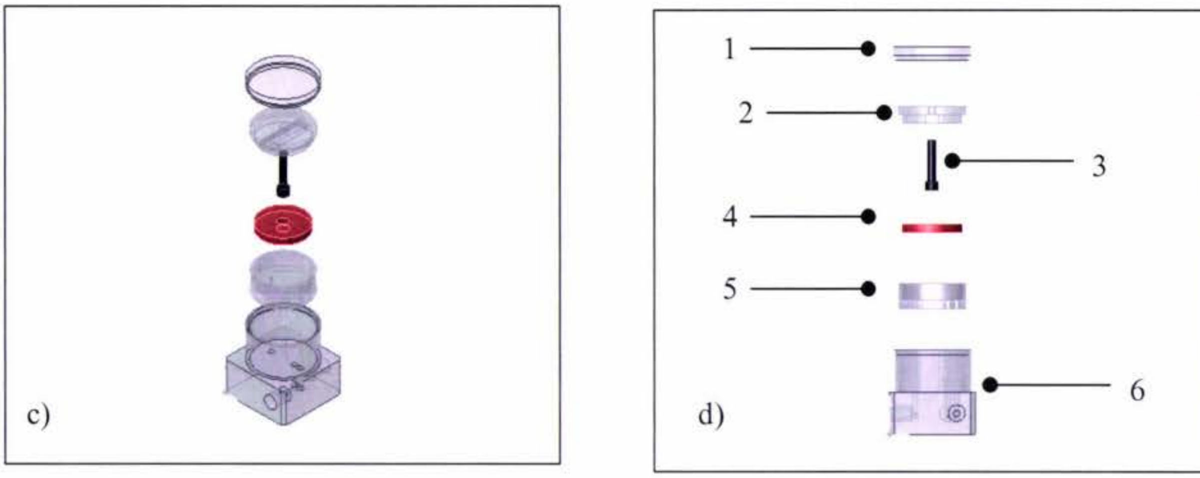


Figure 6-13 CAD models of resulting concept

6.4.2.2 Prototype 2

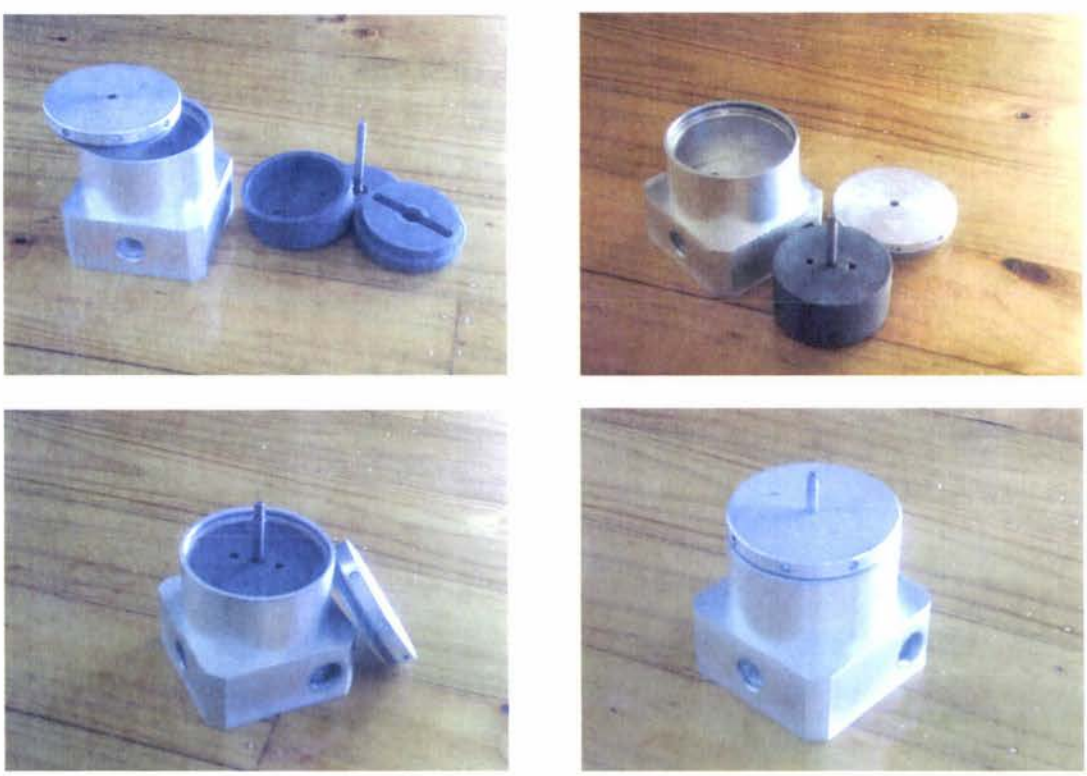


Figure 6-14 Prototype of valve 2 shown in various stages of disassemble

The prototype of the second valve was shown in Figure 6-14. The prototype was shown in four stages each showing the next stage of assembly. The photos clearly identify the internal chamber along with the major components, which make it up.

The same pre testing process was used as was used with the first prototype. The valve was pre-tested to ensure that it worked. Table 6-10 provides a summary of the second prototypes problems found and the resulting solutions and outcomes.

Table 6-10 Second prototype problems solutions and resulting outcomes

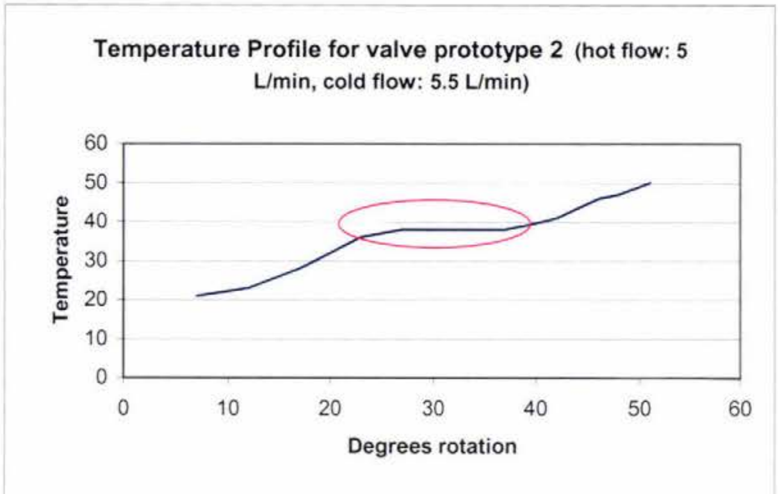
Problem	Solution	Outcome
Disk chamber slightly too small resulting in pressure applied to the bottom internal chamber through the disk instead of through the top internal chamber	Piece of top internal chamber which put pressure on the disk was sanded down	Pressure released however the shaft was wrenched lose of the disk in the process
Loose shaft	Refit shaft using a press fit metal disk	Disk rotates freely inside the internal chamber
Leaking occurred between the bottom internal chamber and valve body resulting in improper mixing	O-rings around each of the inlets	Holes in the valve body too close together to machine o-ring grooves
Holes too close together to fit o-ring grooves	A piece of o-ring rubber used to form the seal with cavities cut out between each inlet port and the outlet port	Appeared to have solved the problem

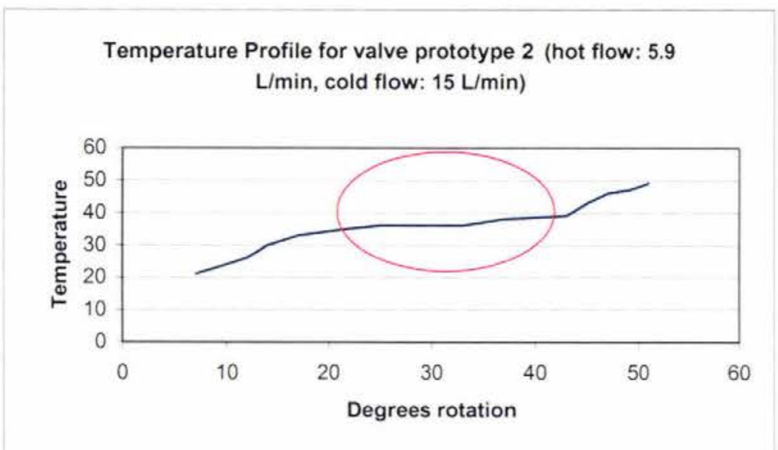
This iteration included no flow control so the methodology used for testing the valve was the same as the temperature control methodology outlined in section 6.4.1.2.

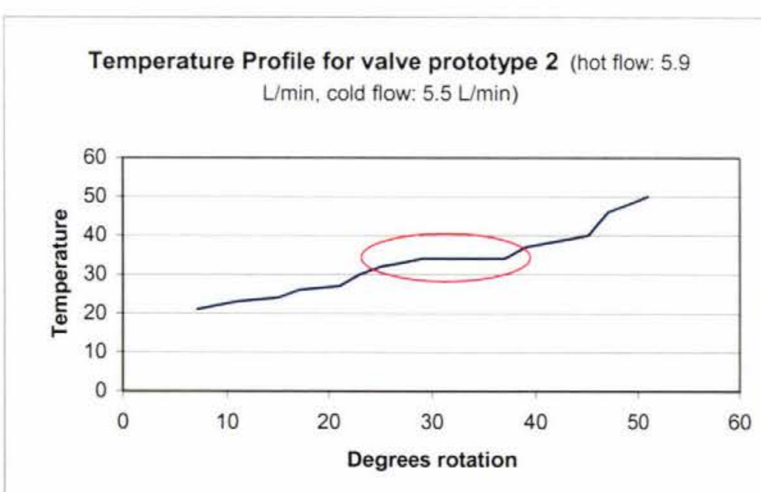
6.4.2.3 Results and Discussion

The temperature profiles obtained form testing the valve are shown in Figure 6-15. The temperature profiles were fairly linear, however there were a number of important aspects, which need discussing. The first was the valves inability to reach above 50°C and below 21°C. The hot water supply was at 61°C and the cold water supply at 17°C. This suggests that there was leaking within the valve between the bottom internal chamber and the valve body. The second point of interest was the flat section of the profile indicated in Figure 6-15 with red circles. These sections were undesirable and could be attributed to two possibilities. The first was the leaking mentioned earlier which probably did have an effect upon the temperature profile and the second was the cavity shapes used to mix the water.

Figure 6-15 Temperature profile for valve prototype two. Each graph involved different inlet flow rates.







6.4.2.4 Outcomes

The second manual valve was again measured against the initial specifications to identify areas that could be improved in the third iteration of development. Table 6-11 shows this comparison presenting the metric, units, which it was measured with, the ideal value and the achieved value.

Table 6-11 Comparison of second prototype to initial specifications. Green ticks show where a specification was met and a red cross shows where a specification was not met. The blue squiggle shows were a specification is close but not quite met.

Metric No.	Metric	Units	Ideal Value	Actual Value	Rating
1	Water on response time	s	>1	1	✓
2	Water off response time	s	>1	1	✓
3	Temperature change response time	s	>3	3	✓
4	Maximum temperature	Deg C	65	50	X
5	Minimum temperature	Deg C	18	20	~
6	Minimum flow	L/min	2	N/A	
7	Maximum flow	L/min	10	N/A	
8	Number of flows	#	3	N/A	
9	Flow step sequence	L/min	2	N/A	
10	Flow response	Deg	2	N/A	
11	Temperature steps	Deg C	1	1-5	~
12	Maximum operating pressure	Bar	10	10	✓
13	Valve weight	g	2000	2000	✓
14	Number of external sensors	#	0	N/A	
18	Installation time	min	30	N/A	
19	Production Cost	NZ$	200	N/A	
20	Valve dimensions	mm	150 x150x150	100x100x150	✓
21	Attachment sizes	mm	15	15	✓
22	Operating time without failure	yrs	10	N/A	
23	Operating Noise	subj	quiet	quiet	✓
24	Incorporates innovative designs	scale	5	5	✓
25	Stops facility overflowing	scale	5	N/A	
26	Temperature safety features	scale	5	N/A	
27	Fluctuation in output flow	L/min	>0.5	>0.5	✓
28	Valve Rotational torque	Nm	>6.5	8	~
29	Control accuracy	Deg	1	2-5	~

This valve met a number of important specifications neglected by the initial prototype. These included: a vast improvement on the temperature profile obtained and, although not perfect, reflected approximately the profile required; A dramatic improvement on the temperature response time, which was a direct result of a reduction in mixing chamber size; A leak proof valve that withstood the pressure it was subjected to; A reduction in size.

There was however aspects of the valve, which still needed refinement, and as a result a third iteration of the valve development was undertaken which had the following objectives.

1. Resolve internal bleed problems.

2. Refine the temperature profile.

3. Incorporate the flow cavities identified.

6.4.3 Development of Valve 3

The development of valve 3 followed an identical process to that identified for valve 2. The development concentrated on aspects neglected by valve 2, prototyping and testing.

6.4.3.1 Development

The three objectives identified from the previous iteration were used to structure the development of the third valve.

6.4.3.1.1 Internal Bleed

Internal bleed was a problem with both valves developed previously. Internal bleed occurred in two places. Bleed Point 1 was between the inlet and outlet ports of the valve and the inlet and outlet ports of the internal chamber. Bleed point 2 was between the inlet and outlet ports of the internal chamber and the disk.

Bleed point 1 - The inlet ports needed to be sealed off from each other, and from the outlet port. O-rings were put around each inlet and the outlet on the valve surface. These formed a seal with the bottom internal chamber, and therefore only allow hot and cold water to mix at the point it hit the disk (bleed point 2).

Bleed point 2 – Required the disk to form a surface seal with the inlet and outlet ports of the internal chamber. All modern disk valves used highly polished ceramic material to form this seal. Plastic to this point had proven ineffective in forming a perfect seal. A search was undertaken to identify a ceramic material that could be used for prototyping purpose. An American supplier was identified who could supply machine able ceramic disks as standard components. It was essential to use standard sizes as the cost of customising size solutions became very great. A concept was generated, which incorporated two ceramic disks, one, which was stationary, to be used as the bottom of the internal chamber and the second to be used as the rotating temperature and flow control disk. The disks were available in a number of sizes however two in particular fit the purposes of this project. A 76mm disk, 6.3mm thick, for the bottom of the internal chamber and a 50.6mm disk, 6.3 mm thick, for the rotating disk.

The size and shape of cavities to be cut into the material could not be achieved using conventional machining processes. The disks will eventually be moulded once the idea is proven however a machining process had to be identified that could be used for one off processing of the ceramic disks. Two processes were tested; water cutting and laser cutting. The results from both processes were compared and water cutting was eventually identified as the more appropriate solution for this particular job. The water process gave accurate cuts with minimal damage to the disk, where laser cutting was prone to chipping the material.

6.4.3.1.2 Temperature Profile and Flow Cavities

The previous mixing cavities were analysed to determine proportions of hot to cold water at various stages along the mixing profile. This led to an understanding of why the temperature profiles had obvious flat sections. The reason being that the cavity shapes used went through a transition phase where the proportion of hot to cold inlet sizes stayed equal for a prolonged period of time. This insight led to a concept, which kept the hot water flow fairly constant and adjusted the amount of cold water to achieve the desired temperature profile. Cavity shapes will not be shown to ensure the protection of related intellectual property.

It was necessary to develop temperature and flow cavities that could fit on a 50.6 mm disk. Sizes and spacing of cavities were tested using SolidWorks.

6.4.3.2 Resulting Concept

The concept was shown in Figure 6-16. The concept incorporated two ceramic disks. The first sealed with the bottom of the valve and provided inlet and outlet cavities.

The second disk was attached to a drive shaft, which rotated on top of the stationary disk. The lid of the valve applied pressure to a spacer which in turn a) provides pressure on the bottom disk to help seal it with the valve bottom, b) held the rotating disk in position on top of the stationary disk preventing the two disks separating under pressure. The stepper motor has also been included to show how the disk will eventually be controlled.

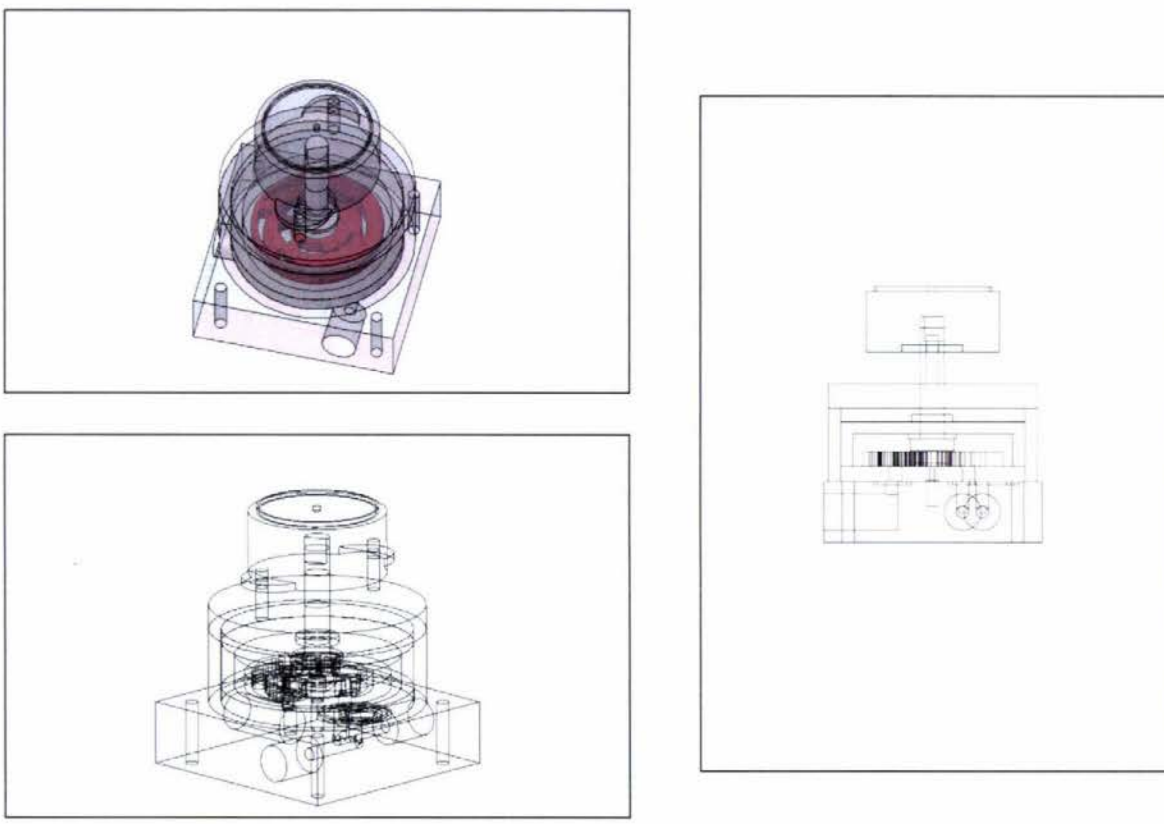


Figure 6-16 CAD models of valve three

6.4.3.3 Prototype

The prototype was manufactured solely from metal, with the exception of the disks, which are shown in Figure 6-17. The cavities in each disk were water cut. Pre-testing of this prototype was successful.

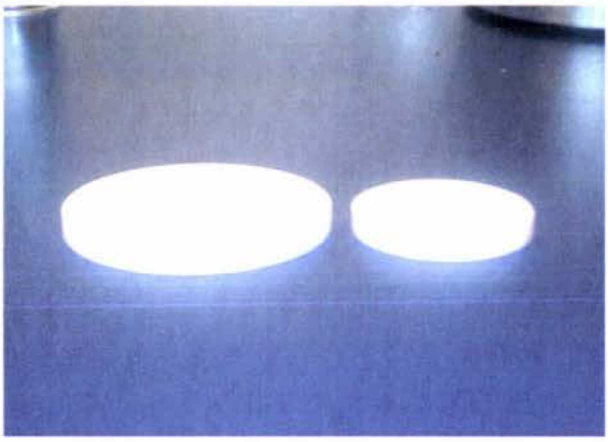
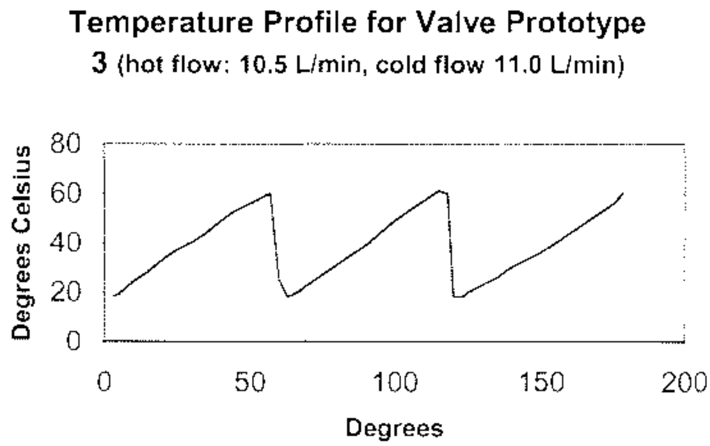


Figure 6-17 Disks used in the prototype of valve three

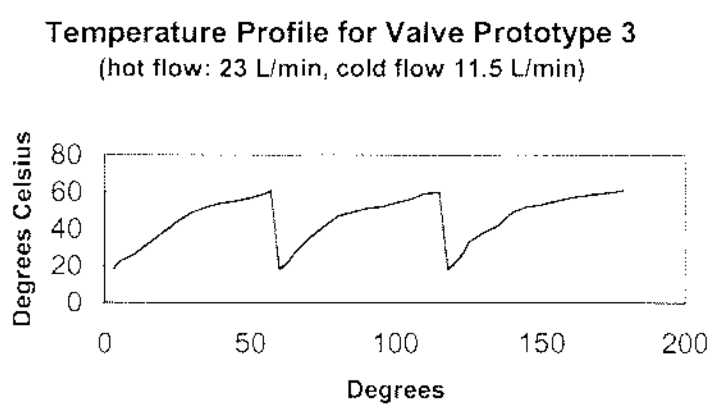
6.4.3.4 Results and Discussion

The testing methodology used was the same as the methodology outlined in section 6.4.1.2. Figure 6-18 shows the temperature and flow profiles obtained from the testing of valve three. The temperature profile obtained was very similar to the desired temperature profile outlined earlier in Figure 6-6. The profile was very linear especially in A) where the inlet flows were balanced in a 1:1 ratio. B) showed the temperature profile when the hot water flow was greater than the cold water flow. As the profile shows this decreased the control of the water temperature at the lower end of the spectrum and increased the amount of accuracy which was achieved at the top end. D) shows the temperature profile under the opposite conditions where the cold water supply was at twice the flow of the hot water inlet. The profile again was skewed however with this scenario it allowed greater control of lower end temperatures and less control of upper end temperatures. The flow profile also matched that of the ideal profile identified in Figure 6-6. The flows achieved were approximately 2,6 and 8 litres per minute.

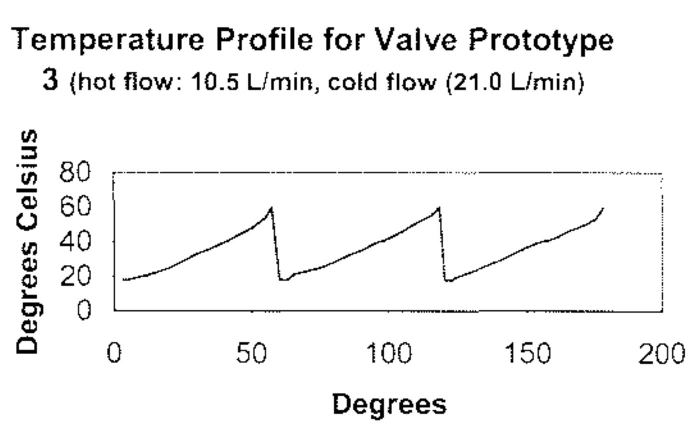
Figure 6-18 Temperature and flow profile obtained from testing Valve 3



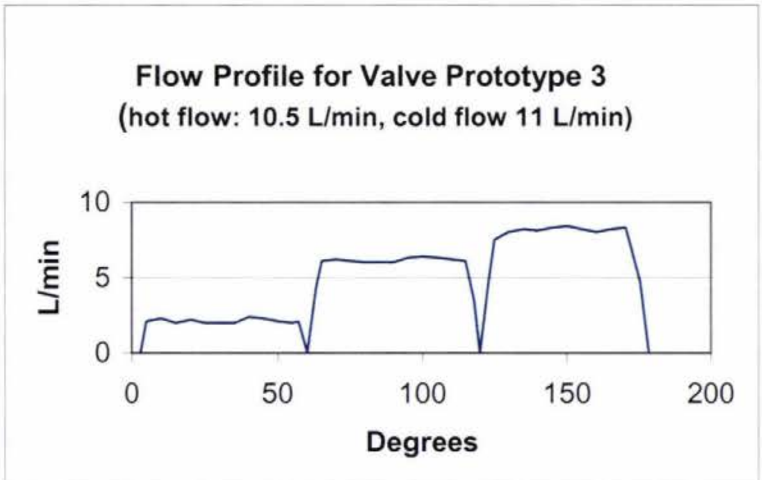
A)



B)



C)



D)

6.4.3.5 Outcomes

The third manual valve was again measured against the initial specifications to measure its success in achieving these requirements. Table 6-12 shows this comparison presenting the metric, units, which it was measured with, the ideal value and the achieved value.

Metric No.	Metric	Units	Ideal Value	Actual Value	Rating
1	Water on response time	s	>1	1	✓
2	Water off response time	s	>1	1	✓
3	Temperature change response time	s	>3	3	✓
4	Maximum temperature	Deg C	65	61	✓
5	Minimum temperature	Deg C	18	18	~
6	Minimum flow	L/min	2	2	✓
7	Maximum flow	L/min	10	8	~
8	Number of flows	#	3	3	✓
9	Flow step sequence	L/min	2	N/A	
10	Flow response	Deg	2	4	~
11	Temperature steps	Deg C	1	1-2	✓
12	Maximum operating pressure	Bar	10	10	✓
13	Valve weight	g	2000	2000	✓
14	Number of external sensors	#	0	N/A	
18	Installation time	min	30	10	✓
19	Production Cost	NZ$	200	N/A	
20	Valve dimensions	mm	150 x150x150	100x100x150	✓
21	Attachment sizes	mm	15	15	✓

Metric No.	Metric	Units	Ideal Value	Actual Value	Rating
22	Operating time without failure	yrs	10	N/A	
23	Operating Noise	subj	quiet	quiet	✓
24	Incorporates innovative designs	scale	5	5	✓
25	Stops facility overflowing	scale	5	N/A	
26	Temperature safety features	scale	5	5	✓
27	Fluctuation in output flow	L/min	>0.5	>0.5	✓
28	Valve Rotational torque	Nm	>6.5	4	✓
29	Control accuracy	Deg	1	1-2	✓

Table 6-12 Comparison of third prototype to initial specifications. Green ticks show were a specification has been met and a red cross shows where a specification has not been met. The blue squiggle shows were a specification is close but not quite met.

Table 6-12 shows that all-applicable specifications were met to a reasonable level. The incorporation of accurate flow control and a refined temperature profile left the sponsor company happy with the level of control achieved by this prototype.

6.4.4 Concept Refinement

A number of needs and resulting specifications still needed to be resolved. This section focuses on the aspects of development not covered in the concept development stage.

6.4.4.1 Over Flow Considerations

The level sensor was identified as serving dual purposes. The first was to prevent users from overflowing facilities. This was a good safety feature and also provides environmental benefits. A lot of existing sinks have built in overflows. These are not only a health risk but also do not stop the wasting of water, they simply prevent it from going on the floor. Some countries such as Australia have made the inclusion of overflows illegal due to the enormous build up of waste in the overflow piping causing stench and bacteria build up leading to possible health risks.

The second purpose of the level sensor was to offers an easy fill option for users. It enabled the user to turn the water on at a desired temperature and return later to a full sink/bath. This was identified as an unexpected and exciting need.

A number of options were investigated for level sensing. Originally options were investigated for a non-intrusive sensor. This meant that the user would not be able to see the sensor. Capacitance proximity sensors were identified as a cheap reliable solution. These were capable of sensing through ceramic materials however it was very difficult to find sensors in a reasonable price range that could sense through stainless steel. An investigation was undertaken to determine whether a capacitance sensor internally mounted in a facility would have an effect upon the desirability of the product. A portable showpiece was designed to show users what a sensor internally mounted in a stainless steel would look like. This was shown in Figure 6-19.

Figure 6-19 Sensor mounted internally in showpiece

A survey was undertaken of fifty-four consumers with and without impairments. Fifty-two of these respondents had no problem with this solution, as long as a number of needs were met. These needs are shown in Table 6-13.

No.		Need
1	***The Sensor***	***Was easy to install***
2	*The Sensor*	*Was reliable*
3	*The sensor*	*Required no maintenance*
4	*The sensor*	*Was easy to clean*

Table 6-13 User Needs relating to an internally mounted sensor

The two respondents, who did not desire an internally mounted sensor, raised the option of selling the product without this feature.

6.4.4.2 Production Cost

The manual valve designed was very similar to existing water mixers. The valve itself incorporated very similar components, was made of the same materials and was approximately the same size. As a result, the production cost, once in full manufacture would be very similar to that of existing water mixers.

The extra expense of this product was incorporated in the controller, with the major cost represented by the stepper motor used to operate the valve.

6.5 FUTURE DEVELOPMENT AND PLANNING

The manual valve has been passed onto the electronics engineer to fit and test the controller. The process was estimated to take two months however this estimate was subject to change.

A patent application has been filed for the manual valve and features of the control system.

A number of companies have already shown interest in finalising the design and manufacturing the product. Negotiations will get underway after the control system was finished and the patent has been approved.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This case study detailed the development of an electronically operated water control system. The development followed a systematic product development process that incorporated critical success factors, development methodologies and tools and techniques, identified in the product development literature. This process led to the successful development on an innovative new product currently under patent application.

A major theme within the case study was inclusive design and its incorporation into the product development process. Inclusive design was a societal influence that involves the development of products so that they incorporate the needs of users with the widest range of abilities, resulting in products that are usable by everyone regardless of age or ability. A review of inclusive design literature identified many arguments for the development of more usable products, however there was an obvious lack of reference to the needs of companies, who require products to be financially successful. Financial success of a product was a direct reflection of its desirability to users. A potential conflict was identified which was not addressed in the literature between developing usable products and developing desirable products. This case study investigated the relationship between these two product attributes; usability and desirability, in an attempt to understand the effect design decisions, relating to usability had upon the desirability of the product to all other users.

This section draws conclusions from the knowledge gained in this case study; Firstly, relating to the product development process used, and secondly, relating to inclusive design and the implications of design decisions made using this approach.

Recommendations with regards to these aspects have also been made. Further research opportunities identified have been included within relevant sections.

7.2 PRODUCT DEVELOPMENT PROCESS

The first objective identified in chapter one was to use the product development process to successfully develop an electronically operated water control system to a stage that is near ready for manufacture. The product development process used in this project predominantly revolved around the stages of development referred to by the literature as the front end development process, (Cooper 2001; Ulrich and Eppinger 2005). This was a direct reflection of the company strategy to develop the product to a stage that enabled the idea and related intellectual property to be sold to another company interested in manufacturing the product.

Literature was reviewed to identify strategies and methodologies that could be adopted within this project to increase the chances of success. The first major strategy incorporated was to split the project into the two major components of the product, 1) The user interface, 2) The valve system. The reason for doing so was to accommodate the obvious differences in the two components, which as a result required two very different approaches to their development.

The user interface was the component of the product that the user saw and could interact with. The product development process used to develop the user interface therefore followed a consumer driven design approach to ensure that all user needs and requirements were incorporated. The process itself followed the general stages of a consumer driven product development process, which was recognised within the literature, as being imperative to a successful product, and included: User needs identification, concept development, concept testing and concept refinement. This basic process was then adapted to incorporate approaches, which effect new to the world products such as this one.

The major adaptation made was the splitting of stage 1; user needs identification, into two phases as suggested by Griffin et al. (2004). The first stage of needs identification resulted in an understanding of problems, benefits, typical uses, and operating environments of existing water control systems. The second stage of the needs identification aimed to both identify possible needs associated with an electronically operated water control system and refine the idea through the use of concept drawings.

Adding this second stage did not unearth any new needs as was suggested in the literature, however it did offer an opportunity to refine the concept and focus the development.

The process used to develop the user interface was effective in developing an interface that met the needs of users with the widest range of abilities as possible. This implies that the interface was both usable by people with a wide range of impairments and desirable to a majority of all users. Evidence of this was reflected in the consumer testing results shown in section 5.3, which resolved conflicts between usability and desirability. 92% of the respondents, with and without impairments found the interface to be usable, and 96% of the respondents found the interface to be desirable.

The process used to develop the valve system was based upon the development process suggested by Ulrich and Eppinger (2005). The development of the valve system was very engineering based in comparison to the interface development process. The process, still used needs identified from the user and the sponsor company to establish target specifications, however the development involved far more engineering design, prototyping and testing using the specifications as the direct measure instead of the user.

The process used to develop the valve resulted in an innovative new design, which is currently under patent application. The specifications recognized as a result of the requirement identification stage were all met by the final design to an acceptably high standard.

Splitting the project into its major components and adapting the process for each was a successful approach to take. It allowed for the development to focus on the aspects of each major component that were most important to ensuring the success of the product. In this case the interface needed to be usable and desirable by all potential users and the valve needed to perform all of the physical manipulations required for adequate water control. Hence the user interface was approached using a consumer based design approach and the valve was approached using an engineering based design approach.

Products often consist of a number of major components that have different characteristics and require different approaches to their development. In such cases the product development process can be adapted to incorporate nested processes each with a focus that benefits one of the major components of the product.

The use of a structured NPD process, taking a consumer based approach helped to identify needs and requirements of users, which would otherwise have been neglected. The development process used has resulted in an innovative new product idea that has associated intellectual property, currently under patent application.

7.3 INCLUSIVE DESIGN

The second and third objectives identified at the beginning of this case study both relate to inclusive design. The conclusions and recommendations to each are addressed below.

The second objective identified was to understand and implement an inclusive design approach to the development of an electronically operated water control system. Inclusive design literature was reviewed and a methodology to incorporate inclusive design into the development process was outlined. The methodology followed a consumer based design approach, which focused design decisions affecting the usability of the product, in this case the user interface, on the needs of users with the greatest impairment. The process involved continuous testing of concepts to ensure these needs were being met. The objective of inclusive design is to make the product usable by users with the greatest impairment and by default make the product usable by everybody else as well.

The inclusive design approach achieved its objective and resulted in a group of concepts that were found by fifty-nine out of sixty potential users, both with and without impairments, to be usable. On average the concepts had a usability rating of 4.3, which places it on a likard scale (refer to figure 3-4), between usable and Very usable.

Developing concepts that are usable however is only half the objective. Concepts must both be usable by people with the widest range of impairments and desirable to the majority of the potential market. The inclusive design approach identified from the literature did not provide any evidence of taking into consideration the desirability aspect of products. The third objective identified at the beginning of this case study therefore addressed this issue. It was to understand to what effect design decisions, related to the usability of a product, have upon the desirability of the product to all potential users. A process followed was adapted to investigate this effect.

It was concluded that some design decisions relating to the usability of products do in fact affect the desirability of the product to other potential users. Evidence of this was given in section 5.2.4 where concepts perceived as usable, were deemed less desirable than similar concepts that did not include a number of usability characteristics. Certain characteristics of the user interface had direct conflicts between what was usable and what was desirable. If these conflicting characteristics had not been identified and explored, then the resulting concept could potentially have lacked the desirability aspects necessary to stimulate potential users into purchasing the product, and as a result compromise the needs of the sponsor company. The process followed in this project avoided this happening and resulted in both a product that was usable and desirable. As stated earlier user testing of the final interface found the concept usable by 96% of respondents and desirable by 92% of respondents, both with and without impairments. This shows that it is possible to incorporate inclusive design principles into product development projects and develop a product that is desirable to the majority of users, and is still usable by people with a wide range of abilities.

It is recommended that any development project undertaken should consider usability aspects in an attempt to incorporate the needs of users regardless of age or ability, however desirability aspects should not be compromised in the process. The process used in this case study may not be applicable to other projects however there are a number of important activities performed in this process which have been identified as crucial to its success. These activities have been identified in Figure 7-1. Further research should be undertaken to verify these activities and incorporate them into a generic NPD process.

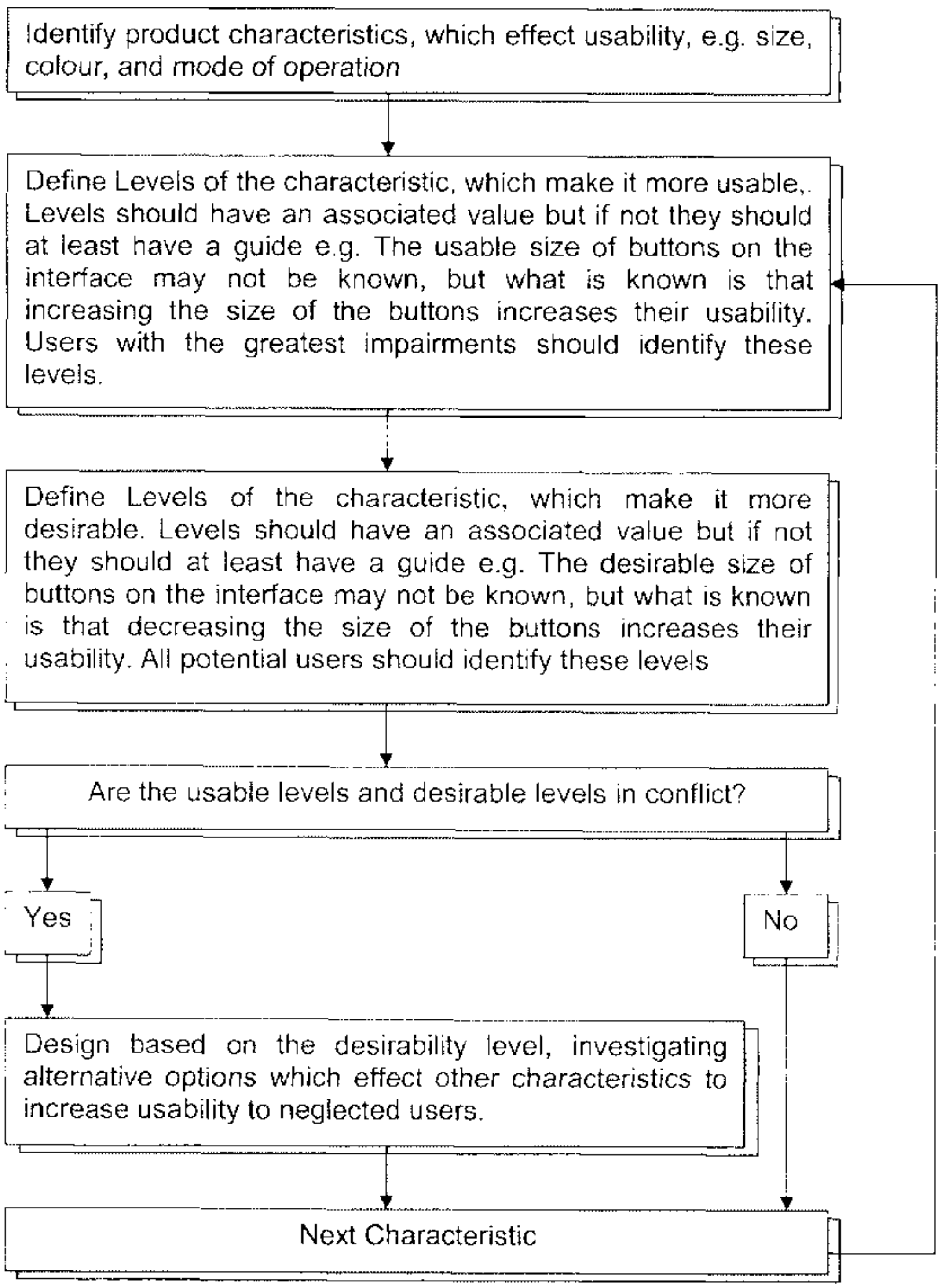


Figure 7-1 Activities recommended to incorporate usability into products without compromising desirability

An attempt was also made to identify whether informing users of the principles of inclusive design used in a products development will effect their perception of the desirability of the product. Only two people out of thirty who did not have impairments registered a change in their perception of the desirability of the user interfaces as a result of being informed of the inclusive design principles incorporated in their development. The reasoning for this change was that these people were directly associated with other potential users who had impairments. The conclusion drawn from the findings in this research is that consumers will not compromise desirability even when informed of the benefits of a product to society. Further research is required to explore this finding and the implications it may have.

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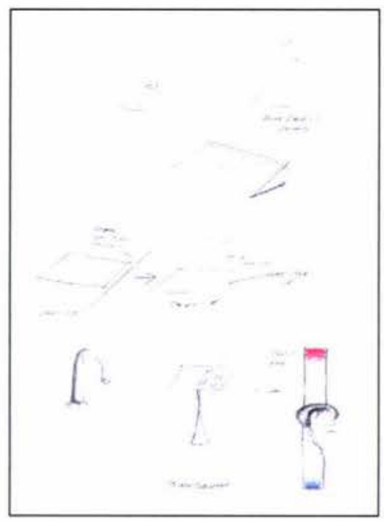
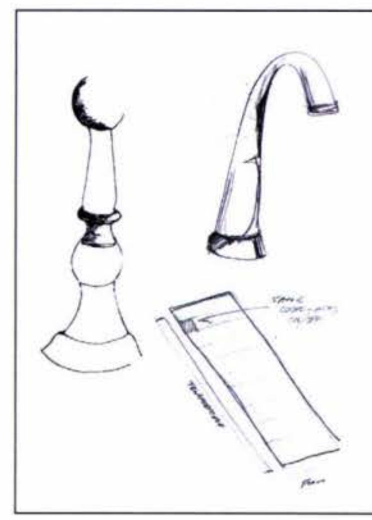
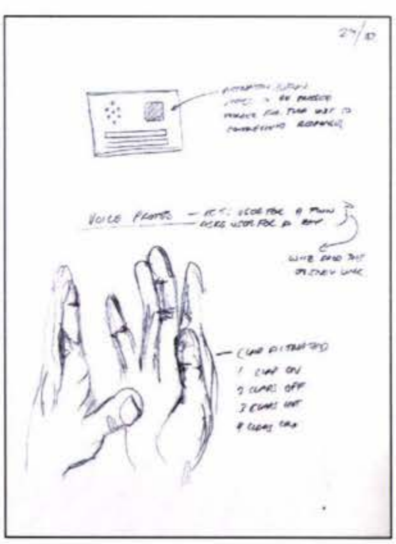
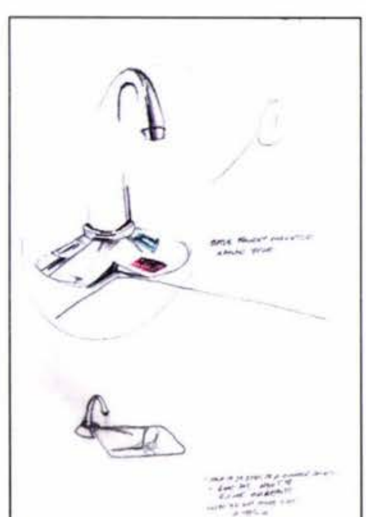
APPENDIX 1

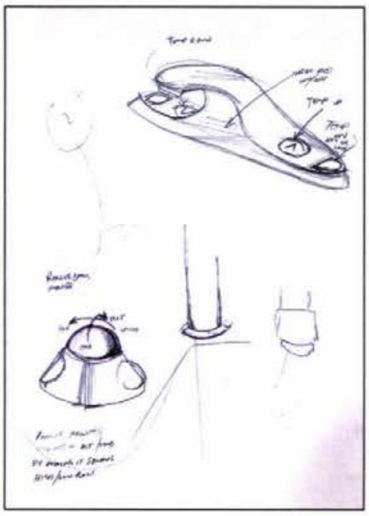
INITIAL INTERFACE CONCEPTS

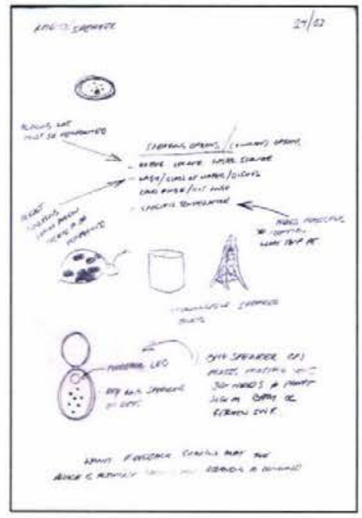


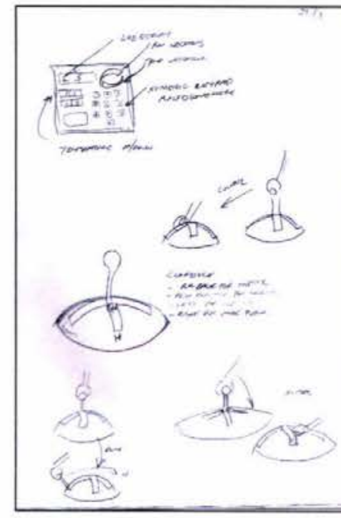


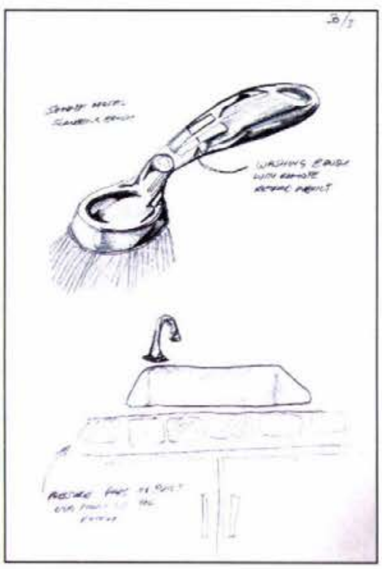


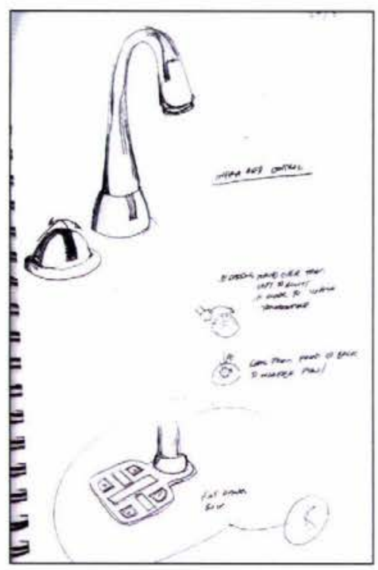


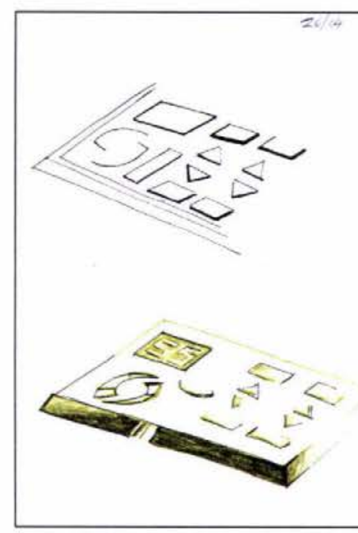


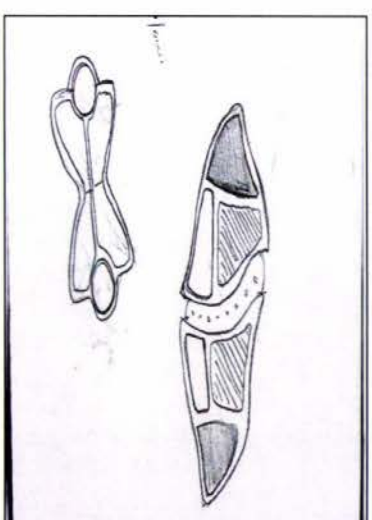


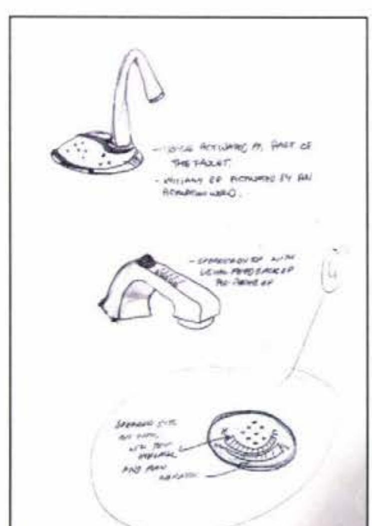




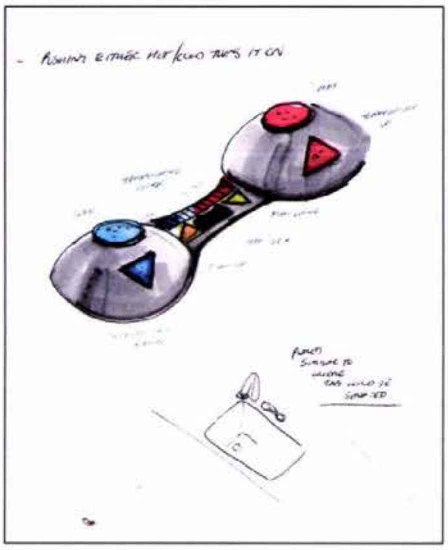


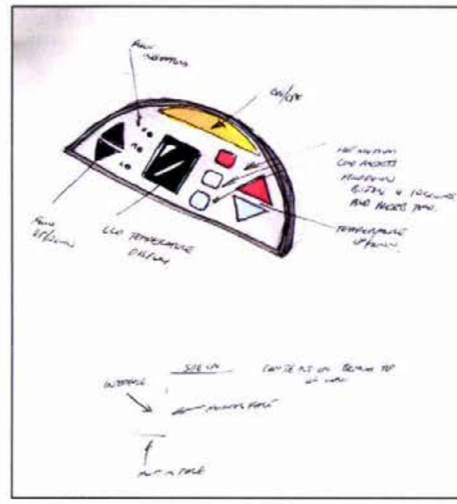


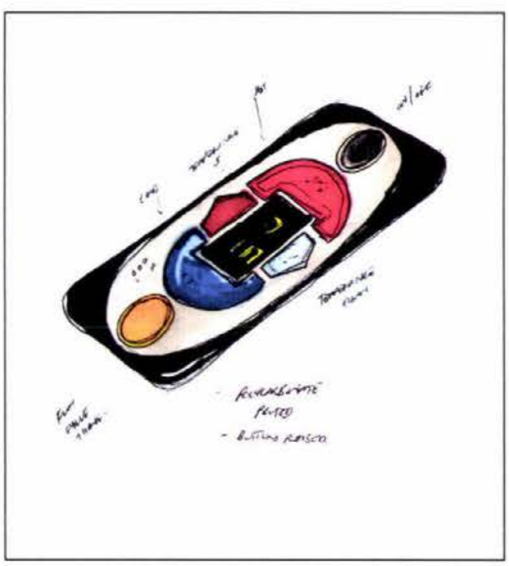


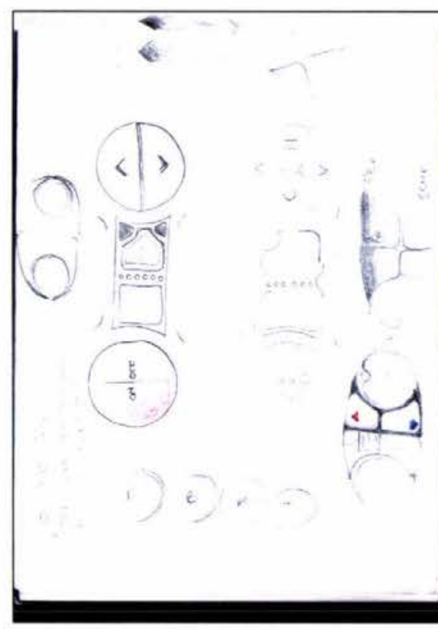


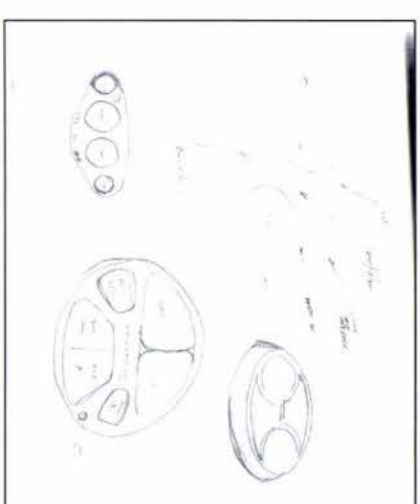
KEYPAD INTERFACE CONCEPTS

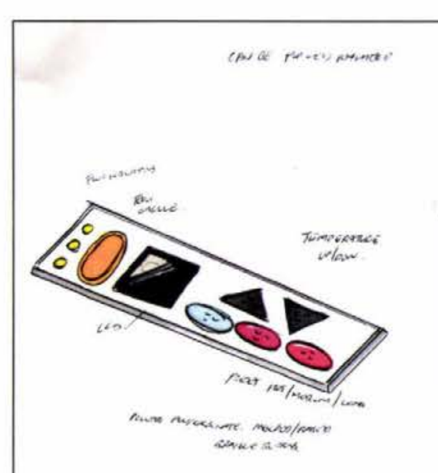


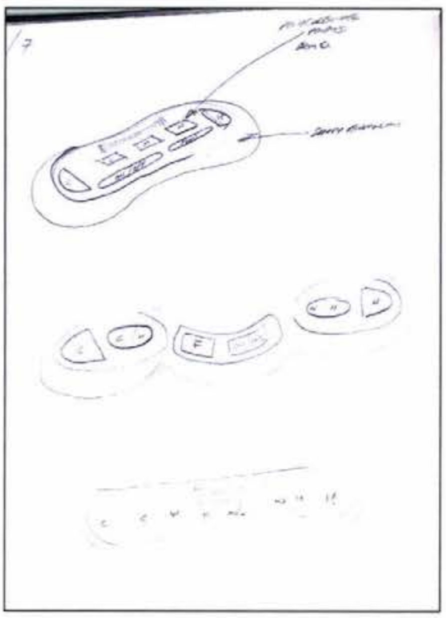


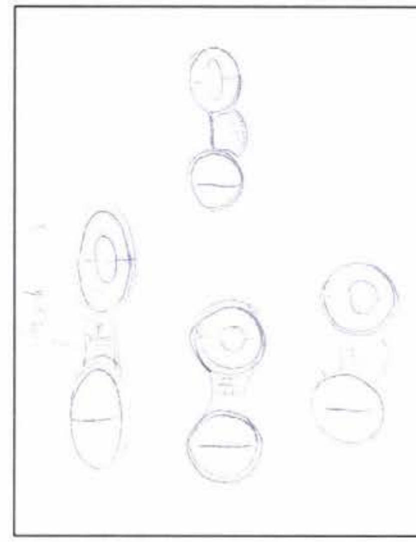


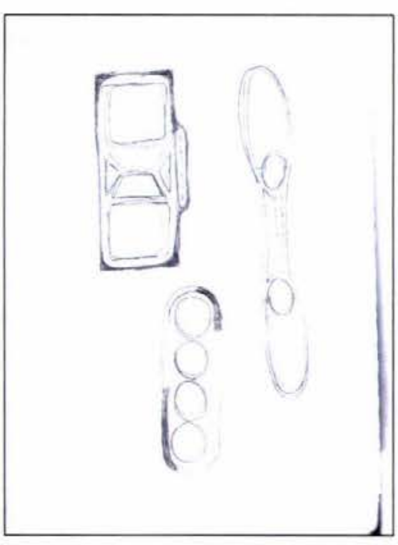


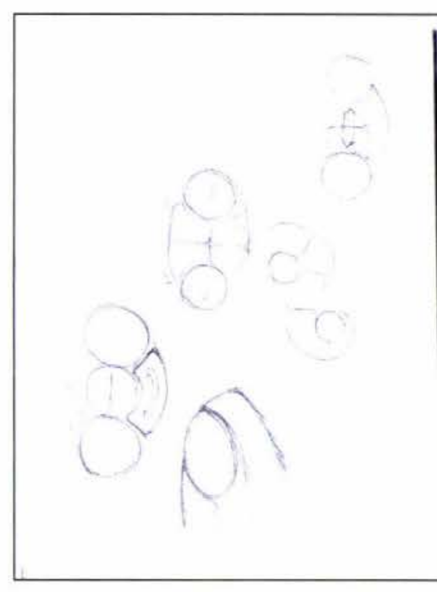






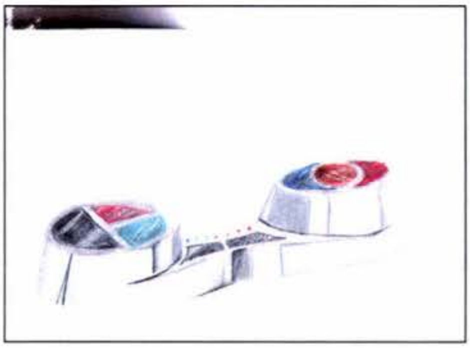


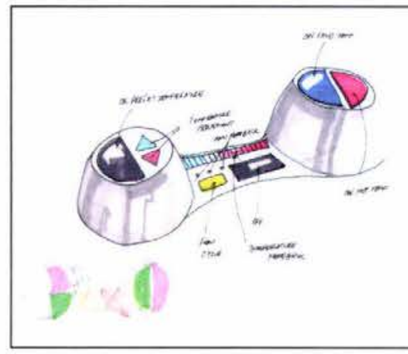




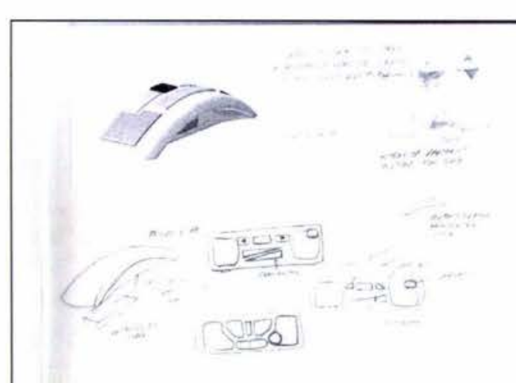
FOUR FURTHER DEVELOPMENTS

Concept one: playstation

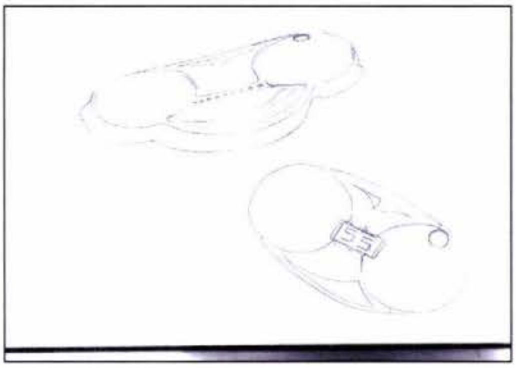


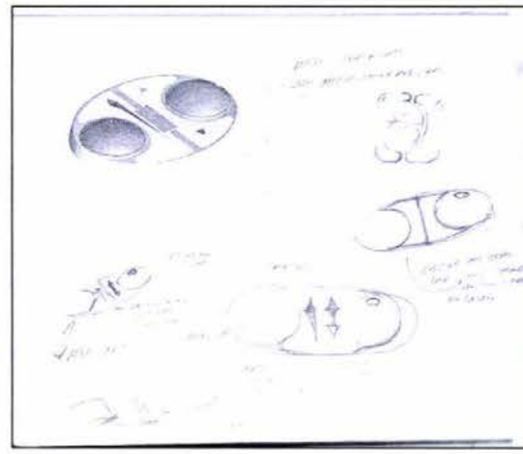


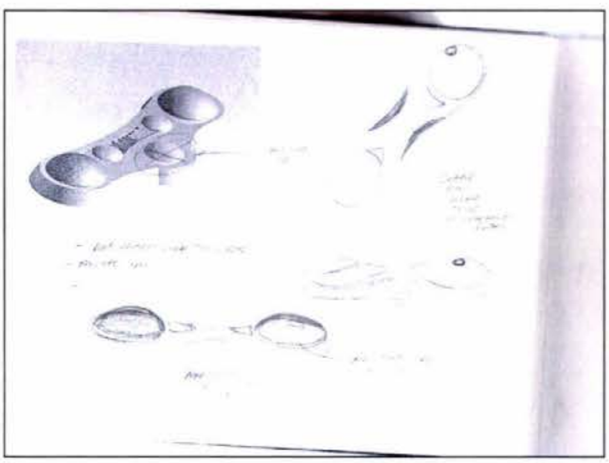
Concept two; curved handle

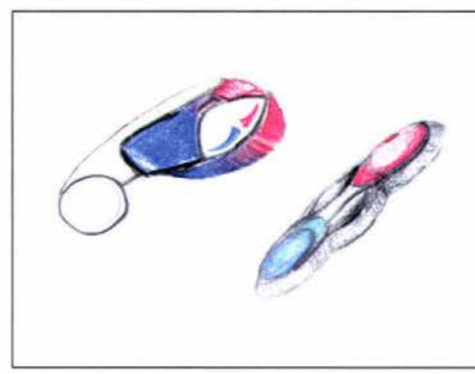


Concept three: round flat

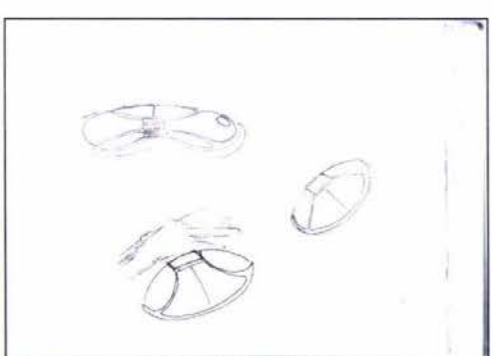


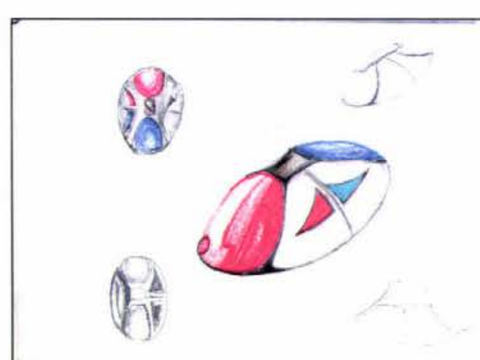


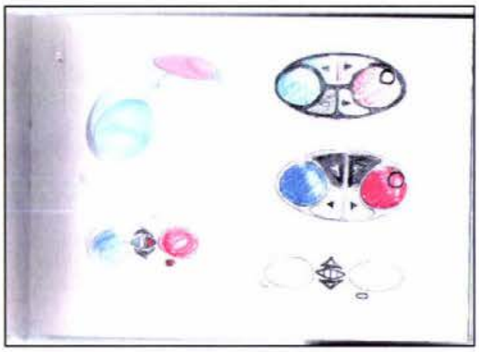


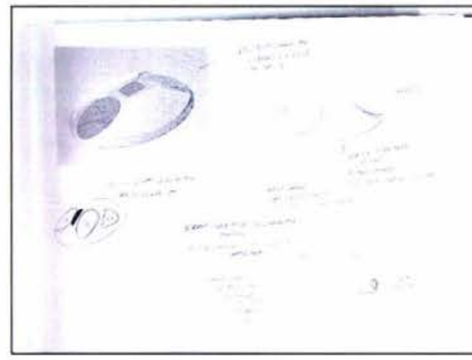


Concept four: dome









APPENDIX 2

CONSUMER SURVEY

Which of the interfaces is most usable? Place these interface designs on the usability scale. Two interfaces can be placed on the same point.

a

EXAMPLE

VERY UNUSABLE — ADEQUATE — VERY USABLE

Which of the following were contributing factors to your decision as to the most usable?
Please tick box. More than one box may be ticked.

- ☐ Interface/button size
- ☐ Interface/button colour
- ☐ Interface style
- ☐ Interface markings, button shape
- ☐ Other ____________

Which of the interfaces would you most like to have in your home (is the most desirable)? Place these interface designs on the desirability scale. Two interfaces can be placed on the same point.

VERY UNDESIREABLE — ADEQUATE — VERY DESIRABLE

Which of the following were contributing factors to your decision as to the most desirable?
Please tick box. More than one box may be ticked.

- ☐ Usability
- ☐ Colouring/marking
- ☐ Interface style
- ☐ Other ____________________

Interfaces A, B, C have been designed specifically for people with special needs to make them usable by these people. Does this change your opinion on the usability or desirability any of the interfaces?

VERY UNUSABLE — ADEQUATE — VERY USABLE

VERY UNDESIREABLE — ADEQUATE — VERY DESIRABLE

Reasoning for change:

USABILITY ANOVA ANALYSIS TABLES

SUMMARY

Groups	Count	Sum	Average	Variance
A	13	61.9	4.761538	1.622564
B	13	61.1	4.7	2.315
C	13	65.5	5.038462	1.102564
D	13	12.1	0.930769	7.638974
E	13	-6	-0.46154	8.957564
F	13	-20	-1.53846	9.085897

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	565.8938	5	113.1788	22.10338	2.37E-13	2.341828
Within Groups	368.6708	72	5.120427			
Total	934.5646	77				

ANOVA analysis of visually impaired usability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	8	36.6	4.575	1.262143
B	8	41.8	5.225	0.122143
C	8	41.8	5.225	0.122143
D	8	31.1	3.8875	0.586964
E	8	20.3	2.5375	3.534107
F	8	14.6	1.825	6.702143

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	81.01167	5	16.20233	7.884576	2.62E-05	2.437694
Within Groups	86.3075	42	2.05494			
Total	167.3192	47				

ANOVA analysis of physically impaired usability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	41	180.2	4.395122	2.333476
B	41	183.8	4.482927	2.506951
C	41	194.7	4.74878	1.360061
D	41	82.9	2.021951	6.156256
E	41	29.3	0.714634	7.38078
F	41	-10.4	-0.25366	8.788549

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	958.3314	5	191.6663	40.31392	5.28E-30	2.251646
Within Groups	1141.043	240	4.754346			
Total	2099.374	245				

ANOVA analysis of general special needs usability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	32	128.8	4.025	3.656774
B	32	135.8	4.24375	1.587702
C	32	128.7	4.021875	2.914667
D	32	110.3	3.446875	3.235474
E	32	77.9	2.434375	6.621038
F	32	72.7	2.271875	9.307248

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	118.2798	5	23.65596	5.194754	0.000173	2.262674
Within Groups	847.01	186	4.553817			
Total	965.2898	191				

ANOVA analysis of able body usability data.

DESIRABILITY ANOVA ANALYSIS TABLES

SUMMARY

Groups	Count	Sum	Average	Variance
A	14	17.87692	1.276923	9.095621
B	14	12.38462	0.884615	6.010533
C	14	-14.1077	-1.00769	5.213018
D	14	21.32308	1.523077	17.38639
E	14	20.13846	1.438462	11.30852
F	14	4.738462	0.338462	8.953136

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	64.76243	5	12.95249	1.34067	0.256085	2.331738
Within Groups	753.5738	78	9.661203			
Total	818.3363	83				

Table 7-1 ANOVA analysis of visually impaired desirability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	6	-0.9	-0.15	4.223
B	6	8.4	1.4	9.04
C	6	-10	-1.66667	5.582667
D	6	24.7	4.116667	5.825667
E	6	20	3.333333	6.134667
F	6	14.7	2.45	2.059

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	142.9914	5	28.59828	5.221046	0.001451	2.533554
Within Groups	164.325	30	5.4775			
Total	307.3164	35				

Table 7-2 ANOVA analysis of visually impaired users who stated size as an influence upon desirability

SUMMARY

Groups	Count	Sum	Average	Variance
A	5	17.8	3.56	10.963
B	5	10.1	2.02	3.737
C	5	1.9	0.38	5.352
D	5	-6.7	-1.34	25.348
E	5	-3.3	-0.66	11.098
F	5	-2.9	-0.58	11.662

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	87.80967	5	17.56193	1.545945	0.213288	2.620652
Within Groups	272.64	24	11.36			
Total	360.4497	29				

Table 7-3 ANOVA analysis of visually impaired users who stated usability as an influence upon desirability

SUMMARY

Groups	Count	Sum	Average	Variance
A	6	2.6	0.433333	9.974667
B	6	11.1	1.85	10.363
C	6	-7.3	-1.21667	10.21767
D	6	20.8	3.466667	14.47067
E	6	17.3	2.883333	12.02967
F	6	10.8	1.8	8.104

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	87.02472	5	17.40494	1.602673	0.189674	2.533554
Within Groups	325.7983	30	10.85994			
Total	412.8231	35				

Table 7-4 ANOVA analysis of visually impaired users who stated colouring and marking as an influence upon desirability

SUMMARY

Groups	Count	Sum	Average	Variance
A	8	-22.3	-2.7875	4.086964
B	8	0.4	0.05	9.808571
C	8	-22.6	-2.825	0.827857
D	8	32.6	4.075	5.776429
E	8	25.1	3.1375	3.322679
F	8	18.7	2.3375	4.696964

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	360.1335	5	72.02671	15.15317	1.67E-08	2.437694
Within Groups	199.6363	42	4.753244			
Total	559.7698	47				

Table7-5 ANOVA analysis of physically impaired usability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	20	-4.6	-0.23	11.97063
B	20	-13.8	-0.69	6.477789
C	20	-30.5	-1.525	6.294605
D	20	40.5	2.025	7.556711
E	20	35.9	1.795	6.373132
F	20	53.9	2.695	9.737342

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	293.5897	5	58.71793	7.277547	5.98E-06	2.293909
Within Groups	919.794	114	8.068368			
Total	1213.384	119				

Table 7-6 ANOVA analysis of general special needs usability data

SUMMARY

Groups	Count	Sum	Average	Variance
A	32	-85.7	-2.67813	8.703054
B	32	-82.5	-2.57813	11.82628
C	32	-108.9	-3.40313	9.277732
D	32	53.35	1.667188	13.00381
E	32	64.5	2.015625	9.494264
F	32	89.6	2.8	10.55742

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1257.377	5	251.4754	24.0024	1.35E-18	2.262674
Within Groups	1948.739	186	10.47709			
Total	3206.116	191				

Table 7-7 ANOVA analysis of able bodied market group desirability data

APPENDIX 3

INFORMATION REGARDING STEPPERMOTOR SELECTION

Stepper Motor – Stepper motors use a magnetic field to move a rotor. Stepping can be done in full step, half step or other fractional step increments. Voltage is applied to poles around the rotor. The voltage changes the polarity of each pole, and the resulting magnetic interaction between the poles and the rotor causes the rotor to move. Stepper motors provide precise positioning and ease of use, especially in low acceleration or static load applications.

Important performance specifications to consider when searching for stepper motors include shaft speed, terminal voltage, current per phase, continuous output power, and static or holding torque. Shaft speed is the no-load rotational speed of output shaft at rated terminal voltage. The terminal voltage is the design DC motor voltage. The current per phase is the maximum rated current or winding for a stepper motor. The continuous output power is the mechanical power provided by the motor output. Static or holding torque is the maximum torque a motor can develop to hold its rotor in a stationary position.

Motor types for stepper motors can be permanent magnet, variable reluctance, or hybrid. Permanent magnet (PM) motors use a permanent magnet on the rotor. Step angles range from 1.5 to 30 degrees. Permanent magnet motors are the most common and versatile stepper motor. This includes both unipolar (bifilar) and bipolar types. Variable reluctance (VR) motors have a free-moving rotor; no residual torque is produced due to the lack of a permanent magnet. The rotor is instead composed of a soft iron metal. Rotor is also composed of its own very prominent poles, tending to stick out more than a rotor found on the PM version. Step angles: 7.5 to 30 degrees single power source required (like a bifilar PM motor). This is the least expensive stepper motor. Hybrid motors consist of a heavily toothed PM rotor and toothed stators, plus prominent rotor poles like a VR rotor. They are capable of very fine step angles: 0.5 to 15 degrees and have a high-speed capability (less chance of a stall). There is a higher available torque than PM or VR stepper motors. Most effective but most expensive stepper motor type. The step angle is the degrees per step of the motor. Stepper motor configurations can have different numbers of leads depending on the specific winding wiring. For example, bipolar PM motors can have 4, 5, or 6 leads, unipolar PM motors can commonly have 5 or 6 leads (two windings with two ends plus centre taps, which may or may not be tied together), hybrid motors frequently contain 8 leads, and multiphase motors can have different lead configurations (for example, a motor wired for 5-phase power could have 5 or 10 leads). Consult with manufacturer for specific winding wiring and lead information.

Gear motor or gear head options for stepper motors include motor configuration, gearing if applicable, gearbox ratio, and gearbox efficiency. Feedback choices include integral encoder, integral resolver, and integral tachometer. Other specifications to consider when searching for stepper motors include shaft orientation or type and number of shafts, design units, motor shape, dimensions of width and length, NEMA frame sizes, enclosure options and special or extreme environments. Features common to stepper motors include integral driver electronics, integral brakes, integral clutches, and brake or clutch combinations.

INFORMATION REGARDING SYNCHRONISE MOTOR SELECTION

Synchronise Motor – AC motors (alternating current) is a very wide class of motors, including single / multiphase, universal, servo, induction, synchronous, and gearmotor types. The magnetic field, generated by AC motors, is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils that produce the magnetic field are traditionally called the "field coils" while the coils and the solid core that rotates is called the "armature." There are many advantages in the use of ac motors aside from the wide availability of AC power. In general, AC motors cost less than DC motors. Some types of AC motors do not use brushes or commutators. This eliminates many problems of maintenance and wear, and also eliminates the problem of dangerous sparking. They are also particularly well suited for constant-speed applications. This is because its speed is determined by the frequency of the AC voltage applied to the motor terminals.

There are two distinct types of AC motors, synchronous and induction. A synchronous motor consists of a series of three windings in the stator section with a simple rotating area. A current is passed through the coil, generating torque on the coil. Since the current is alternating, the motor will run smoothly only at the frequency of the sine wave. This allows for constant, unvarying speed from no load to full load with no slip.

INFORMATION REGARDING ACTUATOR SELECTION

Actuator – Linear actuators provide linear motion via a motor driven ball screw or ACME screw assembly. The linear actuator's load is attached to the end of screw, or rod, and is unsupported. The screw can be direct, belt, or gear driven. Important performance specifications to consider when searching for linear actuators include stroke, maximum rated load or force, and maximum rated speed, continuous power, and system backlash. Stroke is the distance between fully extended and fully retracted rod positions. The maximum rated load or force is not the maximum static load. The maximum rated speed is the maximum actuator linear speed; typically rated at low or no load. Continuous power is sustainable power; it does not include short-term peak power ratings. Backlash is position error due to direction change. Motor choices include DC, DC servo, DC brushless, DC brushless servo, AC, AC servo, and stepper. Input power can be specified for DC, AC, or stepper motors.

Drive screw specifications to consider for linear actuators include drive screw type and screw lead. Features include self-locking, limit switches, motor encoder feedback, and linear position feedback. Screw choices include acme screws and ball screws. Acme screws will typically hold loads without power but are usually less efficient than ball screws. They also typically have a shorter life but are more robust to shock loads. If backlash is a concern, it is usually better to select a ball screw. Ball screws exhibit lower friction and therefore higher efficiency than "lead screws". Screw lead is the distance the rod advances with one revolution of the screw. Other features for linear actuators to consider include holding brakes, integrated overload slip clutch or torque limiters, water resistant construction, protective boot, and thermal overload protection. Design units can be English or metric. Some manufacturers specify both. Dimensions to consider when specifying linear actuators include retracted length, width, height, and weight. The housing can have flanges, rear clevis, side angle brackets, side lugs, tapped holes, trunnion, and spherical bearings. Rod ends can be clevis, female eye, female thread, male thread, and spherical bearing. An important environmental parameter to consider is the operating temperature.