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Empowering Elders to Self-manage Medications Using a Social Robot

PRIYADARSHI TIWARI

December 2012

Supervisor: Professor Jim Warren
Co-supervisor: Dr Karen Day

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Health Sciences, The University of Auckland, 2012
Abstract

Objective: The objective of research was to understand and support quality use of medications in older adults living independently in an aged care facility. Considering ageing of populations, shortage of skilled caregivers, increasing chronic disease burden, use of multiple potent medications and high medication-related risk of morbidity and mortality in older people remain important problems. Improving adherence to and continuity of medications while balancing the risk of medication-related complications and morbidity with the use of information technology remains a desirable but underachieved goal. Instead of being limited to a range of existing solutions, the researcher intended to understand the reality from the perspective of older users. It was considered important to unravel the relationship between personal use of medications and a dynamic social environment in order to understand the implicit needs and demands of potential users from a technology-driven medication management system. The thesis explored the subjective reality of older people while using their medications and also while interacting with a collaboratively designed solution. The research intended to develop and test an interactive dialogue system on the touch screen interface of a social robot focusing on two important research questions:

1. What is the theory underpinning appropriate design of technology to enable older people to better manage their medications?
2. Can an automated medication management solution be developed successfully on a robot while being informed by the theory of automated medication assistance?

Method: It was an interpretive and formative research attempting to discover theory rather than testing it. Based on the methodologies of Grounded Theory (GT) and Participatory Design (PD) within four Action Research (AR) cycles, the research elicited design implications and tested the design configuration addressing the unique task requirements. Within the overarching methodological framework, a variety of qualitative and quantitative methods were used that were appropriate to each stage. The beginning of the AR cycles was informed by an ethnographic analysis of the context of older residents of Selwyn Village (an aged care facility in Auckland). The study participants were elderly residents and concerned healthcare providers, caregivers and family members. The apparatus was designed and developed as part of a multi-disciplinary ‘Healthbots’ project at New Zealand Korea Centre for healthcare robotics, hosted within University of Auckland.
**Results:** An initial ethnographic study mapped medication-related practices and processes, identified actors and scenarios defining the context for Action Research. The first AR cycle developed and tested a paper prototype and identified implications for software architecture and interface design. The second AR cycle observed residents interacting with a prototype and found them to be generally satisfied with it. The results informed further refinement of the prototype. A refined system in the third AR cycle led participants through a series of daily interactions, discovering a pattern of task mastery. The fourth and final AR cycle allowed older participants to independently use a robot within their apartments, discovering a successful interaction and safe medication use.

The research confirmed that an ideal dialogue system aimed at older users could successfully meet the requirements if it was delivered on a touch screen (mounted on a robot as a computing device). A closed-loop system (as opposed to an open-loop standalone reminder) was designed, where the robot/device could work in synchronization with a web-based electronic medication record to enable real-time dynamic interaction with healthcare providers, caregivers and family members. A dynamic and complex set of variables around medication use, possible error situations, need for personalisation, need for patient education, monitoring of therapeutic efficacy and safety was unravelled. In each AR cycle qualitative data was collected and analysed using open, axial and selective coding along the principles of Grounded Theory, to arrive at four theoretical elements to the process of medication management, namely: Empowerment, Engagement, Collaboration and Safety.

**Conclusion:** The research journey uncovered needs of older people beyond a simple reminder alarm and pill box. It successfully developed and tested a medication management module and proposed a theory of automating medication assistance for older people. It showed that older people can independently use a robot to help them manage self-care tasks. Qualitative methods such as the hybrid GT-PD-AR approach may be particularly helpful for innovating and articulating design requirements in challenging situations. A successful automated medication assistant for the elderly should effectively engage with and empower its users to self-manage their medications safely, while collaborating effectively with others who care for them. The research discovered new components to the medication management process in the context of older people and self-care task automation and opened a direction of research into the concept of ‘empowering technologies’.
Acknowledgements

I would like to express my sincere gratitude and appreciation to my mentor and supervisor, Professor Jim Warren, and acknowledge his disciplined and insightful guidance throughout my doctoral programme. I am grateful to him for taking the time and effort for discussion, encouragement and mentoring through a complex and demanding research process.

With admiration, I would like to acknowledge the valuable input to my research and the collegial support extended to me by my co-supervisor, Dr Karen Day. She has always augmented my thought process with her guidance and analytical clarity. Being a qualitative researcher, I would have missed many of my blind spots if she had not pointed them out.

My sincere appreciation goes to Professor Peter Adams for igniting and opening my thoughts towards important philosophical insights, giving depth to my research approach.

Thanks are due to Professor Bruce Macdonald and the members of the ‘Healthbots’ team for supporting the research environment by organising resources and engaging me with a well-managed collaborative team of experts from diverse fields of expertise. Special thanks are due to Rebecca Stafford for helping me with field trials, Ben Robins for supporting with the resources needed for the trial, and Dr Elizabeth Broadbent, Professor Ngaire Kerse & Dr Martin Connolly for their helpful expert advice.

I sincerely acknowledge the residents, caregivers and management of Selwyn Village, especially Dr Bart Nuysinc, for their warm and enthusiastic participation.

Sincere thanks to the National Institute of Health Innovation, especially Malcolm Pollock, Dr Martin Orr and Chris Paton for their support and encouragement.

I would also like to acknowledge both the New Zealand-Korean Centre for Healthcare Robotics and Uniservices for part supporting my scholarship, made possible by research funding from the New Zealand Tertiary Education Commission and the Foundation for Research, Science and Technology grant, the R&D programme of the Korean Ministry of Knowledge Economy (MKE) and the Korea Evaluation Institute of Industrial Technology (KEIT). I would also like to acknowledge Yujin Robotics for providing the robots for the trials and actively responding to my research needs.
The University of Auckland scholarships programme is thankfully acknowledged for providing me with an International Doctoral Scholarship to support my studies and stay at Auckland.

I can never thank enough my colleagues and software engineering researchers for their help and input in the construction of the prototype, especially Dr Hong Yul Yang, Chandan Datta, Dr I. Kuo, Dr Chandimal Jaywardena and Alexander Igie. This research was not possible without their dedicated and sincere efforts. They went the extra mile and took pains to accommodate an ever-evolving set of requirements.

Finally, I would like to thank my family for their continued support and encouragement over the course of my study – my parents who always took pride in my achievements, my wife Jyoti whose loving support kept me going despite the difficulties, and my lovely daughter Adya, who made my burdens lighter with her playfulness and laughter each day.
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### Glossary of Terms

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<tr>
<td>Affective</td>
<td>The way people react emotionally and their ability to feel another’s pain or joy</td>
</tr>
<tr>
<td>Celeron processor</td>
<td>Intel's entry-level processor for basic computing tasks</td>
</tr>
<tr>
<td>Dialogue</td>
<td>A written or spoken sentence by a computing device that may invite the user to indicate his/her response, symbolizing a conversation</td>
</tr>
<tr>
<td>Dependency ratio</td>
<td>Percentage of people aged “65 years and above” to people aged “15–64 years”</td>
</tr>
<tr>
<td>Haptic</td>
<td>Of or relating to the sense of touch</td>
</tr>
<tr>
<td>Ipsative feedback</td>
<td>Ipsative feedback is the comparison of present performance against the prior performance, e.g. how does the blood sugar reading taken today compare to the previous (lower/higher)</td>
</tr>
<tr>
<td>Medicalisation</td>
<td>To identify or categorize a condition or behavior as being a disorder requiring medical treatment or intervention</td>
</tr>
<tr>
<td>Paradigms</td>
<td>Typical examples or patterns of something; models: a worldview underlying the theories and methodology of a particular scientific subject</td>
</tr>
<tr>
<td>Pharmacokinetic</td>
<td>A branch of pharmacology determining the absorption, distribution and excretion of substances administered externally to a living organism</td>
</tr>
<tr>
<td>Polypharmacy</td>
<td>The use of a number of different drugs, possibly prescribed by different doctors and filled in different pharmacies, by a patient who may have one or several health problems</td>
</tr>
<tr>
<td>Psychomotor</td>
<td>The relationship between cognitive functions and physical movement</td>
</tr>
<tr>
<td>Robopsychology</td>
<td>The study of the personalities of intelligent machines</td>
</tr>
<tr>
<td>Robotherapy</td>
<td>A framework of person-robot interactions aimed at the reconstruction of one’s negative experiences through the development of new coping skills mediated by technological tools</td>
</tr>
<tr>
<td>Telecare</td>
<td>Offering remote care of old and physically less able people, providing the care and reassurance needed to allow them to remain living in their own homes</td>
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### List of Abbreviations

*(Entries are listed alphabetically)*

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<th>Description</th>
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<tbody>
<tr>
<td>ACF</td>
<td>Aged Care Facility</td>
</tr>
<tr>
<td>ADEs</td>
<td>Adverse Drug Events</td>
</tr>
<tr>
<td>ANT</td>
<td>Actor-network Theory</td>
</tr>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>API</td>
<td>Application Program Interface</td>
</tr>
<tr>
<td>AR</td>
<td>Action Research</td>
</tr>
<tr>
<td>ASR</td>
<td>Automated Speech Recognition</td>
</tr>
<tr>
<td>CAM</td>
<td>Complementary and Alternative Medicine</td>
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<tr>
<td>CDSS</td>
<td>Clinical Decision Support System</td>
</tr>
<tr>
<td>CMI</td>
<td>Consumer Medication Information</td>
</tr>
<tr>
<td>CPOE</td>
<td>Computerised Physician Order Entry System</td>
</tr>
<tr>
<td>DR</td>
<td>Developmental Research</td>
</tr>
<tr>
<td>DHBs</td>
<td>District Health Boards</td>
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<tr>
<td>ECE</td>
<td>Electronics and Computer Engineering</td>
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<tr>
<td>EHR</td>
<td>Electronic Health Record</td>
</tr>
<tr>
<td>EMR</td>
<td>Electronic Medication Record</td>
</tr>
<tr>
<td>ETRI</td>
<td>Electronics and Telecommunications Research Institute</td>
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<tr>
<td>FDA</td>
<td>Food and Drug Administration</td>
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<tr>
<td>GT</td>
<td>Grounded Theory</td>
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<tr>
<td>HPI</td>
<td>Health Practitioner Identifier</td>
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<tr>
<td>HRI</td>
<td>Human Robot Interaction</td>
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<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
</tr>
<tr>
<td>IIOF FRST</td>
<td>International Investment Opportunities Fund – Foundation for Research, Science and Technology</td>
</tr>
<tr>
<td>INR</td>
<td>International Normalised Ratio</td>
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<tr>
<td>IS</td>
<td>Information Systems</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>IVR</td>
<td>Interactive Voice Response</td>
</tr>
<tr>
<td>KEIT</td>
<td>Korea Evaluation Institute of Industrial Technology</td>
</tr>
<tr>
<td>MKE</td>
<td>Korea Ministry of Knowledge Economy</td>
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<tr>
<td>NHI</td>
<td>National Health Identifier</td>
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<tr>
<td>NIHI</td>
<td>National Institute of Health Innovation</td>
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<tr>
<td>OPD</td>
<td>Out Patients Department</td>
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<tr>
<td>OMG</td>
<td>Object Modelling Group</td>
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<tr>
<td>OTC</td>
<td>Over The Counter</td>
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<tr>
<td>PAR</td>
<td>Participatory Action Research</td>
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<tr>
<td>PD</td>
<td>Participatory Design</td>
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<tr>
<td>PHOs</td>
<td>Primary Healthcare Organisations</td>
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<tr>
<td>PMS</td>
<td>Practice Management System</td>
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<tr>
<td>PHR</td>
<td>Personal Health Record</td>
</tr>
<tr>
<td>PRN</td>
<td>Pro Re Nata (Latin - as the thing is needed)</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identification Device</td>
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<tr>
<td>RCT</td>
<td>Reliance Clinical Testing</td>
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<tr>
<td>REST</td>
<td>Representational State Transfer</td>
</tr>
<tr>
<td>SAR</td>
<td>Socially Assistive Robots</td>
</tr>
<tr>
<td>SDK</td>
<td>Software Development Kit</td>
</tr>
<tr>
<td>SNOMED CT</td>
<td>Systematized Nomenclature of Medicine -- Clinical Terms</td>
</tr>
<tr>
<td>SPO2</td>
<td>Measure of oxygen saturation in blood</td>
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<tr>
<td>STN</td>
<td>State Transition Network</td>
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<tr>
<td>TLC</td>
<td>Telephone Linked Care</td>
</tr>
<tr>
<td>UML</td>
<td>Unified Modelling Language</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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Chapter 1: Introduction

By early 5th century in India, Sushruta, first described the practice of medicine as ‘a branch of knowledge that enabled each person to live a full life’ (Eisenberg, 1982). Enabling a person to take care of his/her own health was then seen as a superior approach to depending on healthcare providers for serving every need. After centuries of experimentation, healthcare professionals are now increasingly realising the value of education and facilitation of the healing journey where a partnership becomes central to the notion of a “person-centric model” of healthcare (Nay, Bird, Edvardsson, Fleming, & Hill, 2009). In addition to an evolutionary philosophical shift, there are compelling drivers that bring the patient back onto the centre stage. The rising incidence of chronic illnesses, ageing of populations and incremental shortage of healthcare professionals put significant operational and fiscal pressures on healthcare delivery systems. Healthcare systems around the globe are finding it increasingly difficult to sustain themselves on provider-centric models of care (Jacobzone, 1998). Modern consumers of healthcare also tend to be better informed, more capable and involved than ever before, and unwillingly relinquish a sense of control over health matters (Raven, 2003). For similar reasons, there has been an increasing emphasis on maintaining health, proactive disease management and care planning, while engaging patients in self-care (Bevan, Helderman, & Wilsford, 2010).

Developing tools and techniques that may enable people to better engage in self-care is the central theme of this thesis. The study was designed and conducted within New Zealand’s high priority area of supporting older people living within the community to successfully engage in medication management as an example of a complex self-care task. The research journey started with developing an understanding of the context, reviewing the literature, reviewing available technologies and future trends, and eliciting views from experts and potential users. With the help of this rich information, a robot was then iteratively developed and tested.

This chapter presents the themes that influence the motivation to undertake this journey and introduces the fascinating field of social robotics that may transform the way healthcare is delivered in the future. Robots are already used to augment productivity, accuracy and precision in major industrial settings; however, their use in human proximity such as service and healthcare applications is still limited due to design, interaction and safety issues. The
reader is also presented with an introduction to demographic and health-related drivers, trends in person-centred healthcare, and the importance of quality use of medications for the elderly. The area of social robotics in healthcare is touched upon, before leading on to a description of the research objectives and finally presenting an outline of this thesis.

1.1 Background

1.1.1 Why focus research on older people?

Populations are ageing worldwide. Recent OECD projections on global demographics indicate major changes in the age structure of populations and, over the next few decades, the proportion of elderly people growing steadily faster than their younger counterparts (Groot & Peeters, 2011). These demographic changes are likely to have a significant impact on publicly funded healthcare systems, where the state’s role in the welfare of its people would put pressure on fiscal resources. For example, one in eight New Zealanders is currently aged over 65, and this fraction is expected to rise to one in five by 2025. A person over 65 years of age is estimated to cost the New Zealand healthcare system five times more than the average person under 65 (Dustan 2006). Furthermore, the cost of care continues to escalate exponentially beyond 65. It is six times more expensive to care for a person at the age of 85 than someone at 65 (Flicker, 2002). Therefore, the overall cost of care is expected to rise dramatically as the population ages, raising a significant concern around meeting long-term healthcare needs (Scott, Chowdhury, & Varghese, 2002; Christensen, Doblhammer, Rau, & Vaupel, 2009).

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<td>2. More likely to have multiple chronic conditions and co-morbidities</td>
<td>2. Higher hospitalization and mortality rates</td>
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<td>3. Higher prevalence of mental or physical disability including arthritis, fractures, vision and hearing losses</td>
<td>3. Rising disability and dependencies</td>
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<td>4. Higher burden of care and resource pressure on the healthcare delivery system</td>
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Table 1.1: Issues and implications for health of older people: prevalence of disease, disability and demands on healthcare delivery systems.
In an attempt to identify the social realities of ageing, Richardson, Weaver and Zorn (2005) explained two parallel and overlapping discourses in literature: ageing-as-a-problem and ageing-as-a-decline. The earlier paragraphs captured the rhetoric of governments across the globe that tend to describe ageing-as-a-problem and explore strategies to “cope” with this demographic “burden of dependency”, of non-productive, sicker, older consumers of resources (Blaikie, 1999). Closely related to this discourse, described by Trethewey (2001, p. 184), is a “narrative of ageing-as-decline” that defines human ageing in terms of a set of biological and physiological processes taking place in the human body with the passage of time, encouraging individuals to voice feelings of “loss, isolation and diminished resources” in relation to their ageing-life experiences. Increasing focus on lived experience and designing systems and solutions to improve the perceived reality of ageing could perhaps better serve to transform ageing as an independent, empowered and healthy experience, instead of remaining limited to disease and disability focussed approaches (Franklin & Tate, 2009).

1.1.2 Why research on medication management?

As many as 80% of people over 65 years have more than two chronic conditions and are on five to fifteen long-term medications at any given point in time (Kaufman, Kelly, Rosenberg, Anderson, & Mitchell, 2002). Out of multiple self-care tasks that an older person with chronic conditions has to perform, the proper use of prescribed medications is one of the most common, clinically relevant and complex tasks. The use of medications is also prone to risks. Medication errors are one of the commonest forms of errors (Kohn, Corrigan, & Donaldson, 2000). Errors of omission and commission in relation to medication remain an important cause of morbidity, hospitalization and mortality in older populations in New Zealand (Davis et al., 2003). Age-related changes in physiology, polypharmacy, use of high-risk medications, frequent changes in prescriptions, changes in care settings and prescribers within a fragmented healthcare system, continue to pose high risks to older people (Roughead, 1999, Berdot et al., 2009).

More knowledge is still needed about the use of medication in older people; this is a highly personalised and complex subject where generalisations can’t easily be made (Conn, Taylor, & Kelley, 1991). There is some evidence to support the effectiveness of adherence interventions on the health of older people (Haynes, McDonald, Garg, & Montague, 2002), but factors like the larger number of medications, complexity of regimen, declining cognitive abilities, and sensitivity to medications not only makes it difficult to adhere but also makes older people
prone to adverse drug events (Gurwitz et al., 2003). Interventions focussed simply on improving adherence in older people often fail to offer any significant decrease in hospitalization and mortality (Holland et al., 2008). Taking medication typically involves the use of prospective memory where an intention to perform a certain task in future is encoded with an action at an appropriate time (Park & Kidder, 1996). With erosion of memory, the intention to take medication can be supported by external cues (Haynes, et al., 2002). On the other hand, the ability to remember medication side effects, recognition of their occurrence and timely informing of the prescriber in order to optimize therapy is not easy either. Therefore, promoting quality use of medication requires a multidisciplinary approach that should ideally include not only promoting adherence but also addressing medication safety, providing motivation, building skills, and improving communication between patients and their providers (Reach, 2009). Supporting the information and communication needs of providers (about patient behaviour) at the point of care is important because collecting a complete medication history and validating this with past prescription records during infrequent brief consultations is impractical. A wider approach could have an incremental influence in improving outcomes for this vulnerable population. But existing interventions fall short of providing a multidisciplinary patient support, leaving scope for exploring innovative and holistic approaches to medication management.

1.1.3 Why self-care for older people?

While it is true that health status tends to decline with ageing, it is the ‘health status’ and not just ‘the chronological age’ that determines consumption of healthcare. Some experts believe a misplaced focus on chronological age alone could lead to erroneous estimations (Gee, 2002; Mullan, 2001). It is increasingly being realised that people in coming times are likely to be healthier and more active than each passing generation (Fogel, 2004; Helmchen, 2003) and actually consume fewer healthcare services. They will be more engaged with health and self-care than previous generations and maintain their health status in younger age (Lubitz, Cai, Kramarow, & Lentzner, 2003). An increasing motivation to keep healthy and well is likely to drive better engagement with self-care at every stage in life (Silva et al., 2010). However, despite optimism, literature also points towards significant barriers to achieve practical results.

Most importantly:

1. Community-based resources and environments that support healthy ageing need to be put in place and administered sustainably (McWilliam et al., 1999)
2. A skilled workforce should be committed for preventive services (Louderback, 2000)
3. People possess self-efficacy, motivation, skills and incentives to engage in their own health (Heidrich, 1998).

The above three interventions aim to prevent disability and reduce the risk of hospitalisation and death by improving disease management, preventing falls, preventing medication errors and improving overall functional status (Figure 1.1). However, a close and critical examination of these interventions could help one prioritise efforts. For example, building community resources requires long-term financial and policy commitments. Integrating community-based services with older people’s lifestyles, cultural diversity, family composition and belief systems is a complex process (Richard et al., 2008). Similarly, significant challenges stand in the way of building workforce capability. The healthcare workforce is not only shrinking in volumes (Zurn, Dal Poz, Stilwell, & Adams, 2004) but also ageing (Burtless & Quinn 2002). Coupled with altered dependency ratios, it simply means that there would not be enough hands available. Moreover, shifts in roles and responsibilities would occur, giving obvious priority to acute care (Wolff & Kasper, 2006). Care-giving is also a stressful task and places a significant burden on the health of the person giving care (Sisk, 2000). Hence, building community-based resources or enhancing workforce capabilities for preventive care could prove to be extremely challenging. It may therefore mean that the third option of building the capability of the person for self-care becomes the most important, promising, lasting and effective intervention.

Figure 1.1: Preventing disability, dependence, hospitalization and death in older people
Enhancing the capability of older people to engage in self-care can not only complement and reduce the burden on the healthcare delivery system or community resource, but also slow down the transition of an independent older person into a state of dependency or admission to a hospital or a rest home (Heidrich, 1998).

The researcher’s synthesis of ideas from various models of chronic care and elder care (shown in Figure 1.1) also serves an important purpose in focussing the place of self-care and medication management as the central theme of this thesis, and justifying the significance of this research within the big picture of elder care.

1.1.4 Can all older people take care of themselves?

Coulter (1999) proposes two main arguments that drive the shift towards increasing patients’ involvement in healthcare. Firstly, it is unethical for patients not to be involved in decisions about their health and, by extension, for the public not to be involved in how care is organised. Secondly, greater patient involvement may lead to greater satisfaction and, perhaps more importantly, to better health. Doctors simply cannot assume imparting instructions efficiently is the end of their responsibility (Weed 1997).

Paternalistic attitudes prevalent within current healthcare systems do not always support such an approach. Their arguments are perhaps valid in situations where healthcare decisions may be clouded by stresses and fears of illness, resulting in anxiety, dependency and a tendency for regression, thus clouding the patient’s decision-making abilities or even causing a physical inability to be able to make decisions (Rodriguez-Osorio & Dominguez-Cherit, 2008). Buchanan and Brock (1989) argue that if patients are given the ultimate responsibility for making all healthcare decisions, then their treatment choices might fail to serve their well-being, as conceived by them. Thus, the same value of patient well-being that requires patients’ participation in their own healthcare decisions might sometimes also require patients to be protected from the harmful consequences to them of their own choices (Rodriguez-Osorio & Dominguez-Cherit, 2008; Seedhouse, 2008). Healthcare system dependency is in diametric opposition to empowerment strategies, yet both can, at least in theory, be operational on the same cycle of individual aged care intervention (Seedhouse, 2008).

Having justified some situations of dependency, this thesis does not place itself in the context of hospitalized or seriously ill people. Rather, it looks at relatively healthy people living in an Aged Care Facility (ACF) and how they could enjoy a greater degree of health and well-being.
1.1.5 Empathetic and person-centric approach

The notion of person-centeredness holds at its core the idea of respecting the other person; this has been explained by Kant as an ideal model of human interaction with mutual respect and sympathetic benevolence (Richards, 1981; Williams & Grant, 1998). While deciding upon a treatment choice or a long-term care plan, the healthcare provider (as an upholder of scientific knowledge carrying ‘perceived responsibility’ of care) would ideally attempt to appreciate and address the ‘recipient’s values and perceptions’ in order to negotiate a mutually agreeable and practical plan. Such ideal communications can happen only in an environment of empathy and mutual respect.

Empathy is defined by Mead (1967) as the “capacity to take the role of the other and to adopt alternative perspectives vis-à-vis oneself” and by Hogan (1969) as the ability to take “the intellectual or imaginative apprehension of another’s condition or state of mind” (Hogan, 1969). Empathy functions as the glue between two people in a mutually respectful interaction and as a cognitive and communicative resource for inter-subjective alignment (Martinovsky, 2006). Being able to take the role of the ‘empathizer’ and the ‘empathee’ is an essential characteristic of the empathetic communication. To exchange empathy, spoken and unspoken language becomes a medium. An empathetic dialogue functions as a tool for collective thinking, verification and focus, in an interpersonal context (Martinovsky, 2006).

One often misses to note that exchange of empathy essentially is bidirectional. It not only requires the provider to be empathetic towards the recipient of healthcare, but also the recipient to express empathy towards the provider. However, it is difficult to empathise if one does not know, understand or become familiar with or relate to another person’s context. Healthcare is the perfect example of alienation for a patient navigating through its complexities. Patients often find it difficult to relate to healthcare providers and develop an empathetic relationship. Standing on a perceptually biased and tilted scale, the values of provider-based empathy look logical, but patient-based empathy towards the healthcare system or the provider seems incongruent. Perhaps this empathetic incompatibility explains deeply ingrained biases in the modern healthcare delivery framework, where tilted scales of empathy are not even seen as tilted.
1.1.6 Information technology and empowerment

An unfulfilled need for the ability to empathise with the healthcare system could be frustrating and might underlie increasing utilisation of external channels of information (e.g. the internet), or seeking personal advocacy and ‘empathetic support’ from peers, motivating and encouraging people to share responsibility of care through social media. Acquisition of knowledge and effective support often helps patients to develop their cognitive and emotive capacity. Once people have the capacity to appreciate the complexities of the ‘once alien’ domain of healthcare, they then gain the capacity to enter into an empathetic communication with the healthcare system and provider. This straightening of tilted scales is probably the new revolution of person-centric healthcare – which could soon become a misnomer, for it appears to tilt the scales in the opposite direction. For the time being, it seems to suggest radical and disruptive shifts in power from the hands of those who give care into the hands of those who receive it, leading to greater empowerment and equality in the relationship (Berwick, 2009).

The development of empathy as an internal resource that provides lay people with the cognitive and emotive capacity to empathise and collaborate can be a part of the empowerment process. For example, information tools or systems provide information, education, feedback and social network while assisting with personal limitations. Unsurprisingly, person-centric care is a common theme in the literature on health informatics as a tool to facilitate a person’s capacity to engage with their own health and with healthcare system (Gibbons, Samal, Lehmann, 2011).

Developed with an understanding of the power balance, the technologies supporting self-management of complex self-care tasks are most likely to be aligned with the rapid evolutionary and revolutionary changes in healthcare systems in the immediate future. This thesis puts forward the concept of empowering technologies (you will gain capacity) as its primary focus, and it philosophically challenges the prevalent ‘implicit ideologies’ behind terms like assistive (I will help you) technologies, monitoring (I will keep an eye on you) technologies, and persuasive (I will ensure that you comply) technologies that tend to carry forward the notion of tilted power scales. Such a bold statement could sound naïve in current times but may very well receive wider recognition in times to come.
1.1.7 Technology for elder care

Faced with a diminishing number of healthcare professionals, caregivers and people available to provide useful companionship to the older people (Grundy, 2003), there is a growing demand for solutions for performing automated tasks (Leveille et al., 1998). A large share of the focus is on support systems aimed at promoting ‘ageing in place’ (Brownsell, Bradley, & Porteus, 2003). These efforts are aimed at facilitating independent living in one’s own home for as long as possible and reducing the burden on institutional care. For those requiring institutional support, enabling them to live in aged care facilities (ACFs) with minimal human dependence for routine tasks and activities is desirable (Gibson, 1998).

However, there are multiple compelling arguments to explore wider potential of technology, especially information technology, in the context of elder care. Firstly, the demographic imbalance and expected shortage of healthcare providers to support the ‘silver tsunami’ justifies exploring some form of automation and capability extension, so that smaller numbers of professionals become more productive (Nguyen, Carrieri-Kohlman, Rankin, Slaughter, & Stulbarg, 2004). In the face of constraints on funding and staffing, innovative and cost-effective solutions involving automation are particularly attractive. A wide variety of new healthcare concepts for supporting and assisting users in technology-enhanced home environments have emerged in the last decade or so. The spectrum of emerging technical applications covers a broad variety of developments, reaching from implants for monitoring physiological signals over devices integrated into clothes, to healthcare robots or smart home technologies which support older people in keeping up their independent life at home (Magnusson, Hanson, & Borg, 2004). These innovative smart healthcare technologies promise to deliver significant improvements in access and quality of care, and the efficiency of the health sector. In order to reach a high degree of user acceptance, it’s not only the technical and engineering parts that are of importance but also the human aspects of these technologies and the user’s criteria regarding privacy, dignity and useful medical technologies (Ziefle 2010). Although there are still many unknowns, some home monitoring and tele-health technologies seem to have demonstrated in multiple Randomised Controlled Trials that they are acceptable and effective tools to help people manage their chronic conditions better and reduce the burden on the healthcare system while saving costs (Gaikwad & Warren, 2009). In this context, technology can be seen as a potential solution to avoid, delay or defer ‘dependence’ and support ‘ageing in place’ (Gurley & Norcio, 2009).
1.1.8 Usability of computers for older people

Older people could be enabled to engage in self-care by support in understanding and managing their needs and motivating themselves to take charge. Moreover, convenient sharing of useful and usable information on demand may in time help both providers and receivers of care to optimize resources (Brett, Lee, & Sorhaindo, 1997). “New technologies are for kids and grandkids, not for grandma and grandpa” was a popular myth about older people until recently. While it may be true that older adults take longer to learn, are slower to adapt, and experience greater difficulty in managing sensory limitations, that need not alienate them on the other side of the digital divide. For example, 40% of people over 65 years were already using computers in 2002, and more than 35% of them were accessing the internet (Czaja & Lee, 2001). Similarly in 2004, 13-17% of the nation’s total internet users, so called ‘silver surfers’ were comprised of people over 65 years of age in Australia, UK, Europe and Canada (Burdick & Kwon, 2004). The number of older people using a variety of information technology applications is expected to have increased steadily since then (Wagner, Hassanein, & Head, 2010).

For effective use of computers and information technology, people need to learn and acquire complex skills significant to cognitive and psychomotor abilities (Sayago & Blat, 2010). Common limitations for an effective use of information technology faced by older people include sensory (visual/auditory) deficits, cognitive and perceptual difficulties in understanding, remembering and executing complex tasks, and motor difficulties due to lack of coordination or arthritis that prevent effective use of mouse and keyboard (Hancock, Fisk, & Rogers, 2001; Sayago & Blat, 2010). However, researchers (Czaja et al., 2006; Hancock, et al., 2001) suggest that proper training coupled with adequate system design can lead to dramatic increases in system usage accuracy by most older users. Melenhorst (2002) found another striking characteristic of older users on both sides of the Atlantic when she analysed data from the US and Netherlands, where neither usability, cost nor difficulty mattered if the people perceived clear benefit in using the computers. They were willing to invest time, resources and money once they realised the benefits in using computers for themselves. Hence, there are significant benefits in making interfaces useful, usable, meaningful, assessable, rewarding and fun for everyone, including older adults (Pew, 2002). Technological interaction with a robotic form could be one such opportunity worth exploring.
1.1.9 Robots in elder care

As the software and hardware capabilities progress and we learn more about interactivity, we may begin to see science fiction becoming a reality in everyday life. Interactions with a computer and with a robot are dramatically different, and scientists have learnt that robots are capable of delivering a far more powerful experience. Present generations have seen the evolution of computers change our lifestyles and the way we work and live. It is up to the current generation of scientists to learn the best ways of designing a useful and relevant application of robots that fits appropriately with our lives as humans, not the other way around.

It may be useful to briefly trace the salient features of the evolution of human computer interaction to build a background for the arguments presented later. Before the advent of personal computers, paper-based instructions (e.g. prescriptions, educational booklets, drug monographs) were the only way to share clinical information between providers and consumers. During the early days of programming languages and user interface (UI) development, Shneiderman (1980) presented the idea of computer instructions and guidelines for displaying information by direct manipulation and video displays. The idea that a computer can display useful information that the user can interact with found rapid acceptance. In the late ’80s and early ’90s, Pattie Maes (1990) presented the idea of a computer or software program as an agent that can help the user to navigate through information in contrast to direct manipulation. The concept was further extended and rapidly evolved to include concepts from complex artificial intelligence and social interactions to assume more complex behaviours. The concepts that gained wider acceptance are *conversational agent* (Hayes & Reddy, 1983), where a computer was envisaged to engage in conversation with the user, *relational agents* (Bickmore & Cassell, 2001) using animated avatars that could form relationships with humans, and the concept of *embodied agents* (Brave, Nass, & Hutchinson, 2005) where the computer represented a form (such as a robot) and had the capacity for emotional interaction. The application of a robot as an embodied conversational agent in complex human-like social interactions gave rise to the concept of social robotics (del Moral, Pardo, & Angulo. 2009). Figure 1.2 summarises the evolution of the concept of agent and robots.

![Figure 1.2: The evolution of human computer interaction - technological trends on a continuum.](image-url)
Reeves and Nass (1996) explained how the evolutionary trend in technological interfaces could begin to express social cues in their interaction with humans and begin to be perceived as more human-like. This idea moved tangentially away from traditional Human Computer Interaction studies to design that was useful for and usable with computer interfaces. This theme was further developed at the Massachusetts Institute of Technology (MIT), where Cynthia Breazeal in her thesis of 2000, and using an expressive robotic face named Kismet, argued a case for social cues generated by robots. She proposed an alternative way of communicating with machines and called it a ‘sociable robot’, capable of engaging humans in natural social exchanges. She later went on to compare a standard computer interface (an animated avatar on the computer screen) with an actual robot to explore how the persuasive nature of anthropomorphic communication can contribute towards altering human behaviour (Breazeal 2000). Comparing a physical robot, an animated avatar and a human (Figure 1.3), researchers found the behavioural and social response of a physical robot closest to a human. The researchers went on to explore the value of physical presence as compared to virtual animation or video. The robot’s actuality improves both credibility and engagement with information presented (Kidd, 2003).

Therefore, there is reason to believe that a robot can be a more effective mechanism for carrying and conveying a longer term behavioural change intervention than traditional computer interfaces (Kidd & Breazeal, 2008). The rapidly advancing field of Human Robot Interaction (HRI) and social robotics is discovering the value of gestures, form, functionality and features during an interaction.

The concept of social robotics in elder care is not new (Bemelmans, Gelderblom, Jonker, & Witte, 2011; Oborn, Barrett, & Darzi, 2011). Initial efforts were made by Martha Pollack et al. (2003a) where they tested a ‘Nursebot’ named ‘Pearl’ to assist older people with their day-to-day activities. Similarly, multiple experiments elsewhere have been conducted using animal robots to provoke an affective reaction in older people, as reviewed by Broekens, Heerink, &
Rosendal, (2009). Cory Kidd, again from MIT, extended the concept in 2008 to include people, devices and other conventions as the larger network of social interaction over a long term while testing its capability to help people lose weight. He coined a term ‘sociable robot system’ in his PhD thesis (Kidd & Breazeal, 2008). Such research projects do contribute to a deeper understanding of HRI and also offer some relevance to serious healthcare functions.

The idea of robots playing a role in healthcare has been proposed for more than a decade and has mainly been developed for rehabilitation as well as personal assistance for the activities of daily living; however, robotic applications supporting social behaviour are a more recent development (Butter et al., 2008). Marti, Bacigalupo, Giusti, Mennecozzi, & Shibata. (2006) describe socially assistive robots (SAR) as being capable of mediating social interaction, designed to engage people in experiences stimulated by the physical, emotional and behavioural characteristics of the robot and not merely for service automation. In a recent review of literature around social robotics and healthcare, Bemelmans et al. (2011) explored the contribution of robotics for rationalising, maintaining or improving the quality of care against a backdrop of a dwindling healthcare workforce. They suggest the possibility of robots contributing to healthcare support in terms of capacity, quality (performing very accurately and task specific), finance (supporting or even adopting tasks of trained personnel) and experience (increasing feelings of autonomy and self-management).

This thesis attempts to explore the concept of a social robot, in relation to the process of medication management, within the context of elder care, as guided by the philosophical concept of user empowerment and person-centred care, and to evaluate its relevance and document the lessons learnt along this exciting research journey.
1.2 Research process

1.2.1 Identifying the research gaps

It is useful for research to identify gaps within the literature and attempt to answer them for the advancement of collective understanding. Three research gaps have been identified that are further explained below. Firstly, a theoretical understanding of healthcare technology for older people; secondly, the application of social robotics in real life clinical problem solving; and finally, developing a holistic solution to the management of medication as a self-care task performed by the elderly.

Table 1.2: Summary of research gaps identified in the literature

<table>
<thead>
<tr>
<th>Developing theoretical understanding of use of self-care technology by older people</th>
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<tbody>
<tr>
<td>• Dynamic relationship between human ageing and support technology</td>
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<tr>
<td>• Socially situated interactions and impact on wider support network</td>
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<tr>
<th>Understanding application of Robots to enable self-management</th>
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<tr>
<td>• Supporting self-management of chronic conditions, and medications in particular</td>
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<tr>
<td>• Learning from exposure to older people in real-world scenario</td>
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<tr>
<td>• Matching behavior &amp; functionality with a trusting relationship</td>
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<tr>
<th>Medication management related research gaps</th>
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<tbody>
<tr>
<td>• Improving informed prescribing</td>
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<tr>
<td>• Medication management as a closed loop systems</td>
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<tr>
<td>• Invoking patient participation</td>
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1.2.1.1 Theoretical understanding of use of self-care technology by older people

Burdick & Kwon (2004) in their textbook on ‘Gerontechnology’ suggest that a comprehensive theoretical approach for understanding the dynamic relationship between human ageing and healthcare support technology is still to be developed. Tensions were also identified between an independent, emancipated social context, person-centred delivery of healthcare, acquisition and maintenance of cognitive and emotive skills and successful engagement with self-care over the long term. However, there is a paucity of literature that binds together in a synthetic whole the themes of usability, acceptability and generalisation of self-care tools in order to support elder user empowerment, participation and collaboration with the wider healthcare system. Technology usage to support older people with self-care tasks in the milieu of an evolving social context has received little attention (Burdick & Kwon, 2004, p 54-58).
The value of relationships with care providers in light of the social complexities of old age are often ignored while proposing technology-driven solutions (Joyce & Loe, 2010; Lindley, Harper, & Sellen, 2008). It may be possible to design applications according to medical needs, but a deeper understanding of personally assigned meanings, values and perceptions is equally important if such technology is to become part of the everyday life of an older person. The literature on applications that cover a wider range of socially situated, personally engaging healthcare interactions is still in its infancy (Dix, 2010). It is difficult to make assumptions that could be generalized, especially to those with some cognitive and physical limitations.

1.2.1.2 Robots for enabling ‘self-care for older people’ research gaps

Engaging with healthcare as well as self-care is not always a pleasant experience (Hirsch et al., 2000). A task that reminds a person every day of how unwell he/she is will be hard to be seen as enjoyable. Therefore, presenting healthcare tasks mingled with fun or social interactions could be one way of overcoming a part of this challenge (Sundance Institute, 2012). However, these possibilities are yet to be converted into real applications and tested in real scenarios. The importance of attending to the psychological aspects of people-robot interaction (to avoid only meeting the functional needs of users) has been highlighted (Magnusson, et al., 2004). However, most of the studies have been small-sized studies exploring design requirements. ‘Robotherapy and robopsychology’ type studies have attempted to study older people’s perceptions and communication with robots and robotic creatures, such as a pet seal or a cat, which act as companions for older people and provide positive stimulation for isolated older people and/or elders with cognitive disabilities (Broekens, et al., 2009). In clinical terms, the placebo effect of robots without actual health related intervention lends very little to developing an understanding of applications for supporting the hypothesis about the capability of robots to influence the core of health outcomes.

There has been some work done in social robotics and conversational agents for engaging people with self-care (Kidd & Breazeal, 2008, Bickmore, Puskar, Schlenk, Pfeifer, & Sereika, 2010) but these studies bear little relevance in the context of the multifaceted nature of chronic condition management, situated within the real world complexities of the wider social context of self-care. Also, the subjects tested have been younger cohorts, so the responses of older people to similar stimuli in residential care or independent living in the real world have yet to be fully answered. More recently, the concept of applying robot companions to assist older people with medication-related self-care tasks is being explored (Evers & Kröse, 2010). However, the testing conditions were limited to controlled environments of specially designed
homes, limiting applicability to independently living older people. Moreover, at the time of writing this thesis, it remains a hypothesis, with unknown implications for a real world scenario.

Building a therapeutic relationship between machine and human is a highly ambitious goal. Reeves & Nass (1996) have explored the concept of computers as social actors and the importance of trust as a significant part of accepting technology in day-to-day life. To build that trust, a very sophisticated human-like social behaviour is required. Bruemmer et.al (2005) argue that highly autonomous robotic behaviours and complex artificial intelligence (AI) models to design human robot interaction do not necessarily provide an additional advantage or performance benefit. Instead, they carry a risk of being perceived as ‘pretending to be smart’, thereby provoking user distrust and confusion. There is a need to balance a trusting relationship and accuracy of communication with the behaviours and functionalities of a machine, which remains to be accomplished in the field of self-care task automation.

1.2.1.3 Medication management research gap

Medication management is a complex task (Agrawal, 2009) and its applications in community settings are still in their infancy. It involves multiple professionals, informed prescribing (by doctors) and dispensing (by pharmacists), and ensuring proper administration (by nurses, caregivers or self). Though recent advances in information technology have shown significant bridging of information gaps by implementing a closed-loop system, the effort still remains focussed within hospitals (Agrawal, 2009; Franklin, O’Grady, Donyai, Jacklin, & Barber, 2007). Quality use of medications in the community is not just about adhering and complying with the help of reminders, but also about collaboration and informed decision-making. What older people desire from a medication management system is known, but a practical solution to meet those needs is yet to materialise in a safe and reliable way (Lee, Bien, Mokhtari, Kim 2009). There seems to be potential for further learning particularly in three areas, namely informed prescribing, making medication management a closed-loop system and invoking patient participation.

1.2.1.4 Informed prescribing

In addition to information about diseases and medications, it is equally important for the prescriber to know precisely how the patient has been using and responding to medications, any concurrent use of over the counter (OTC) medications, nutritional supplements, and any problem or issue that the patient has with his/her medications. The physician is also responsible
for timely detection of adverse drug events and the overall effect on the patient’s quality of life and other co-morbidities. Though this is the domain of the prescriber, sharing information is the patient’s role. A prescriber cannot know the finer nuances of medication use or misuse, the patient’s beliefs and expectations and the response to treatment unless the patient chooses to disclose and share relevant information. There is a paucity of research on tools that fill this information gap and assess the impact of such intervention on the prescribing behaviour of physicians.

1.2.1.5 Making medication management a closed-loop system

When medications, the healthcare setting and prescribers frequently change (as is often the case for older people), it is difficult to keep track of all current medications. Older patients may fail to monitor medication prescribed by different prescribers or cope with the complexity of the regimen. Taking medication that should have been stopped, duplicating medications or missing the right medication in the right manner is common (Corsonello et al., 2009; Patterson et al., 2002). An ideal medication management system is envisaged to be a closed-loop system which bridges the information gaps between patients and their providers (Gurwitz & Rochon, 2002). The prevailing flow of information is often one way, from physicians to pharmacists, and to the caregiver/family member and/or older person (Figure 1.4). Physicians often do not know what has been dispensed and administered unless the pharmacist, caregiver or the patient goes back to them with questions or information (Mark Monane, Matthias, Nagle, & Kelly, 1998).

![Open-loop medication management system](image)

Figure 1.4: Open-loop medication management system

An ideal medication management system would be a closed-loop system (Figure 1.5), where each actor in the chain is receiving and sharing information with each other for safe and effective medication management (Gurwitz & Rochon, 2002). The physician would know what has been dispensed and how it has been administered, older persons and their family members and caregivers would know what has been prescribed and changed in the prescription, and the pharmacist would have all the information available for effective medication reconciliation, irrespective of the patient’s setting. Such a system could contribute greatly to the quality use of
medication and reduce or detect promptly any medication errors (Datta, Yang, Tiwari, Kuo, and MacDonald, 2011).

![Diagram of closed-loop medication management system]

However, in reality, each actor in this scenario works in his/her silo of information. The physicians use their electronic health records to generate prescriptions, pharmacists use their pharmacy management system to process dispensing and refilling, while caregivers and older patients rarely use any system pertaining to medications. In the hospital setting, interoperable systems have recently been introduced to track and flag information flows between doctors and pharmacists (Agrawal, 2009; Franklin, et al., 2007), but there exists little research to demonstrate information across actors bi-directionally to close the loop in the community. There is a great need for developing and testing systems that enable this information flow – a research gap with high clinical relevance that this thesis aims to address.

### 1.2.1.6 Invoking patient participation in medication management

Proper use of medications is often considered key to successful ageing (M. Monane, Monane, & Semla, 1997). It is not only about taking medications as prescribed but also personalisation of medications by decoding and calendaring of complex regimens, setting up reminder cues and fitting in with the person’s lifestyle and routines (Chrischilles et al., 1992). Older people face challenges in completing various tasks related to self-management of medication; for example, obtaining prescriptions, refills, coping with changes (doctors, pharmacies, settings of care, medications, doses, brands), coping with complex regimens, short-term upsets in routine (travel, hospitalisation, an acute episode requiring new medications), as well as varying cognitive capabilities, as most older people have good phases and rough patches at different times. Patients need to be encouraged to have a discussion about these issues with their physicians and agree on the safest and most practical solutions (Berry, Michas, Gillie,
Forster, 1997). Such engagement requires the ability to negotiate during the consultation and knowledge about and understanding of medications.

There is still little known about what people do with their medications in their everyday life, how older people use them, assign meaning to them, and make them a part of their everyday routine (Barat, Andreasen, & Damsgaard, 2001). Unless some of these fundamental insights are gained, the attempts to improve the use of medications will remain limited. The interventions that assist people to manage their medications could be more effectively designed if research is focussed towards understanding how older people’s capability to handle the tasks and challenges related to medication management could be improved.

1.2.2 Research to narrow the gaps

Many of the problems and research gaps identified earlier are large scale systemic issues that are being researched globally. It would be an ambitious proposition to address all of them within these limited resources, but it is possible to identify significant yet manageable areas to direct research efforts to that can contribute to the larger body of knowledge.

1.2.2.1 Developing a theoretical understanding

Responding to the first research gap, an attempt was made towards understanding the dynamic relationship between the theory and practice of person-centred healthcare in the context of older people and medication management. In order to build a comprehensive theoretical framework, social scientists have utilised systematic methods to give a concrete shape to the researcher’s immersive experience in the context of the research area. A similar approach would be required to decipher deeper issues and philosophical insights to inform elements of a theory of automating medication management for older people.

1.2.2.2 Developing and testing a module on a social robot

In order to achieve a balance between a trusting relationship and accuracy of communication with the behaviours and functionalities of a machine, it would be futile and perhaps risky to replace a human care provider totally with a machine. Possibly at this point in time the best use of a computing device would be to store and exchange information, while allowing humans within the medication loop to enrich relationships around this information. Therefore, instead of attempting highly complex artificial intelligence applications, a simple application enabling social networking was considered to be safer, cheaper and more reliable. A mixed initiative interface would be most useful if it could simplify interactions, hide complexity, and keep users in control to cover the majority of scenarios in a cost-effective and practical manner. The
researcher proposed to develop such a module and put it through usability and feasibility testing within real life conditions. This was accomplished by working within a larger, multidisciplinary team involving healthcare specialists, software and robotic engineers, psychologists, and HRI experts. It was eventually intended to allow participants to handle the robot independently, in a real world situation, and to assess its implications.

1.2.2.3 Developing a closed-loop medication management system

It is known that at least one in five elderly people continues to receive inappropriately prescribed medication (Zhan et al., 2001); therefore, without denying the importance of adherence, it is worth questioning a drive for improving adherence without addressing appropriateness and safety of prescribed medications. The literature to bridge this important information gap is thin, and clarification is needed as to whether the association between higher incidence of medication-related morbidity and mortality is due to ‘poor adherence’, *or* to ‘good adherence to inappropriate prescription’ *or* to ‘errors in medication use’?

In this light it was considered useful to design features that could help researchers better understand the phenomenon of non-adherence to self-care tasks in older populations. Figure 1.6 explains an assistive information system to be designed that facilitates older people to safely and correctly self-administer and manage their medications. During such activities, some challenges and behaviours would be encountered that may be plotted to discover patterns. A meta-understanding of these patterns could in turn inform the larger healthcare system about the use of medications by the elderly. Relatively minor interactions on the ground could help researchers gather valuable information to discover patterns and issues which could consequently inform healthcare providers, drug manufacturers, and even policymakers.

![Figure 1.6: From fine grained data to informing system change.](image)
The proposed tool could be a potential platform to achieve this dual synergistic benefit for the older person, as well as for the wider healthcare system. The information about the nature of medication use and why people do what they do, as well as how they behave or their experience at the actual point of medication intake, is of common interest to prescribers as well as to researchers.

1.3 Thesis domain

This research explores the intersection of three large and important research domains. Elder care, medication management and social robotics are, in themselves, a specialty; yet there is a rapidly growing body of knowledge that informs the intersection between eldercare and social robotics (Bemelmans et al., 2011, Hirsch et al., 2000). Similarly, eldercare and medication management is another important intersection, looking at safety and quality use of medication in the elderly (George, Elliott, & Stewart, 2008). Not much is currently known about social robots and medication; however, other healthcare applications of a social robot are being envisaged and experimented in laboratory situations (Evers & Kröse, 2010). This thesis explores the intersection of elder care, social robotics and medication management (Figure 1.7) to direct the focus of the research process towards a high risk group, by using a rapidly evolving technology in an area of high clinical relevance.

Figure 1.7: Thesis domain – The intersection between eldercare, social robotics and medication management
While exploring common ground for these three domains in a real world situation, the research poses specific questions and seeks answer to them. On a broader level, the research intends to discover the issues and problems around medications faced by older people, specifically those living within an (ACF). It would also be interesting to explore the value proposition of, and challenges in, developing and deploying such a solution

1.3.1 Research questions

The two research questions raised in this thesis were:

1. What is the theory underpinning appropriate design of technology to enable older people to better manage their medications?
2. Can an automated medication management solution be developed successfully on a robot while being informed by the theory of automated medication assistance?

1.3.2 Research objectives

The specific objectives of the research outlined in this thesis were:

1. To understand the context of an aged care facility in New Zealand and the healthcare setting within which a robotic medication management support system would function, and determine the feasibility of implementing such a system.
2. To review the literature assessing the best practices in human computer interaction for older people, automated dialogues in healthcare, and issues around quality use of medications.
3. To collaboratively design and develop an application that would integrate with the residential ACF environment as well as with the wider healthcare system.
4. To investigate the views, perceived values, and performance of older users while simultaneously using the designed application to explore the impact it could make on the clinical workflows, decision-making, and quality of care provided by healthcare providers.
5. To inform the commercial development of the solution and justify funding for this research.
1.3.3 Hypotheses

The major hypotheses tested were:

1. The use of technology by older people to self-manage their health can be explained better by developing a theoretical construct.
2. An Information and Communications Technology (ICT) application can successfully be designed to balance theoretical and practical implications for self-care tasks in older adults who are around or over 80 years of age.
3. These older adults can use such an application to manage their medications and would see value in such a proposition.
4. Hosting of interrelated modules on a social robot has an additional utility, ‘beyond simply providing reminders’ that enriches the value of medication management application.

1.3.4 The structure of the thesis

As this thesis ventures into a less researched, innovative domain, it is principally devoted to describing the space, scope, features, inter-dependencies and feasibility testing as well as the type of system pertinent to the context of independently living older people in an ACF. There are two main sections in this thesis that cover the journey from discovering the research space to arriving at a fully functional, independently deployable application.

The first section (Chapters 2 and 3) describes the research methodologies and the research environment. The environment means the personal, social and healthcare environment within which a robotic self-care support system would be implemented with specific reference to medication management. It briefly covers the ACF scenario where people are living independently, and the medication prescribing, dispensing and administering routines to dependent (on caregiver support) and independent residents. This draws the boundaries of the canvas which later would be used to paint the research journey.

The second section (Chapters 4-7) unfolds the story of the research process in four iterative cycles of designing an application following Action Research (AR) methodology. AR is a four step cyclical process of ‘Plan – Act – Evaluate – Reflect’. These steps define and describe the process of prototype development and testing. Informed by the context in Chapter 3, Chapter 4 describes how a paper prototype to inform the design direction was arrived at. Chapters 5-7 cover the journey of converting the requirements into software specifications, collaborating
with software development and testing the usability of an initial prototype. The first usability testing was done during single interaction (Chapter 5), then changes in usability and performance over multiple interactions in supervised settings were observed (Chapter 6), and finally users were left alone with the apparatus in relatively unsupervised settings (Chapter 7). The interactions progressed from single use to continuous use by the participants over four stages of iteration. The location of interaction progressed from social space to personal space and from researcher-assisted to independent handling of the robot over subsequent cycles.

The system developed during this research would be referred to as two inter-related terms. The term ‘robot’ comes from the Czech term ‘robota’ meaning compulsory labour and is often referred to as a machine that may (or may not) look or act like a human but performs complex repetitive tasks automatically. In this thesis ‘robot’ refers to specific machines that were acquired by the research team and are described later. The term ‘automated medication assistant’ refers to a computerised system (such as a robot) presenting itself as an agent to assist an older person with his/her medications, whereas the term ‘medication management module’ refers to the software system that enables the handling and exchange of medication-related information, as well as enabling user interaction (through the touch screen). The term ‘dialogue’ refers to information or questions presented in written or spoken format by the machine to a human user, often inviting him/her to indicate their response by choosing an option from the menu of choices.

Before starting the research process, it was important to clearly define the research direction – the research questions. Appropriate methodologies to address those questions and an appropriate environment in which to conduct research were also defined. The description in the following chapters starts from defining a research background and methodologies and leads on to the description of the process by which an amorphous idea was converted into a concrete solution.
1.4 Chapter summary

The ageing of populations and the increasing burden of care bear important implications for healthcare delivery. Interventions addressing issues at community level could be more appropriate and cost effective in reducing the impact on the healthcare system as well as improving overall levels of health and productivity in the silver years. Self-care is an important part of the overall healthcare delivery system. Medication management is a significant component of self-care tasks and has been shown to improve health status and clinical outcomes. The pivotal function played by technology in enabling self-care will continue to evolve and be refined and may find a central place in healthcare, as well as eldercare of the future. Despite their limitations, older adults can be supported to gain enough cognitive and emotive capability to develop empathy, partnership and collaboration with healthcare providers, so that a waning sense of vulnerability lessens their dependence on the healthcare system. There are many interesting ICT applications currently being proposed but significant limitations continue to exist. Social robotics can be explored as options, but we still do not know the best applications in the context of self-care for the elderly.

This chapter presented the background for research, identified research gaps and proposed a strategy to close some of those gaps. It also outlined the research journey that would describe the process of finding answers to the research questions in the rest of this thesis. The next chapter will explain the methodologies chosen to pursue these questions and present their rationale.
Chapter 2: Methodology

2.1 Introduction

Finding answers to the two research questions needed a suitable methodology and relevant tools. Taking existing solutions like a pill box and wiring it to a robot could have been a possible subject for a clinical trial, but it would not have been the best way to answer the research questions. Medication management for the elderly is a complex and clinically sensitive problem to solve and difficult to penetrate given the high risk of exposing study participants to an unproven intervention. The complexity and sensitivity of the problem could be one reason for less enthusiasm in scientific circles from both the engineering and healthcare domains to develop an automated medication management assistant. Taking a fresh look at the ground situation and developing ideas guided by ground realities was expected to reveal fresh insights that could inform and enrich the theory and practice of developing interventions in such situations.

This chapter outlines the research philosophy, justifies methodological choices, and explains the epistemological stance relevant to the research questions. It also describes the interdisciplinary research teams and the test bed of an ACF situated within the broader context of the New Zealand healthcare system before explaining the research design and data collection methods. The chapter ends with identifying the limitations of methodologies used.

2.2 Rationale for research into the personal activities of elders

The research questions (especially the first question) demanded a closer look at the reality of older people and how they manage themselves within their current living conditions, with a view to discovering the best ways of using (or not using) technology to assist them. This chapter explains further why the seemingly straightforward self-care task of taking medications has its bearings in a complex environment, determined by the country’s healthcare system, people involved in the medication processes (multiple prescribers, pharmacists, caregivers), and the personal and professional relationships of the person. The variables of the cognitive, psychomotor and affective capacities of a person dynamically change with ageing, health status and living arrangements. In addition, people’s perceptions and subjective interpretations of how they assign meaning to medications or to a piece of assistive technology would add another layer of subjectivity. In these situations, deriving assumptions about the nature of reality using a ‘deductive approach’ may not be ideal.
Synthesising information while exploring a delicate yet complex social phenomenon requires an interpretive approach rather than a positivist or critical approach (Checkland, 1999). In this study, the researcher closely observed and developed a deep understanding of the context first and allowed the situational information to guide his thinking, design and development. The efforts were aimed at developing insights into how older people and their care providers handle self-care tasks, especially medications through “prescription, dispensing, usage, periodic evaluation and refilling” cycles. With a desire to learn about the information gaps, information flows, interactions, potential for medication errors and possible solutions, a wider social context was used. There was an intention to understand the implications of introducing a technological intervention within a real world situation instead of looking at medication use as an isolated phenomenon and presenting a solution divorced from users’ realities. The interpretive approach to understanding the social and personal realities of people fitted well with the study objectives to find realistic, useful, practical and appropriate solutions for them (Klein & Myers, 1999). Understanding social reality from the point of view of the elderly, observing the work flows and needs of service stakeholders, while taking the value position of improving quality and safety, were considerations on the ground. The study attempted to understand phenomena through assessing meanings that participants assigned to them, understanding subjective meanings attached to social action (including a robot) and constructing interpretations and direct, meaningful actions (Neuman, 2002). It is also worth noting that the human mind is not only a product of interaction with people but also with technology (Kaptelinin & Nardi, 2009), making the case for exploring people’s relationship with technology and the way it is implemented.

2.3 An interpretive research approach

The purpose of research being the acquisition of knowledge and an effort to separate the truth from a belief, the researcher is often faced with the question: What exactly is knowledge, how do we know what we know? Epistemology is a branch of study that attempts to cover this philosophical domain. Chua (1986) gives a description of epistemologies as interpretive, positive and critical. Interpretivists attempt to gain insights through discovering meanings by improving their comprehension of the whole. Positivism asserts that the only authentic knowledge is that which is based on sense, experience and positive verification, whilst critical theory denounces entrapment in domination and encourages self-reflective knowledge to understand and explain social phenomena (Chua, 1986).
The interpretive approach lends itself to understanding the reality of the situation and helps the researcher to derive an understanding of context through social constructs such as language, consciousness, shared meaning, documents, tools and other artefacts without attempting to impose preconceptions. Keynes (1936) argues in favour of an interpretive approach, pointing towards the limited understanding of reality gained through positivist deductive and quantitative approaches, which bypass the richness of multidimensional real life situations that are subjective, dynamic and variable. ‘Reality’ for the qualitative researcher is a ‘construction’ and understanding different perspectives is more important than erasing them (Goles & Hirschheim, 2000). A scientific enquiry from a positivist stance considers reductionism, repeatability and refutation of unfounded belief to establish the validity of acquired knowledge (Oquist 1978), whereas interpretive researchers respect saturation, triangulation and transferability of acquired knowledge in dynamic social situations that defy objective measurement (Kuper, Lingard, & Levinson, 2008). *Saturation* occurs when the collection of data stops providing new insights, or when more data does not add value to the data already collected; *triangulation* reflects coherence of information from multiple sources which seems to corroborate each other; and *transferability* allows observations in one setting to be applicable to another, the validity of which is left to the readers to assess (Kuper et al., 2008).

The knowledge is acquired using certain tools and techniques (methods) following specific methodologies and is then used to explain the nature of the phenomenon (domain ontology). Interpretive research is often synonymously used with qualitative research, despite them representing different connotations. Strauss and Corbin (Strauss & Corbin, 1998) give a very broad definition of qualitative research as “any type of research that produces findings not arrived at by statistical procedures or other methods of quantification”. On the other hand, Denzin & Lincoln (2000) consider qualitative research as a situated activity that locates the observer in the world and turns the world into a series of representations, using a wide variety of interrelated interpretive practices like field notes, interviews, and observations and so on. Understanding that the reality can never be captured independent of the researcher’s interpretation, they equate the qualitative researcher with a “bricoleur” or a quilt maker, who gathers “patches” (of reality), uses his craft (of subjective interpretation) and deploys a variety of methods to weave a meaningful story that pushes the boundaries of knowledge. Often, it is not possible to comprehend the entire design and its implications when we apply it to real life scenarios; it requires learning from the mistakes and inadequacies of the work and refining the approach (Baskerville, 1999).
2.4 Research design

This section describes the methodologies that informed the research process and justifies the rationale for their choice. Primarily, the research followed the iterative approach of learning and refining ideas iteratively following the action research approach, but also used principles of participatory design to bring appropriateness to the context as well as grounded theory to analyse data and derive theoretical implications to bring rigour to the research process. The synergy between the three methodologies complementing each other is also explained.

2.4.1 Action research (AR) and empowerment as impetus behind change

Action research is a proposed research methodology out of Kurt Lewin’s work in the early part of the twentieth century to bring about social change (Checkland & Holwell, 2007). Action research has been described as a technique characterised by intervention experiments that operate on problems or questions perceived by practitioners within a particular context (Baskerville, 1999), where researchers and people in the situation collaborate in a process of critical inquiry, focussing on the wider social context and following a deliberate process of reflective learning (Argyris, Putnam, & Smith, 1985). Susman and Evered (1978) described AR as a five-stage cyclical process that requires the establishment of a research environment. The five identifiable phases are diagnosing, action planning, action taking, evaluating and specifying learning. However, most authors have described AR using a simpler four-stage process (Figure 2.1), namely planning, acting, observing and reflecting (Altrichter, Kemmis, McTaggart, & Zuber-Skerritt, 2002).

![Figure 2.1: Action Research cycles (Altrichter, et al., 2002)](image-url)
Many action researchers portray AR as a “research methodology” not merely a “method” that can be applied to a wide range of scenarios (Lau, 1999; Reason & Bradbury, 2001; Cassell & Johnson, 2006; Chandler & Torbert, 2003; Marsick & Gephart, 2003; Baskerville & Wood-Harper, 1998). The thesis was informed by AR philosophy as a research methodology applied to the context of prototype development reflecting a pragmatic interpretation of AR.

Iterative cycles of AR trigger a cognitive process which depends upon the social interaction between the observer and those in the surrounding environment (Baskerville & Wood-Harper, 1998). Baskerville and Stage (1996) support the idea of AR as a very useful methodology for the purpose of prototyping and risk management, especially in sensitive and complex scenarios. The next section identifies weakness in AR methodology and rationale for combining with other methodologies, explaining how AR cycles were structured and imbued with a socially relevant philosophical direction. This research is presented in a four-stage process in each of the four AR cycles as an iterative cyclical process.

2.4.1.1. AR cycles

This thesis presents four iterative cycles of AR, each successively building upon the learning gathered in earlier cycles. Each AR cycle was composed of four steps, namely Planning, Acting, Evaluating and Reflecting. The planning step included design planning that involved preparing use cases, documenting architecture, features and functionalities, changes and improvements to the design, a literature survey to inform and/or validate the plan for the design and field testing and planning for the field trial, applying for ethics approval, followed by recruitment and consent gaining with each iteration. The next step of acting represents the process of field testing the application after incorporating changes and improvements. The evaluation step details the results of the field trial, observations, field notes, questionnaire results, analysis of log records, video recordings and the taped interviews. The reflection step upon these findings leads to deeper insights into the factors that may influence the development of theory and reflect strengths, weaknesses and opportunities within the on-going design and development of the prototype. Four AR cycles with four steps in each cycle are illustrated in Figure 2.2. The lessons learnt in each cycle helped to reiterate the design and test it over the next cycle to understand the implications of design. The results challenged the researcher’s perception of what would work for older people and initiated a realization of the practical implications of introducing such an intervention. The process also raised new research questions and demanded reframing of the research goals.
Figure 2.2: Action Research cycles and their descriptions in this thesis
Before starting the action research, it is recommended that the environmental and situational context should be analysed and documented (Reason & Bradbury, 2001). Therefore, this research started with an ethnographic study to map the existing processes and understand prevalent practices (Figure 2.3). The analysis of this data informed our thinking when planning the first AR cycle. The numbers within the shaded circles are the steps of planning, acting, evaluating and reflecting and in the middle is the number representing an iteration of the AR cycle.

To clearly demarcate the scope and direction of this work, it may be useful to point out here that this is not a typical IS application research because here a prototype was developed in contrast to deploying an IS intervention. Neither it is an engineering research where software modelling and innovations in social robotics would take the central stage; nor is it evaluated as a clinical intervention because research did not pursue a trial to test clinical outcomes. Instead, this thesis presents a fresh look at some of the complex issues and compiles learning from an interdisciplinary perspective that is open to interpretation and evolutionary changes for application of robots in eldercare – a promising idea that is still in its infancy.
2.4.1.2 Extending the social agenda

Peter Reason (2006) argues and justifies the essential purpose of action research as an attempt to address everyday concerns of individuals and communities. Widening the scope of AR contributes to the increased well-being (economic, political, psychological, spiritual) of humanity and to a more equitable and sustainable relationship with the wider ecology of the planet of which we are an intrinsic part (Reason & Bradbury, 2001). The overarching purpose of developing technology in this research was ‘enhancing capabilities’ of self-care to help older people achieve a higher level of well-being. ‘Capability’ is defined as ‘the systematic ability to achieve higher levels of functioning, reflecting a person’s freedom to enjoy higher levels of well-being’ (Nussbaum & Sen, 1993, p 30). Nobel laureate Amartya Sen and Martha Nussbaum introduced the concept of capability as a value-based approach to conceptualising measures and interventions that has found application in a wide variety of fields including economics, sociology and even healthcare and technology development (Johnstone, 2007). More notable examples of its application are in the fields of social development (Ruta, Camfield, & Donaldson, 2006), including the United Nations Development Program (UNDP) Human Development Index (Anand & Sen, 1994). Both Sen and Nussbaum acknowledge the influence of the Aristotelian concept of ‘flourishing’ as the basis of good human life, the Kantian notion of dignity and autonomy, Marxist concerns with liberation, and the Rawlsian concept of justice and fair distribution. Alkire (2002), commenting on the capabilities approach, identifies parallels with modern theories of emancipation, holistic wellbeing and empowerment. The capabilities approach rests upon fundamental tenets of an individual (or group) having a capacity within given resources and the environment to possess a set of functioning that an individual or group has a reason to value. ‘Capacity’ here stands for three concepts:

- ‘Basic capacity’ of perception, analysis and action.
- ‘Internal capacity’ that is a developed state such as the ability to form mature relationships, hold and express a point of view, and have a notion of responsibility for self-care.
- ‘Combined capacity’ which is internal capacities combined with an environment in which they can be expressed; for example, a funding and policy framework that permits patients to express their demands within a healthcare system.

Furthermore, Nussbaum (2001) identifies ten categories of combined capacities relating to the spheres of life, health, bodily integrity, sensation, imagination and thought, emotion, practical
reason, affiliation, other species, play, and control over one’s social and material environment. It is perhaps important to note that all capacities are not capabilities. Nussbaum points out that people have the capacity for deception, exploitation and harm, which do not necessarily contribute to the achievement of a valued state of well-being. ‘Capabilities’ are required for the determination and realisation of wellbeing, rooted within ethical principles of justice and morality (Nussbaum, 2001). Conversely, the term *functioning* refers to a set of vectors of *being* (being happy, being pain free or symptom free and so on) and *doing* (taking medications, caring for themselves, obtaining services, informing physicians and so on) that exist within an ‘agency’ (meaning an individual or a facility or a society) in various combinations. The application of these principles to the context of medication management in the elderly could be visualised in the context of agency, environment, resources and functioning (Figure 2.4).

Therefore, the ultimate aim of any value-based intervention, including technology development and deployment, could be tested on its effectiveness on this scale.

1. Its ability to build internal capacities and capabilities.
2. Increasing availability of and access to resources.
3. Creating an empowering environment.

Viewed from this perspective, the capabilities approach is another way of looking at a practical application of ‘empowerment’, where the person is enabled by the environment or the resources or by the internal developmental process to enjoy higher levels of well-being. It is relevant to note that changes in environment and resource availability have little meaning
unless the person is empowered to make a change within their functioning of being (happy/symptom free) and doing (self-care tasks). It is therefore an internal process of transformation that contributes to a lasting impact of any intervention.

In the context of this research, it is important to point out the relevance of the capabilities approach. Older people tend to have limited capacities in terms of limitations in basic sensory abilities (vision and hearing, for example), motor limitations (arthritis, tremors) cognitive limitations (of memory and retention of all steps involved in a task), motivation and beliefs (for example a tendency to become introverted, avoiding voicing of concerns, raising the alarm, and accepting old age as a compromised state). Many of these limitations are relevant to engagement with self-care tasks, and medication management in particular. Similarly, resources like relevant drug information, safety and quality protocols feedback about their own health condition and performance are often missing. On the other hand, the prevailing healthcare environment imposes its own restrictions on freedoms while establishing acceptable behaviour norms and power scales. These observations may justify a different approach to intervention design in this context.

From a viewpoint of computer ethics (Bynum, 2001; Wiener, 1988), similar concerns around capacity for effective usage are raised about the purpose of designing technology. Aligning with human values like health, freedom, democracy, knowledge, privacy, security and self-fulfilment, Bynum (2001) identifies the importance of value-sensitive design. Moreover, Brey (2000) describes enhancing user safety and capability as important considerations while approaching potentially powerful interventions in sensitive situations. Starting with an emancipatory agenda on the research journey adds significance to discovering the theory of automated medication assistance, validating or refuting such assumptions while finding answers to the research questions.
2.4.1.3 Related AR methodologies

It may also be pertinent at this point to briefly look at another related methodology of Participatory Action Research (PAR). PAR involves both researchers and practitioners to having more or less equal yet different domains of ‘theoretical knowledge’. It has been applied in organisational settings where researcher and management work collaboratively in order to bring about a shift in organisational practices (Baskerville, 1999). It is this increased client participation that brings them to the status of ‘co-researcher’ and makes PAR distinct from other forms of AR (Elden & Chisholm, 1993). In our work, the emphasis remained on the researcher’s attempts to discover the designing implications; therefore, no attempt is made to qualify this thesis as PAR.

The characteristics of research presented in this thesis also differentiates it clearly from diverse sets of methodologies like ‘design research’, ‘contextual inquiry’ and ‘formative research’ that mainly focus on narrow domains of product design and development, and not a wider context influencing its practical implementation.

The action research approach presented in this thesis is essentially an ontological methodology that gives a shape and direction to the interpretive epistemology (Klein & Myers, 1999). This work differentiates itself as AR by concerning itself with a practical problem, congruence with theory, incorporating social context, progression over multiple iterations, and involvement of the participants, while simultaneously attempting to redress the balance of power in knowledge creation in an educative manner that increases the participants’ capacity to engage with medications (Reason, 2006). Attempting to address a practical, relevant problem of medication management by older people, this work looks at the wider and deeper implications of solution design in theory and practice. Supporting the notion of user empowerment and invoking a democratic participation in the research process, it follows an iterative learning and improvement strategy to find answers to the research questions that have relevance to both the theory and practice of health informatics. It is possible here to justify the entire research process with one methodology of action research, given its broad scope. However, there are some weaknesses in AR that present a compelling argument to include GT and PD which will be explained after the other methodologies have been presented.
2.4.2 Applying Participatory Design (PD) to develop a prototype

There are several methodologies used for developing a prototype, collectively called Design Science (Hevner, March, Park, & Ram, 2004). Participatory design (PD) is commonly used research methodology applied to develop the design of computer-based systems. PD is defined as a way to derive ‘knowledge by doing’, to make explicit the traditional, implicit and often invisible ways in which people perform their everyday tasks, and to construct the emerging design co-interpreted by researcher/designer and the participants who will use the design (Spinuzzi, 2005). It draws on various research methods such as ethnographic observations, interviews, analysis of artefacts, and sometimes protocol analysis, methods which are often used iteratively to construct the emerging design (Muller & Kuhn, 1993). The common aim of PD is to arrive at a design that fits the needs of the user. Lazar (2001), in advocating participatory design, recommends that the prototype be evaluated by the potential users as well as by using expert reviews. Experts can comment on deeper issues while users can point to small problems related to the envisaged activities or tasks.

PD was historically promoted with the specific goals of balancing technical design with political and stakeholder views (researchers, developers, workers and management) by involving academics and trade unions in the design process in Scandinavia (Foth & Axup, 2006). It was essentially an attempt to restore the balance of power where workers would perceive computer systems as an attempt by the management to control their work. A Marxist collaborative approach to research and design was seen as a way of encouraging wider acceptance and sustainability. Currently, the core idea of participation remains to shorten the communicative distance between research activity and real world activity, and the distance between researchers and researched. PD focuses more on ‘tacit’ knowledge to be made ‘explicit’ with the researcher’s ‘facilitation’ in order to design an improvised system with the aim of ‘empowering the users and respecting their needs’.

The PD research methodology has three stages (Figure 2.5) which can be iterated many times:

1. Initial exploration of the research space, context and situation, achieved by ethnography, process analysis, walkthrough, examining existing systems, and interviews.
2. The discovery process where the situations are co-examined and the future is envisioned, allowing the researcher/designers and users to understand goals and values to agree on desired outcomes (Bødker & Grønbæk, 1991).
3. Prototyping is the final stage which could be done in many ways such as mock-ups, paper prototypes, wizard-of-Oz, designed artefacts and many others (Bødker & Grønbæk, 1991).

![Diagram of the Participatory Design methodology](image)

**Figure 2.5: Participatory Design methodology**

The methodology of PD has its roots in participatory action research and recommends an iterative approach that has identified itself in the methodology and design space of information systems.

### 2.4.3 Grounded Theory approach

Grounded theory (GT) is a systematic inductive methodology to collect and analyse data using various qualitative and quantitative methods that generates a theoretical framework through a rigorous process of coding to explain the collected data (Glaser, Strauss, & Strutzel, 1968). Historically, grounded theory attempted to bring objectivity, rigour and validity into the prevailing interpretive theories of the time, which faced criticism from established positivist research methodologies proposing rigor, repeatability, and objectivity as the true nature of scientific research. In this attempt, grounded theory had to face challenges from interpretive puritans calling GT imbued with objective positivism (Denzin & Lincoln, 2000; Van Maanen, 1998). They argued on epistemological grounds, finding similarities with positivists, alleging that GT also assumes an objective external reality, as a neutral observer who discovers data by way of a reductionist inquiry of manageable research problems that is assisted by objective rendering of data. Taking these criticisms over the years, the concept of GT has been evolving, and multiple variations have been proposed since its discovery in 1997 by Barnie Glaser and Anselm Strauss, as well as attempts to find common grounds between these variations (Glaser, Strauss, & Strutzel, 1968; Charmaz, 1995; Dey, 1993; Melia, 1996). Nonetheless, commonly accepted basic tenets of grounded theory have been well summarised by Cathy Urquhart (2001, p.107), quoting Dey (1999) and Creswell (2007), as:
- **Aim and objectives**
  - The aim of GT is to generate or discover a theory.
  - Theory focuses on how individuals interact relating to the studied phenomenon.
  - Theory asserts a plausible relationship between concepts.

- **Data collection**
  - The theory is derived from the field data (interviews, observations, documents).
  - Further data collection after initial analysis is based on emerging concepts.
  - Data collection can stop when clear concepts emerge.

- **Data analysis**
  - Data analysis is a systematic process beginning as soon as data is available.
  - Analysis proceeds through identifying categories and connecting into the concept.
  - Concepts are developed through constant comparison with raw data.
  - Data analysis proceeds from open coding (identifying categories), through axial coding (examining conditions strategies and patterns) to selective coding (emerging storyline).

- **Prerequisite** – the researcher needs to set aside preconceived ideas to allow a substantive theory to emerge from the data.

- **Reporting** – the resulting theory can be reported in narrative framework or as a set of propositions.

Grounded theory principles are illustrated in Figure 2.6 as understood by the researcher.

![Figure 2.6: Simplified representation of Grounded Theory: Open, Axial and Selective coding to inform fully formed theory](image)
While coding the data and building the theory, it is recommended that the theoretical categories are developed from the original data source. Categories must fit the data and be able to explain it instead of reiterating preconceived concepts and categorising data. The analysis should be able to provide useful conceptual rendering of data to explain the studied phenomenon while being able to explain variations. An evolving theory should be able to modify itself with evolving contexts, as conditions change and further insights are gathered (Glaser, 1978). Figure 2.6 shows the progression of data collection to three stages of coding (explained later) while constantly comparing the codes with original data (and literature), allowing a theory to emerge.

Therefore, by following a systematic process, grounded theory offers a method for the discovery of the subjective nature of reality, relative understanding of empirical reality, and the ability to express this understanding as a meaningful scientific discovery. It does so by building a theory that is precise, rigorous and consistent with empirical observations (Orlikowski & Baroudi, 1990). It is desirable that a good theory be generalizable and extended to a wider context, as well as be consistent with literature, and be flexible in justifying deviations from established thinking (Corbin & Strauss, 1990).

To achieve these objectives, the grounded theory method requires ‘theoretical sensitivity’ from the researcher (Glaser & Strauss, 1977; Glaser, 1978). Being immersed in the reality of the situation, the researcher becomes an equal participant; it is desirable for him/her to have two essential qualities which build theoretical sensitivity:

- The researcher is expected to be well grounded in the literature, as well as from personal and professional experience, and be thorough in collection and analyses of the data (Corbin & Strauss, 1990).
- They are expected to have the ability to set aside their own theoretical ideas, look at the situation with fresh eyes, and move out of the confines of standard ways of thinking about the data. (Glaser & Strauss, 1977).

The participants were selected by *theoretical sampling* which aims at extending or deepening the emergent analysis in order to aid development of the new theory, where a researcher interviews cases that do not appear to fit within the current conceptual system. This serves a useful value in building a theory that is inclusive of wider, often contradicting views to discover the reality that may be underpinning such variations (Marshall, 1996).
Strauss and Corbin (1998) recommend transcribing all of an initial set of interviews and coding them before moving on to the next set of interviews. Early phase data collection for a new researcher should be thorough; later some experience is gathered to guide selective transcribing, which is often time, energy and money consuming (Corbin & Strauss, 1990).

2.4.3.1 Coding process followed in this thesis

Coding in qualitative research is a way to explore bits of information, looking for similarities and differences within these bits to categorise and label the data accordingly (Patton, 1990). In this thesis, with each AR cycle, the interviews conducted at the end of each evaluation of the prototype were transcribed and subjected to open coding in the first instance. To resolve the ambiguity at the beginning of the coding process, Dey (1993) suggests breaking down data in order to classify it. Open coding is arranging these broken pieces of data in every way possible; in other words, running the data open. Open coding allowed the interviews from various participants to be broken and reassembled along common categories alluded to by those participants. Such time-consuming analysis not only helps coding but also provides insights to the designing process (Strauss & Corbin, 1998). Instead of passively coding the data line by line, the researcher tried to break the data apart (in accordance with what was actually being said) to generate concepts or codes while maintaining close ties with the data (Charmaz, 2003). This breakdown and analysis process can be done either manually or using a software system. Some believe the use of software essential to a rigorous analytical process (L. Richards & Richards, 1994), while others argue that unnaturally pushing the data to make conclusions rather than hearing what actually is being said is ill-advised (Kelle, Prein, & Bird, 1995; Mauthner & Doucet, 1998). Mason (2002) explains the analytic approach depends on the theoretical stance of the researcher, which could either be literal, interpretive or reflexive. A literal approach focuses on language and grammatical structure, an interpretive approach attempts to make sense of the participant accounts, while a reflexive approach focuses on the researcher and on his/her contribution to the data creation (Mason, 2002). Since the discussions during this process were also guided by the researcher and looked at a design development, an interpretive as well as reflexive approach to data analysis was considered more appropriate. The data in this research was coded manually. Further, the researcher faced a struggle to conceptualise initial sets of codes, which led to a couple of iterations of coding (in Chapter 3). This struggle led to the realization of a need for collecting more data from diverse viewpoints. It was then, the meaning of theoretical sampling and its importance was brought to the fore.
Axial coding means grouping the fractured codes back together in new ways by making connections between categories and subcategories of data (Corbin & Strauss, 1990). During coding, the use of “constant comparison, verification and analytic memos” is suggested both by Glaser and Strauss (1977). Memos are viewed as critical to the theory development, and the use of such memos is not limited to grounded theory but generic to qualitative research as a whole (Newman & Benz, 1998). The researcher prepared several memo notes to aid in the analytical process. Further triangulation of data from questionnaires, video analysis and field notes substantiated the building and saturation of categories until clear themes began to emerge. At this stage, more selective coding was undertaken to derive thematic and theoretical implications.

Selective coding is a process that systematically relates the core category to other categories, and it integrates and refines the categories into theoretical constructions. If open coding is “fracture and integrate” and axial coding is “correlate and integrate”, then selective coding means “select and integrate” to arrive at themes that weave a coherent storyline along a central theme or a theoretical hypothesis (Kendall, 1999). Here, the core categories with the most variations, associations and dominance are selected under which other categories tend to fall. The categories are analysed at a higher level of abstraction in this final stage, allowing a theory to emerge (Charmaz, 2003, 2006; Walker & Myrick, 2006).

2.4.4 Weaknesses of individual methodologies and rationale for combining them

The primary goal of the exercise was to bring to light the theoretical elements of medication processes while arriving at an optimal system design that could be useful and effective to the reality. While pursuing these research questions, the challenge was to balance fluidity with rigour and leverage the collaborative involvement of both researcher and participants. This enabled bridging action and research, theory and practice into the participatory pursuit of discovering a practical solution to issues of concern to older individuals, their families and caregivers within the chosen context and settings (Reason & Bradbury, 2001). AR was found to be a highly relevant and primary methodology for being creative and reflective, and developing ideas while studying a challenging process and to solving significant problems (Avison, Baskerville, & Myers, 2001; Babüroglu & Ravn, 1992; Baskerville & Myers, 2004).
2.4.4.1 Limitations of AR

Action research, despite its broad scope, rationale, inclusiveness, and action-oriented approach, suffers from methodological weaknesses. Firstly, AR has been criticized for its lack of methodological rigour (Cohen, Manion, Morrison, & Morrison, 2007), its lack of distinction from consulting (Avison, 1993; Myers & Avison, 1997), and its tendency to produce either “research with little action or action with little research” (Dickens & Watkins, 1999, p. 131). Secondly, presentation of findings from AR is not always easy. To make the presentation of action research as a rigorous and systematic process requires artfully using a mix of results derived from qualitative and quantitative tools. The use of a variety of data collection and analysis methods justifies complementing action research with additional methodologies that have equally well-established scientific bases to enable a clearer presentation of findings (DeLuca, Gallivan, & Kock, 2008). De Luca et al. (2008) point out several weaknesses within AR as a standalone methodology, which specifically apply to this research context given the heavy predominance of positivist, quantitative and rigorous confirmative research tradition prevalent in medical sciences. They also recommend addressing the divergent dialectic of research by synthesising AR with other methodologies (front loading Grounded Theory in particular) that could bring rigour and objectivity. To bridge inherent weaknesses within AR as well as GT and PD, the three methodologies were considered a useful adjunct to each other and in effectively supporting the quest for finding answers to research questions.

2.4.4.2 Limitations of GT

Barbour (2001) points out a series of flaws with qualitative techniques, especially with the use of GT, in healthcare. Limitations of grounded theory are mainly considered in its subjective nature of interpretations. It is possible to address these limitations by adding ‘participatory respondent validation’ and ‘iterative refinement along with triangulation’ at each stage (Barbour, 2001). These recommendations clearly support the case for combining PD (participatory respondent validation) and AR (iterative refinement along with triangulation) to maintain rigour.

2.4.4.3 Limitations of PD

PD also has its limitations; for example, involving users to define system requirements tends to generate a long and ever-growing wish list that cannot be addressed with available technology or budgets, making it difficult to define success or failure in the eyes of the users. Additionally, PD does not follow a systematic way of analysing qualitative data and presenting it. It also runs
the risk of basing design decisions on superficial assessment or assessment of only a few opinion leaders or biases of designers, creating tunnel vision (Forsythe, 1999). PD also runs the risk of limiting its narrow focus on designing artefacts without a social context, despite claims of empowerment and evolutionary change underpinning its origins. It may remain focussed just on the tool design and ignore the way processes are/would be changed by technology (Spinuzzi, 2005).

**2.4.4.4 Rationale for combining – complementing strengths**

**AR and GT**

Orlikowski and Baroudi (1990) analysed 115 publications between 1983 and 1988 on AR investigations and observed a fundamental problem in maintaining a clear understanding of an epistemological research perspective. They observed that in order to bring objectivity majority to AR, researchers use a positivist reductionist approach while ignoring the essential interpretive stance. Though AR is flexible in its approach, leaning on soft Interpretivists approaches threatens the validity of research results. Kock (2003) identifies those threats as uncontrollability (where the researcher has no control over the dynamic research environment), contingency (where there is too much shallow data with little reliability and applicability), and subjectivity (introduction of personal bias). To address these threats, the use of grounded theory has been suggested as one of the key antidotes since it allows a clear sense of direction, association and objectivity to interpret the data (Kock, 2003). Baskerville and Pries-Heje (1999) argue in favour of GT as a tool to bring rigour and objectivity to a mutually compatible AR process, and they even coin the term “grounded action research”. However, they note AR is usually a pre-determined, problem-oriented approach, limiting the scope of GT that would allow the concepts and research directions to emerge, but there is a value of GT as a way to refine, re-define and inform the iterative collaborative learning of AR. This refinement involves integrating GT into AR by:

1. Use of GT tools like field notes, reflections and recordings as data collection methods during diagnosing and action taking phases of AR.
2. Continued use of GT coding system as the essence of action planning, evaluating and specifying learning.

Integration between GT and AR therefore addresses the methodological and epistemological gaps, bringing rigour without stripping the richness of observations in an empirical world. The beginning of the AR cycle narrows the focus of GT while saturation of GT categories indicates
completion of the AR cycle. In this study, we successfully used GT to inform various stages and cycles of AR, particularly to analyse perspectives of participants for iterative improvement of our design.

**AR and PD**
The ideas of iterative prototyping and user involvement in PD bring it very close to the iterative methodology of AR. In fact, Ehn (1988) considers PD as essentially an offshoot of AR, whereas Foth and Axup (2006) consider PD and AR as two related yet distinct research approaches. They explain the difference with the help of case studies describing the design of information technology solutions. PD primarily aims at “optimizing design of technology” by understanding and gathering user requirements. On the other hand, AR would look at “wider social context, assess relationships, look at power issues and discover conditions associated with practical uptake and rollout of technology” (Foth & Axup, 2006). AR would critically reflect, evaluate and inform the next action cycle in order to best address systemic issues that might hinder technology from being practically applied.

In order to discover potentially ‘implicit’ behaviours that might not be straightforward and rooted in complexities of social structure and perception of reality, an interpretive iterative developmental strategy could be strategically advantageous. More specifically, the PD approach to making implicit knowledge explicit combined with the flexibility and iterative approach of AR would offer an ideal combination. AR also gives an evolutionary learning opportunity; an opportunity to immerse in the lived experiences of older people, and elicit participants’ descriptions of issues within the dynamic social environment.

Developmental Research (DR) as proposed by Hevner et al. (2004) has been combined with AR to propose Action Design Research (ADR) by Sein and colleagues (Sein, Henfridsson, Purao, Rossi, & Lindgren, 2011). ADR reflects the premise that IT artefacts are ensembles shaped by the organizational context during development and use. The method conceptualizes the research process as containing the inseparable and inherently interwoven activities of building the IT artefact, intervening in the organization, and evaluating it concurrently (Sein et al., 2011, p 1). De Villiers (2005) has also described a design methodology using a combination of DR, AR and GT.

Deviating slightly from the recommendation by De Villiers (2005) and Sein et al. (2011) to use DR along with AR and/or GT, this research leaned more towards the methodology of PD for two important reasons. Firstly, DR only partially compensates for a weak rigour in data
analysis and interpretation. Secondly, DR offers little advantage over PD when used in combination of AR and GT. Therefore, it was felt more appropriate to use PD which is a mainstream methodology and would add a unique contribution both to AR and GT while contributing to a robust design process.

**GT and PD**

Many researchers have used GT to analyse recorded interactions with users during PD (Luck, 2003). GT and PD have been combined into a hybrid GT-PD approach to draw on the strengths of both methods. PD provided the means of user engagement to obtain a rich perspective on drawing system requirements and user interface design. GT provides the means of analysing and coding the data to allow us to understand the attitudes and beliefs surrounding clinical processes and the information used within those processes in order to develop a theoretical framework. The data from quantitative and qualitative methods can be ‘triangulated’ and still appear valid and coherent, and the resulting theory can be ‘transferrable’ to a wider context without showing significant flaws in its construct (Kuper, et al., 2008).

Both GT and PD bring rigour to the phases of AR cycles. For example, PD is an effective means of facilitating understanding of tacit and explicit user requirements; on the other hand, GT is a way to minimise subjectivity for accuracy and safety as long as the qualitative methods generate data to ‘saturate’ categories where further data collection from multiple sources falls within or aligns with existing themes. Table 2.1 summarises the strengths and weaknesses of three methodologies, giving the reader a snapshot of complimentary logic.
Table 2.1: Summary table showing strengths and weaknesses of AR, GT and PD

<table>
<thead>
<tr>
<th></th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Action Research</strong></td>
<td>Iterative and evolutionary learning, social context, transformative focus</td>
<td>Uncontrollability, contingency and subjectivity, weak rigor in analysis of data and presentation of results</td>
</tr>
<tr>
<td><strong>Participatory Design</strong></td>
<td>Participation of potential users, Engagement and validation in real life situations, converting implicit needs into explicit requirements</td>
<td>Unrealistic demands, lack of rigor in field data analysis and interpretation, sampling bias influencing results by those with louder voice, narrow focus on tool design</td>
</tr>
<tr>
<td><strong>Grounded Theory</strong></td>
<td>Robust process of qualitative data analysis through coding, saturation, triangulation and theoretical sampling</td>
<td>Subjective interpretation limiting transferability, little emphasis on cross validation of findings with respondents, does not address changing views as understanding evolves iteratively</td>
</tr>
</tbody>
</table>

2.5 Data gathering and analysis methods

Though an interpretive stance and subjective analysis are valid vehicles to acquire and synthesise knowledge, they do not deny the value of objectively acquired data as a tool to support and align the rational thinking process of the research (Lingard, Albert, & Levinson, 2008). A series of studies in iterative AR cycles deployed a variety of qualitative and quantitative methods to elicit this information. These AR cycles pursued answers to both research questions in parallel, mainly seeking the theory as well as developing a design. Within each AR cycle, the research used qualitative and quantitative methods of data collection. This approach had at its core an objective of discovering knowledge and maintaining rigour while carrying the responsibility of ascertaining the promise of futuristic technology.

Appropriate participants were chosen using convenience sampling, snowballing and theoretical sampling, for the purpose of testing. The findings from multiple perspectives, researcher notes and other tools used within each cycle were triangulated, cross verified and analysed to inform further developments.
Qualitative data in this study consisting of interviews, observations, field notes and documentation of situational and personal challenges encountered was analysed using GT. The recordings were transcribed, concepts were coded, and results were compared, triangulated and compiled into a meaningful theory that explained the data as informed by the grounded approach. The analysis enriched our understanding of people and processes as well as that of technology and allowed us to articulate successes, issues and challenges in this context. Most action researchers (Baskerville, 1999; Kock, 2003; Rapoport, 1970) affirm the essential nature of action research to be epistemologically interpretive and methodologically qualitative; at the same time, they allow for quantitative data to triangulate information in meaningful ways. The quantitative data consisted of questionnaires and computer logs of user activity. These were analysed using simple statistical methods to support the findings from qualitative observations. Table 2.2 summarises the main methods used in this research.

Table 2.2: The use of mixed methods to bring more rigour to AR. Triangulating information adding objectivity while attempting to minimise bias

<table>
<thead>
<tr>
<th>AR Cycle 1</th>
<th>Qualitative</th>
<th>Quantitative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interview, pictures</td>
<td></td>
</tr>
<tr>
<td>AR Cycle 2</td>
<td>Field notes, Semi-structured interview, Video recording</td>
<td>Questionnaire, Computer logs</td>
</tr>
<tr>
<td>AR Cycle 3</td>
<td>Field notes, Semi-structured interview, Video recording</td>
<td>Questionnaire, Computer logs</td>
</tr>
<tr>
<td>AR Cycle 4</td>
<td>Field notes, Semi-structured interview, Video recording, video logs</td>
<td>Questionnaire, Computer logs</td>
</tr>
</tbody>
</table>

2.5.1 Brining rigour to the research process

The following strategies were used to bring rigour to the research process

1. Clearly identifying research goals and research questions
2. Supporting methodological weaknesses by a combination of AR, PD and GT
3. Use of qualitative and quantitative tools, and triangulation of findings
4. Robustly addressing ethical dilemmas as action research is subject to three dilemmas linked to ethics, goals and issues (Rapoport, 1970). The details are described in the next sections.
2.6 Ethical dilemmas and limitations

The ethical dilemmas faced were related to a part of the project being driven by larger commercial interests, at times colouring pure research interests. The researcher signed an agreement in which it was agreed that the intellectual property (IP) generated by the research would belong to the funding agency. As an action researcher, a truly interpretive viewpoint is at risk of being biased by such arrangements and expectations (Rapoport, 1970). The research, however, followed the middle path and attempted to resolve the issue in three ways.

The research was focused on solving medication management problems rather than justifying a robot’s value or exploring the finer nuances of human-robot interaction. The focus of research was on exploration of older people’s reality while they manage their medications, but it cannot be denied that the attributes of the robot have played a significant role in systems functionality and development of theory. Later refinements included building additional features and functionalities that could make medication use engaging, safer and convenient. The closed-loop medication management system depended more on a cloud-based application (called Robogen—see Chapters 6-7) that could operate independent of the robot. Robogen could inform any touch screen device using compatible software application. Thereby, the research attempted to strike a middle ground – remaining true to the research process at the same time as delivering on the project plan.

Secondly, the focus on development of theoretical constructs that underpin and determine the automation of medication management assistance for older people was independent of the research funding requirements. It was the researcher’s efforts and contribution to the research process that were independent of the research project plan. Action research concerns itself with theory as well as practice. The research could have remained limited to development and testing of a prototype, but delving deeper into social and more abstract domains to define a theory, while seeking answers to research questions, reflects the researcher’s attempts to maintain integrity of action research.

Thirdly, in AR Cycle 4 (Chapter 7) and in accordance with the user’s feedback and emerging concepts, the research direction changed to use a smaller, static robot instead of the one that was conceived earlier by the larger project plan. The results of this research not only redefined the researcher’s perceptions but also informed the direction of thinking for the larger project.
The ethics committee required a written statement from Uniservices not to embargo this thesis in case it documents commercially sensitive information, which Uniservices kindly agreed to provide. Furthermore, other ethical dilemmas faced were related to confidentiality and security of information as well as to safety of elderly residents while experimenting with an unknown technology in sensitive context of medications. To address these concerns, the ethics protocols laid by the University of Auckland Human Participants Ethics Committee (UAHPEC) mandated us to maintain confidentiality of patient information and explain how we will ensure the safety of study participants. As an additional measure, UAHPEC mandated obtaining a signed consent from the CEO that the residents’ stay at the village and employment of the participating staff would not be adversely affected by the nature of opinions shared during the research.

This research also suffers from broad societal bias arising from imagery painted by the popular media into the minds of participants, e.g. movies such as Star Wars and Isaak Asimov’s famous story, iRobot. The perception that robots will ‘take over jobs’ instils a sense of unspoken resistance against robots among the staff members at Selwyn Village. On the other hand, robots ‘taking over the world’ imagery made it difficult to recruit participants, both personnel and residents. Expressions of fear of technology fear of loss of human contact and fear of domination and ‘big brother watching’ made participants and their family members defensive. In deference to these sensitivities, the researchers in the Healthbots project developed a vocabulary for expressing their work, aiming at a way of talking about robots that did not upset or offend anyone involved or potentially involved in the research. The researcher’s attitude and expression were critical to acceptance or rejection of the entire research process, because any insensitive comment could very easily put off the potential participants. Instead of being just a passive observer, the researcher had to spend time counselling and alleviating their concerns and actively manage risks, which an AR approach fully supports. This defensive posturing by the researcher, on the one hand, has the potential of introducing bias that might have affected the subjective interpretations of qualitative data, while on the other, more positive side, it forced additional rigour to the research process through objective description to the participants. For example, the researcher would explain:

“We do not know enough about the robots in the healthcare domain. They could be of use or may not be useful. We need your help to understand what is useful about them and what is not and how you could use them in your everyday life.”
Repeating the reassuring dialogues at each opportunity with staff members, residents and management of Selwyn Village helped to minimise suspicion and resistance. Alternatively, if the research environment was preconditioned to accept the value of robots, everything would have been too easy and positively biased, where the researcher would not have been able to tease out objective findings and justify a research process.

2.7 Subjective perspective of the researcher

An interpretive researcher attempts to rationalise a value-based yet context-driven design methodology, but still retains his viewpoint and sees the world coloured by the colour of his/her lenses. Therefore, it is important to declare the subjective viewpoints and biases for the reader to draw conclusion about the nature of the interpretations. The research questions and research domain reflect the researcher’s background as a clinician manager and an advocate of enabling technologies. Practising as a general physician in rural settings before accepting the role of a senior manager within a large chain of hospitals in India perhaps left an indelible influence. For the last five years, the researcher has been involved in developing a mobile phone-based intervention to make healthcare accessible and affordable for people living below the poverty line (Tiwari, 2010). The work had largely been influenced by the emancipatory, libertarian and empowerment concepts (Foucault, 1982; Sen, 1993), where technology was developed as a resource that enabled local empowerment, and the development of internal capabilities within the rural Indian healthcare environment riddled with problems of poverty, exploitation and deprivation.

Taking an interpretive stance would have required being open to all possibilities, whether participants liked or rejected the idea of the robot. However, the project required a successful design to be developed and delivered according to the project plan on the given robotic platform as a part of research funding. On many occasions, the researcher struggled with the real world complexities of managing resources, relationships and concerns about the potential of exposure of study participants to unwarranted risks while attempting to pursue research goals. Such challenges limit the scope of research and induce a sense of urgency to finish the task and meet deadlines. But on the other hand they induce discipline that helps to finish research in a timely manner as well as allowing learning about the multidisciplinary translational research process.
2.8 Research context

This section attempts to familiarise the reader with the research context of this funded PhD. Some details are given regarding the multidisciplinary research project within the University of Auckland that developed the software and the international partnerships through which robots were obtained from Korea. There is a brief outline of the context of the publicly funded healthcare system in New Zealand, whose fiscal stability in coming years is facing predictions of doom by silver tsunami. Finally, the context of the venue for this research – an aged care facility, Selwyn Village – is presented.

2.8.1 The Healthbots project

This research has been conducted in an interdisciplinary environment where engineers, clinicians, informaticians, business professionals, and international collaborators work together towards developing innovative solutions. It has been a common practice in leading universities around the world that link academic research with its commercial applications in order to develop solutions while reducing ‘lab-to-market’ and ‘bench-to-bedside’ gaps.

This setting up of engineering infrastructure and project coordination was done by the New Zealand-Korean Centre for Healthcare Robotics, established at the University of Auckland. The project was named the ‘Healthbots project’ with multiple research agendas to fulfil its objectives. One of the objectives was to develop a ‘medication management module’. Others include the psychological evaluations of human robot interaction, vital signs monitoring, and entertainment. Some of the main participating departments within the University are ECE (Electronics and Computer Engineering), Department of Psychological Medicine, School of Population Health, housing the Department of General Practice, and the National Institute of Health Innovation (NIHI). NIHI has its focus on Health Informatics teaching and research. This PhD candidature is based out of NIHI with associated supervisors. Figure 2.7 attempts to illustrate a simplified depiction of important relationships existing within a large project.
The joint NZ-Korean Centre for Research on Healthcare Robotics was established through the business arm of the University of Auckland (Uniservices) that negotiates the linkages and academic business associations with a view to assisting commercialisation of research. The centre receives its funding through research grants from IIOF FRST (International Investment Opportunities Fund – Foundation for Research, Science and Technology), Ministry of Science and Innovation as well as from ETRI (Electronics and Telecommunications Research Institute) established by the South Korean Government. The funding aims to promote research into elder care systems that could mutually assist New Zealand companies to explore and expand markets while helping Korean companies contextualise their robots in a Western environment for international marketing. One of the key vendors who supplied the robots for this research is Yujin Robotics. Most of the robots used in this study were supplied by Yujin through ETRI. The Healthbots project has external linkages with local biomedical equipment manufacturers, software developers, and aged care facilities.
2.8.2 The role of the researcher within a large multidisciplinary team

The interdisciplinary team of researchers included a range of cadres from professors and heads of departments to doctorate and masters students. In addition, there were two doctoral candidates, one post-doctoral, and one masters’ candidate, all from the Department of Electronics and Computer Engineering. Moreover, one doctorate candidate from Psychological Medicine and one from Health Informatics played important roles in the designing process and the conduct of field trials. The researcher’s role was to convert the vision for medication management function as conceived by the overall NZ-Korean robotics project into reality by building a feature list from scratch and coordinating the development of software application. The author of this thesis led the design, development, testing and refinement of the user interface as well as the web-based portal that took more than two years. The work included eliciting design requirements from potential users, caregivers, managers, clinicians and other experts involved in elder care, then converting the field data into a conceptual design framework, using case diagrams, flow maps and other illustration tools to assist software engineers to understand the details and code the application. Implicit in this work was the consideration of clinical complexity, ethical issues, risk involved with medications, and sensitive clinical conditions, and the need to draw boundaries for balancing efficacy with safety. The software programming was done by engineering researchers who were part of the larger interdisciplinary team at the NZ-Korean Centre for Healthcare Robotics. This doctoral thesis does not focus on the software engineering side of application development, but on the implications and outcomes of design from usability, feasibility and potential clinical applicability of the solution, following an AR approach.

2.8.3 Research funding

The following organisations have contributed to the funding of this PhD:

1. Joint NZ-Korean Centre for Healthcare Robotics
2. Tertiary Education Commission and Foundation for Research, Science and Technology, Auckland, New Zealand
3. Uniservices, the University of Auckland
4. University of Auckland PhD scholarships programme
5. R&D programme of the Korean Ministry of Knowledge Economy (MKE)
6. Korea Evaluation Institute of Industrial Technology (KEIT) [2008-F039-01, Development of Mediated Interface Technology for HRI].
2.8.4 Context of New Zealand’s healthcare system

The New Zealand healthcare system is a publicly funded system whose services are delivered through twenty District Health Boards (DHBs) that run the hospitals and contract with Primary Healthcare Organisations (PHOs) to deliver primary care. There are shared concerns regarding the looming threat of escalating healthcare costs, given the vulnerable nature of its small economy. The recent formation of the National Health Board attempts to consolidate cost heads to leverage cumulative purchasing power and reduce backend operations costs. The Health Safety and Quality Commission of New Zealand acknowledges the importance of medication safety, especially in elderly populations, and is actively pursuing a Medication Safety Program as a national priority. A dedicated National Health IT board within the Ministry of Health is currently working with the Commission to develop e-Medication Management capabilities within hospitals and reduce the information silos between various providers. Most General Practitioners in New Zealand use computers to record and manage medication information (Schoen, Osborn, Trang Huynh, Doty, Peugh, & Zapert, 2006).

New Zealand has had a strategy for older people’s health in place since 2002 and the Ministry of Health (2011) recently published a medicines care guide for residential care that clearly highlights the need to follow a closely regulated systematic medication management process as part of the strategy for elder care (Figure 2.8). The guidelines clearly state the need for documentation and process to be followed while administering medications. These processes might work in cases of those elders who are personally supervised/assisted by caregivers and nurses in high dependence areas. However, more independently living elders, despite being exposed to similar risk from potent medications and being prone to adverse events are not that closely supported. Therefore, Ministry’s recommendations are not currently being applied to meet the needs of a majority of the population ageing within their home and community.

The extensive and growing use of IT systems in the New Zealand healthcare system rationalises the development of an automated medication assistant. If the actors did not use computerised technology then it would make little sense to weave an information network. Moreover, ageing of populations and pressure on the healthcare system to perform in New Zealand is real. The high prevalence of medication errors and strategic focus on safe medication management for the elderly makes the research more relevant and valuable, thus enabling funding streams to nurture research that may impact on real issues and challenges.
Figure 2.8: Medication administration guide for caregivers and nurses working in aged care facilities (Ministry of Health, 2011)
Such environmental factors are particularly relevant to this research. In situations where caregivers are not physically available to follow such protocols, then development of a solution to automate some of these processes becomes particularly relevant. The design of an application needs to comply with safety protocols and adhere to recommended conventions. Developing such a system and creating options and alternatives that ensure the health of older people, the safety of medication management and sharing of information across providers is therefore of high significance.

2.8.5 Research environment within an Aged Care Facility - Selwyn Village

The population aged 65 years and over in New Zealand was 13% in 2009 and is expected to reach 21% by 2031. The number of people aged 65 years and over is projected to increase from around 550,000 in 2009 to 1 million in the late 2020s (84% increase in less than a decade), when they will outnumber children (Statistics New Zealand, 2009).

Table 2.3: A snapshot of aged residential care services in New Zealand (Grant Thorton 2010)

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More than 35,000 aged residential care beds within more than 700 certified rest homes, the number of which is growing rapidly. It is estimated that by 2026 the number would be doubled.</td>
</tr>
<tr>
<td>• 57% residents are in rest homes, 31% in high dependency care and 8% in dementia care units.</td>
</tr>
<tr>
<td>• Around 70% of these facilities are operated ‘for profit’ and around 35,000 employees currently work in aged residential care sector. More than 75% increase in workforce demand is expected over the decade.</td>
</tr>
<tr>
<td>• Services to eligible candidates living within these facilities are funded by Ministry of Health through District Health Boards (DHBs). DHBs contract Needs assessment and Coordination (NASC) Centers to identify and inform eligibility and availability of services. Currently 64% residents qualify for public funding while rest are self-funded.</td>
</tr>
<tr>
<td>• $785 million were paid to facility operators in 2008/09, which roughly amounted to 120$ per resident per day and there is constant demand to address inflationary pressures.</td>
</tr>
<tr>
<td>• Publicly funded healthcare system bears additional costs where aged care residents in New Zealand consume 27% higher acute hospital days, 42% higher prescription drug usage and more than twice the number of emergency department visits than international benchmarks.</td>
</tr>
<tr>
<td>• Further funding to older people within the community is provided through multiple agencies e.g. Meals on wheels, District Nursing/ home care services, Disability Support Services (DSS) and Accident Compensation Corporation (ACC).</td>
</tr>
</tbody>
</table>

The Selwyn Foundation is a not for profit private agency that operates as one of New Zealand’s largest providers of services to the older generation. The Selwyn Foundation offers services
across nine villages in the upper North Island. In addition to the independent retirement living quarters and rest homes, the foundation runs hospitals, hospice and day care centres. It also has an emphasis on education, research and management consultancy services for the benefit of the industry. It is this inclination for research and its proactive aspirations to provide the latest, state-of-the-art services for its residents that makes Selwyn an ideal partner for conducting this research. The facility chosen during these trials was Selwyn Village, located in one of the suburbs of Auckland. The facility is set up within 29 acres of beach-facing land with two co-located arrangements, Selwyn Village and Selwyn Heights. There are currently 224 apartments and villas at Selwyn Village and 72 at Selwyn Heights, housing more than 400 residents within eight different buildings and villas.

The Lichfield towers, Randerson Apartments and Bishop Selwyn Apartments are independent living quarters where mostly self-dependent elders or couples live with minimal personal assistance. Lichfield Towers was originally built as rental and rest home accommodation. These apartments feature well-appointed kitchens, bathrooms and living areas. The building has a fully appointed lounge on the ground floor, with views of the Selwyn Garden. Figure 2.9 illustrates some of these settings.

![Selwyn Village and independent residential apartments](image)

Figure 2.9: Selwyn Village and independent residential apartments

The facility described here is an example of a well-organised aged care facility in New Zealand. It may be expected that findings from this facility may be applicable to most similar upmarket facilities in the near future. The context analysis and paper prototype testing
described in Chapters 3 and 4 were conducted across multiple buildings and the medical centre, whereas the participant interactions for usability testing described in Chapter 5 were conducted in public spaces in Lichfield Towers and Bishop Selwyn Apartments. The iterative interactions described in Chapter 6 were conducted on the second, third and fourth floors of Lichfield Towers and independent handling of the smaller robot described in Chapter 7 was accomplished by participants living in Bishop Selwyn.

2.9 Chapter summary

This chapter outlined the approach to research methodology and justified its relevance in the given context. The thesis stated primarily as an action research (AR) that iteratively revised the design. The methodological weaknesses were addressed by combining participatory design (PD) and grounded theory (GT) to bring more rigour into the collection and analysis of data and to coherently construct the story. Instead of adhering to a rigid formula recommended by canonical schools of thought, this research attempted to follow a flexible, heuristic strategy at stages of data gathering and analysis. The chapter also explained the research context and the given variables that determined the scope and limitations of this research.

The next chapters will describe the development of theory throughout the research period as well as describe the design and development of the automated medication assistant. It will also describe the context and the research environment that became the test bed for developing the theory and the prototype.

It is also important to inform the reader typically expecting a literature review chapter after one on methodology, that this thesis takes a deviation from the standard practice. In each cycle results pointed the researcher to explore different aspects of the literature. The literature has been a constant companion for guiding and reflecting upon findings at each stage, thereby leading to references being dispersed throughout the description. The reader would also find a separate literature review less helpful in maintaining the context and illustrating or reflecting on the evolutionary progression of ideas that happened during this research journey.
Chapter 3: Defining the research context

3.1 Introduction
To answer the research questions concerning theoretical elements that underpin medication management support for older people and developing an apparatus for the same, it was imperative to understand the environment and the context of the study. The intention was to find out more about the clinical, social and personal environments within an aged care facility. One of the characteristics of action research is applicability and impact within an environment (Myers et al., 1997). Therefore defining its environment through an ethnographic study would be an appropriate prelude to commencement of AR cycles (Gold, 1997). Assessing design space, identifying potential users, understanding their workflows and expectations before arriving at design specifications is also an important part of design science (Mayhew, 2005). This exploration not only helps to identify actors (Lamb & Kling, 2003; Mantzana, Themistocleous, Irani, & Morabito, 2007) but also to learn those actors’ perspectives, wherein they derive their own meaning and assign usefulness to the proposed intervention.

Medication management within aged care facilities is known to be error prone, multifaceted and complex (Williams & Nichol 1999). Many studies conducted across the globe capture the importance of medications for older residents and document how serious the issue is (George et al., 2008). The next section presents an overview of these studies mainly from a clinical perspective, as addressing the validity of this research to the medical profession and alignment to evidence-based practice was an important goal. This chapter describes the findings from the literature around medication-related events in aged care facilities, and documents the details of an ethnographic study mapping medication processes to recognise ground level issues in a typical ACF.

3.2 Literature survey: Clinical relevance of medication use by the elderly
The literature around medication-related issues in older people and especially concerning those living in aged care facilities informed the direction of enquiry. It also focussed and sensitised the researcher towards the gathering of field data (Glaser et. al 1998). This section describes the findings around problems and solutions described in the literature on adverse drug events.

In an ideal situation when treating patients, the doctor is expected to generate an accurate prescription which is then expected to be served accurately by the pharmacist, and medications are expected to be used correctly by the patients, resulting in the desired outcomes. In reality, the conditions may be far from ideal and the process may break down at each level. Prescribers
could make errors in choice of medications; they may fail to monitor high-risk medications and unintentionally expose patients to risk of adverse events. Pharmacists may make dispensing errors and the patients themselves may not follow ideal process; they may fail to comply with directions and use medication inappropriately, while these process breakdowns may not be communicated back to the prescriber. The literature was reviewed to validate or refute these assumptions and the outcomes are presented here.

3.2.2 Adverse Drug events in Elderly

*Adverse Drug Events* (ADEs) refer to events of medication-related patient injury, whereas the term *medication error* encompasses all errors that may occur at any stage of the medication process, with or without patient harm (von Laue, Schwappach, & Koeck, 2003). Not all medication errors lead to ADEs since the majority of errors made in the medication process are inconsequential; however, a few may become ADEs and some potential ADEs actually become clinically significant events, leading to morbidity or mortality.

According to recent systematic reviews, 5-40% of patients received inappropriate prescriptions (Beers 1991; Beers 1992; Dimitrow, 2011; Rojas-Fernandez, 2003; Thomsen, 2007). Polypharmacy (defined as use of multiple medications that may or may not be indicated in a particular patient) is common, so is misuse, overuse or underuse of medications (Linjakumpu et al., 2002; Chassin & Galvin, 1998). Moreover, a number of unique and important physiological changes occur in older age that alter the pharmacokinetic behaviour of most medications (Bressler & Bahl, 2003). Unsurprisingly, every year 20-30% of residents in nursing homes and elder care facilities are reported to experience one or more ADEs (Gurwitz et al., 2000). Admittance to a rest home for patients with multiple conditions and on multiple drugs is the highest risk factor for them to experience potential ADEs (Fialová et al., 2005; Field et al., 2001; Rigler, Jachna, Perera, Shireman, & Eng, 2005).

3.2.6 Medication safety in rest homes

Some side effects are an inherent part of most medications and cannot be mitigated even by ideal prescribing or usage. These undesirable effects need to be monitored and managed to strike a balance between the desired and undesired effects of a medication. On the other hand, it may be that the problem is not inherent within the drugs, but in the way they are prescribed, dispensed, taken and monitored. For example, Warfarin is well known to prevent strokes in older patients who have had atrial fibrillation (White et al., 1999) yet the use of this medication...
in everyday clinical practice is problematic. Prescribers fail to monitor INR levels, adjust dosage or frequency or even fail to withhold drugs that may interact with Warfarin; as a result, bleeding occurs which may be fatal (McCormick et al., 2001). Therefore, the drug in itself is useful, but the problem lies in its use and many errors are often revealed only in retrospective reflection and analysis.

Another important aspect of ADEs in elders is failure to recognise them (Ballentine 2008). Often patients, caregivers, or even physicians mistake side effects for the onset of a new illness or, worse, for aging itself. Such side effects include confusion, forgetfulness, gait instability, tremors, incontinence, and fatigue. Moreover, evidence-based prescribing based on evidence generated in younger cohorts and extrapolating results to the elderly is fundamentally flawed (Gurwitz & Rochon, 2002). In frail, older people, there are additional issues like judging the evidence in light of the individual’s condition, increased risk of ADEs, patient and family views on risk, ability to understand and consent to treatment, and even cost effectiveness of treatment (Coulter, 1999).

In the context of elder care and ACFs, there are four specific recommendations made for system improvement (Williams, Thompson, & Brummel-Smith, 1993; Williams et al., 1999).

1. Better monitoring of medication use in ACFs could improve medication safety
2. Accurate record keeping
3. Periodic review and reconciliation of medications by pharmacists or healthcare providers familiar with geriatric care
4. Providing education to staff and patients about proper use of medications and adverse effects of medications.

Appropriate use of technology for promoting a closed-loop medication management would be an important option to enable a major portion of these four recommendations. Electronic prescribing and signal-based alerts have already been used in hospitals to monitor ADEs (Handler & Altman, 2007) and similar systems could be designed to focus on ordering and monitoring issues in the nursing home as well (Gurwitz & Rochon, 2002).
3.3 Ethnographic Field study: Mapping medications processes

Issues of clinical relevance, medication-related issues in the elderly, and the areas of improvements precipitate an assessment at ground level in one of the ACFs in New Zealand in order to gain a better understanding of the situation.

3.3.1 Objectives

The objectives of the initial phase of research were:

- To map and describe how medications were prescribed, dispensed and managed by the caregivers and residents of the ACF
- To match the findings from the literature around safe medication management with those in actual practice within the ACF.

3.3.2 Methods

Qualitative methodologies have successfully been used to understand the complex nature of relationships, processes and systems in social situations. Among the qualitative methodologies, the ethnographic method has a long and distinguished history. Gold (1997) defines ethnography as a method of fieldwork that offers unique investigative, substantive, and theoretical contributions to social research. Historically practiced by anthropologists and social scientists, ethnography involves a particular set of methodological and interpretive procedures that study a culture or a group to understand, compare and present their findings (Blumer, 1986). Ethnography has been used in New Zealand to derive an understanding of ground realities within organisations for development and deployment of information systems (Myers & Young, 1997). The method directs researchers to study human society from the points of view of its members and refrain from relying on a preconceived framework; it aims to discover and create analytical frameworks for understanding and portraying research material grounded in the informants’ actual experiences.

Mantzana et al. (2007) describe four actors in the implementation of health information systems: providers of healthcare services, recipients of care, controllers, and supporters. In this study, it was attempted to understanding the actors, their context and profiles within an ACF environment – in relation to the medications – through observations of people, processes and flow of information.
The ethnographer is considered the principle instrument of observation and becomes intrinsic to the analysis as they empathise with the study group in that situation. Participant observation is supplemented by a variety of data collection tools which may range from key-informant interviewing, collection of life histories, semi-structured interviews and questionnaire administration, and silent observation and taking notes. The main reason for employing a variety of data collection procedures is to enable the investigator to cross-check results obtained from observation and recorded in field notes (Sanday, 1979). This field study mapped the medications processes in an ACF using ethnographic observations. The following tools were used:

1. Shadowing of caregivers as they went about performing routine tasks
2. Field notes, pictures and videos taken by the researcher while following caregivers in the facility and pharmacists in the pharmacy
3. Discussion with various actors (1 doctor, 2 pharmacists, 3 caregivers, 1 nurse, 3 residents and 2 managers).

3.3.2.1 Preparation

Before starting this ethnographic study an approval was taken from the ethics committee (UAHPEC). The committee required clarifications about the commercial interests involved, the possibility of stressing busy employees and how that would be addressed through organisational employee assistance programme. On submitting clarifications to the satisfaction of the committee, an approval was granted (UAHPEC Ref. No. 2009/180)

For the purpose of this study, high-dependency rest home and dementia patients as well as hospitalised patients were excluded, as they needed highly skilled assisted care. The ethnographic study focussed on residents living independently who were managing themselves with or without any personal assistance. Of special interest were residents who were personally assisted by caregivers for their medications because they would be most informative about manual medication management assistance.

A range of people, including a manager, two caregivers, the facility’s doctor and pharmacist, and three residents (one of whom was accompanied by her daughter and another by her grandson), were formally interviewed. The transcript analysis details are not given in the current chapter but will be described in Chapter 4. A general reading of transcripts without coding helped at this stage to draw conclusions about processes and map them accurately.
3.3.3 Field study outcomes

This study resulted in two main outcomes:

1. Social structure around medications
2. Medication-related processes within Selwyn Village.

3.3.3.1 Social structure around medications

The field study at Selwyn Village discovered that complex networks of interactions and dependencies exist within the village in relation to medications being managed by relatively independent residents. Most of the residents manage their medications by themselves or with some help from their spouse, while a small number are personally assisted by a caregiver who visits their rooms at specific timings during the day to personally administer and supervise intake.

Resident: They can be living singly or as couples; they may or may not keep close contact with the family and family may or may not be closely involved in their medication use. The resident is free to choose a GP employed at the Selwyn Village Medical Centre or outside the campus, as some residents prefer to keep their former GPs. Likewise, the prescriptions could be served by a pharmacy outside the campus or in the neighbourhood of Selwyn Village. Some residents may also be receiving specialist care for their chronic conditions.

Pharmacist: Pharmacists in New Zealand run private businesses dispensing medications as per prescriptions and are subsidized by the Ministry of Health for the medication bills. Older users, especially those who carry a high usage card, are required to co-pay only a small amount to the pharmacy. This has a significant positive impact on older people’s access to medications. Most pharmacies use a computerised system to manage their work. There are mainly three types of pharmacies supporting Selwyn Village residents. The first one works closely with the medical centre and supplies medications in pouches to those residents who have been recommended by the medical centre GP. The other pharmacy is located in the neighbourhood of Selwyn Village and is a convenient place for many residents to pick up their prescriptions or refills. This pharmacy supplies medications either loose (bottles, strips and so on) or in blister packs. The third type could be located anywhere in Auckland, usually a pharmacy with which the residents have had a lifelong association.

Physicians: GPs within the medical centre have special interest in geriatric care and coordinate services between the in-campus hospitals and high dependency units as well as offer outpatient
department consultations in the medical centre. GPs also support residents by providing a single point of coordination between specialists, hospitals, allied health practitioners, caregivers, and pharmacies. The specialists usually work in outside hospitals and support higher levels of care. Most GPs in New Zealand use an EHR that is part of their Practice Management System (PMS) and prescriptions are printed using a CPOE. However, there is no interoperability between pharmacy systems and PMS.

**Caregivers, Managers and Nurses:** The services to patients on a day-to-day basis are provided by fulltime or part-time caregivers on permanent or short-term contract. Some patients are physically served their medications by trained caregivers. The medications may be served in many settings, e.g. in the morning they go on a round, or in the afternoon during lunchtime in the common dining room. In these cases, the patients are under the care of the medical centre GP. The caregivers store medications in safe lockers along with the necessary paperwork in one of the residential buildings. Caregivers use a paper-based documentation system that helps them recognise right patient and right medication at the right time; they supervise the correct route and dose of medication and the success or failure of intake is recorded in their ‘drug chart’. This drug chart is periodically shared and updated by the medical centre nurse and the GP. The village nurse is on call 24 hours a day. The village nurse monitors emergency alarms and responds to calls, and coordinates with residents’ providers in case of problems with their medications. They conduct the medication round and physically assist residents who are under supervised care, especially on the weekends and afterhours when the caregivers are not present on the campus. Managers have a supervisory role, backing up caregivers as well as coordinating access to medications charts, and responding to calls.

Figure 3.1 captures the complex network of social relationships that exist between the actors. There are multiple users, providers, pharmacists, caregivers, managers, family members, and all share different relationships. It is multidirectional, unpredictable and partly independent of spatiotemporal constraints. It is important to understand this rich network, so that the proposed intervention does not interrupt or replace relationships, but rather further enriches them with useful information.
Figure 3.1: Social network related to medications in Selwyn Village. The circle represents the Selwyn Village campus and arrows represent interactions.

**Legend:**
- Informal communications
- Medication related communications
- Consultations communications
- Inter-professional communications
- Administration related communications
3.3.3.4 Medication-related processes within Selwyn Village

This section describes processes that were synthesised using the field notes, analysis of the images, and videos and audio recordings made during a series of visits over a few days. The focus of this exercise was to capture the way a human caregiver assists older people. Instead of tracing the usual process followed by an independent resident, we looked at nine dependent people being served around the village and mapped the following processes:

1. Process of prescribing, dispensing and delivery of packaged medications
2. Process of enrolling patients and organising medications by caregivers
3. Process of caregiver dispensing medications
4. More details and possible variations to the above process.

The process starts at the level of the GP who synthesises information from previous records, present complaints and investigation reports to generate a prescription using PMS (Medtech 32 in this case). This prescription is usually printed (handwritten in some cases) and faxed to the pharmacy, where it is validated and re-entered into the pharmacy management system (Toniq). The electronic medication list is split into two parts, one into a list of pills (tablets, capsules, tubules, gel caps etc.) and another list of other non-pill forms (syrups, sprays, drops, patches, creams, lotions etc.).

The list of pills is electronically sent to a robotic packaging system that has the most commonly prescribed pills stored inside it. The pills that need to be halved are manually loaded in a separate tray. This robot reads the prescriptions for a person and packs pills for one or more of ‘breakfast, lunch, tea and dinner’ time sachets. A roll of such sachets packs the entire supply for a week or a month for a particular person.

From the medical centre, the boxes are distributed to the patients or collected by the caregiver. Each sachet contains the designated tablets for a particular person for a particular time of the day. Figure 3.2 illustrates the compliance packaging system being used in Selwyn Village. It shows the sachets containing pills and that are labelled. Rolls of such sachets are packaged in a cardboard box. The patient can pull out one sachet at a time from this box.
The GP is usually the deciding authority who assesses the need or receives requests for assistance, and may choose to put the patient on weekly or monthly refill cycles. More stable patients are on monthly cycles whereas those who take sensitive medications (like Warfarin) or whose medications change rapidly due to fragile medical status are put on weekly cycles. Once the decision is made to put someone on assisted medications, this information is conveyed to the designated caregiver and her manager.

These images inform the designing process where the automated medication assistant’s ability to correctly predict the information printed on the sachet and the user’s ability to read and identify the right sachet for the right time and day is critical to accuracy of intervention.

During the ethnographic study, processes and activities related to medication handling by the caregivers were mapped and examples are shown in figure 3.4 and 3.7. Process mapping helped the researcher to identify information gaps, risks and generated ideas for intervention.
Figure 3.3: Processes involved in caregiver enrolling and attending to new patients. Caregivers pick up the medications, drug charts and other details from the medical centre from the start of the next dispensing cycle. Thereafter, the caregiver includes the new patient in her daily medication rounds. Often, the caregiver is substituted by the nurse during after-hours service.
The processes illustrated in Figure 3.3 show that not everyone needs assistance with medications. Most of the users manage medications by themselves. Only a few who are unable to manage and are able to afford a personal caregiver to help them with medication, receive this service. There would be many who are struggling with their medications but do not inform or cannot afford this extra service; they could be assisted by some form of automated service. However, appropriate business models to deploy expensive technology remain to be explored. One such mechanism would be to incorporate automated support services within delivery infrastructure, an option that Selwyn Village favourably considers. The figure also informs that those on special assistance are on packaged medications, implying that to assist those on loose or unpackaged medications in a complex regimen would be a far more challenging situation. Moreover, the automated assistance would find it difficult to procure medications from the pharmacy on the user’s behalf; it can only prompt the user or another actor when a medication is finishing and a refill is due.

3.3.3.5 Human caregiving in medication assistance sessions
During a typical medication assistance session the medication round serves two important functions. Firstly, it can detect a serious emergency or a fall that might have happened in an earlier part of the night/morning and secondly, it gives an opportunity to assess the elder’s overall condition and address mobility problems.

A human caregiver is typically able to assess personal needs and preferences, which many residents tend to be very particular about. Importantly, they tend to cross-verify the caregiver’s accuracy in dispensing, indicating the need for knowledge and affirmation. An experienced caregiver should seize this opportunity to transfer knowledge and educate about the medication. They also tend to engage in social conversation and include the assessments and dispensing of medications as part of a social interaction, rather than making a separate issue of it. Furthermore, the caregiver can verify successful consumption of the medication through empirical observation. She is also able to troubleshoot minor problems like dropped pills and requests for medical assistance. Caregivers also record and report the outcomes for other members of the team, to maintain continuity. It would, therefore, be very useful to carry the richness of this interaction into an automated system notwithstanding the limitations of technology.

The process starts with the caregiver accessing the secure medication storage cabinet and checking the list of patients that she has to visit that day or at that time of the day. As seen in
Figures 3.4 and 3.5, the medication closet is located in a public area for easy access but is securely locked. Since some residents take their lunchtime medications in the dining area, it makes it easy for the caregiver to access medications while assisting residents with their meals.

![Figure 3.4: The medication closet (red arrow) next to the dining room (orange arrows)](image)

These images also informed us that if a robot has to navigate the area, it must manage itself through the clutter of the furniture as well as moving people, walkers, wheelchairs and mobility scooters. Also the camera needs to be able to handle sharp contrasts and moving crowds to reach its target.

![Figure 3.5: The caregiver collecting medications from the closet, and the drug chart kept on the table](image)

Every time the caregiver unlocks the cupboard, she collects her medication supplies along with the medication chart which is kept on the table outside the cupboard, as seen in the image above. After matching the names on medications with the names on the chart she heads to the living quarters. The process diagram shown in Figure 3.6 explains the medication dispensing process by the caregiver.
The process map informs the design implications by showing a high probability of risk, and emphasises the value of elaborate and timely mechanisms for risk assessment and call for assistance. It also calls for a robust medication-related activity recording and reporting mechanism, given many things could possibly go wrong and not all of them can be addressed by a robot.
3.4 Discussion

Action research is context-bound, and not context-free. Therefore it is difficult to determine the cause of a particular effect that could be imbedded within the environment, unless one thoroughly examines the context of action research (Baskerville et.al, 1996). The conceptualisation of a solution ideally begins with understanding of the problem/s. An intervention should ideally be grounded in the reality and perceptions of people and processes (Rivers, 1992). To derive this understanding, it is important to map the processes and understand perceptions accurately within the research environment. An ethnographic study serves this purpose.

The research direction towards resolving issues around medication management for the elderly was supported by the literature. Medication management is known not only to be a complex but also an error prone process, putting people at high risk, and especially those octogenarians living in ACFs who consume multiple medications every day. The practice of polypharmacy and regimen complexity, the inherent toxicity within potent medications, and the physiological sensitivity and cognitive deficiencies common in old age, all contribute to that risk. Multiple approaches have been suggested to reduce this risk. From the prescriber’s perspective, balancing risk of prescribed medication with desired therapeutic effect, a regular & timely feedback mechanism, close monitoring and team work to review and reconcile medication is recommended. From the older patient’s perspective, promoting adherence to medications is good but not always a safe practice. Recommended risk-countering mechanisms include patient education, addressing beliefs and attitudes, and training, reminding, and building capacity to safely manage and communicate medication-related issues.

In the survey, it was confirmed that medication management is considered a high-risk scenario within this setting. Skilled staffs personally supervise and monitor vulnerable patients. However, risk mitigation measures (section 3.2.6) are patchily implemented at best. Not all patients go to one doctor and they all have different skills and interests. The resident physician within the facility has special interest in geriatric medicine but other GPs may not. A medication reconciliation process when a patient is transferred between settings is not a routine practice. The information systems used by physicians and pharmacists do not interoperate and information silos are prevalent despite high use of computers. The responses are collected on a paper format by semi-skilled caregivers who may not always recognise an ADE. Physicians do not always receive the feedback on a regular basis and clinical monitoring tends to be irregular.
and incomplete. Moreover, not all residents are personally supervised and there may be many who are struggling with their medications but do not report or cannot afford an extra service.

Compliance packaging in the form of pre-packaged and labelled sachets do reduce regimen complexity but have little impact on the practice of polypharmacy and possibilities of administration errors. Errors during administration are common, where people forget, drop medications, miss doses, and miss refills, refuse to take medications and even cough or vomit medications out. Compliance packaging serves a useful purpose of reducing complexity, but by converting plurality of medications to a singularity, it strips away the opportunity to build skills.

During mapping a potentially dynamic web of relationships was uncovered. People tended to develop a relationship with caregivers rather than with their medications. The caregiver is not just a reminder alarm who knocks and drops the medications but also addresses needs for respect, motivation, monitoring and support. This may be important for a designer to note so that the proposed technology does not alienate the user or replace personal relationships but enriches them with useful information. In addition the caregiver is backed up by nurses, managers, pharmacists and physicians. Social contextualization of medication processes and the value of a rich social network remain insufficiently emphasised in the literature. There may be useful learning from this social network that an automated system could benefit from and aspects that it should not attempt to replace.

Situated in a positivist framework, publications tend to make uniform assumptions about the capabilities and risks of older people, whereas in reality a wide range of variations exists. Some people are perfectly capable of managing their medications at any age whereas others may need close support. It simply means that one size would not fit all; an automated assistant needs to be customised to each individual’s needs and capacities. An ideal system would give full autonomy to a capable person, supporting task delegation for a semi-dependent one, while recognising those who cannot use technology and would need human support only.

With this rich understanding of context and implications, the description of the design process will commence from the next chapter.
3.5 Chapter summary

This chapter described the commencement of the research journey, starting with developing an understanding of the context, using an ethnographic study before starting action research cycles. Research has focussed on reducing prescription errors at the clinician’s end and administration errors in the hospitals, leaving research gaps to address closer monitoring of medications, early detection of adverse events, and quality use of medications by older patients living in the community. With this direction, a field study mapped the medication-related processes and identified a rich social network around the use of medications in a facility, challenging the assumption of self-care (or self-management of medications) as a personal activity in isolation from other actors. The study also uncovered the routines and regimes, processes and protocols, complexity of communications and personalisation of interactions that underpin the use of medications by older people in a typical aged care facility.

Having gained some information about the environment of a facility, the next steps would be to explore further implicit and explicit assumptions of actors to inform the development of a theory and practicality of the design process. Introducing an automated medication assistant would need to fit within this environment and attempt to address, if not mimic, these workflows and protocols. It would also be useful to gauge how the doctors, managers, caregivers and residents perceive and would probably react to a new automated agent, and how would their assumptions about a robot influence their perceptions. In the next chapters, the implications of these observations to inform the design of a prototype will be described.
Chapter 4: AR Cycle 1: Initial design process

4.1 Introduction

The previous chapter presented a rich description of the environment and social context of medications within Selwyn Village. It also showed how the actors were identified and the role they play in various medication-related processes. The initial understanding that evolved during ethnographic analysis was presented to describe the backdrop. This chapter explains the way in which subsequent discussions (with actors identified earlier) informed a theory-building process by grounded analysis of discussion transcripts as well as the development of a paper prototype. The two streams of research seeking answers to the two research questions concerning the theory of an automated medication assistant and the design of a prototype were developed in parallel. This parallel processing approach runs throughout the thesis, but particularly in this chapter, the description is detailed in order to lay the foundation for subsequent chapters. The description focuses on:

1. How grounded theory was used as a foundation for the development of themes via intermediary units of categories and codes
2. How participatory design led to the development and validation of a paper prototype of conceptualised robot behaviour
3. How 1 and 2 above were interwoven in the fabric of action research and presented under the four steps of the AR cycle, namely Plan, Act, Evaluate and Reflect
4. The chapter concludes with reflections on the design and data model, as well as axial and selective coding of the data in accordance with grounded theory principles.

Before starting with the field study and jumping into prototype development, it was felt important to scan the literature about how the medication management process has been addressed earlier. Strauss and Corbin (1998) describe the important role that literature survey plays in grounded theory research. They describe five aspects to this exercise:

1. Stimulating theoretical sensitivity – sensitise the researcher about the potential known issues, concepts and relationships within the domain to inform interviews and coding. Also being informed about existing theories could help verification of data
2. Providing a secondary source of data – quotations from published research or events, actions, settings and perspectives of actors
3. Stimulating questions – formulating what to probe or ask the interviewees so as to verify or contradict what has been observed earlier in other contexts
4. Directing theoretical sampling – where to explore for entirety of phenomenon or to fill gaps in the initial data
5. Providing supplementary validation – to validate the theory against the literature and add references to assert the theoretical assumptions and recommendations.

The following section collects findings from the literature and summarises the multiple viewpoints into eight important issues concerning use of robotic technology in elder care.

4.2 Literature survey: Issues around supporting the elderly with technology

Home monitoring of older adults living in their homes has been extensively studied in recent years. Systematic literature reviews have found patients and providers accepting the technology and discovering indications of positive effects on chronic illness outcomes such as self-management, re-hospitalizations, and length of stay, in addition to reduced healthcare utilization and travel costs (Barlow, Singh, Bayer, & Curry, 2007b; Botsis & Hartvigsen, 2008; Bowles & Baugh, 2007; Demiris et al., 2004). More recently, robots have been identified as a potential option to add another dimension to home monitoring by adding mobility, improving communication capabilities, supporting continuity of care and relieving the burden of routine repetitive tasks on caregivers (Boissy, Corriveau, Michaud, Labonte, & Royer, 2007b).

Preliminary studies at the Joint University of Auckland/ETRI Centre for Healthcare Robotics (Elizabeth Boradbent, 2008) have also shown the possible role of robots in monitoring location, recording vital signs, detecting falls and assisting with medications. Out of many implications of information and assistive technology, in this early phase of research it was felt important to assess ethical, socio-cultural, economic and regulatory considerations. The literature highlighted the following issues that need to be understood and addressed.

4.2.1 Issue 1: Autonomy vs. safety

The choice of deploying a robot poses significant responsibility to address possible concerns (Koch, 2006). Introducing any intervention in the care of humans should be done with due respect to four cardinal ethical principles: respect for autonomy, beneficence, non-malfeasance and justice (Beauchamp & Childress, 1994). The assessment of ethical implications on healthcare technology involves consideration of the entire range of user experiences relating to personal autonomy, privacy, dignity, safety and choice, surrounding the use of technology (Lehoux & Williams-Jones, 2007).
A constantly aware agent that can record, transmit and communicate personal health and activity information could be seen as an infringement (Percival & Hanson, 2006). The ethical dilemma arises where we design features that may or may not enable choice; that is, a robot may make certain decisions based on its programming whereas a user may or may not allow certain features (Peter, Alan, & Mary, 2002). A possible solution could be found in the user’s ability to customise the robot’s behaviour. For example, observational recording could be switched off when a user did not want to be observed (Wessels et. al, 2003). On the other hand, giving users greater autonomy may compromise safety; e.g. a potentially lifesaving intervention could be missed if the device remained switched off while the person had a serious fall. Therefore, a satisfactory balance between autonomy and safety should be sought by designing appropriate rules and by creating some functions that can be defined by the user in partnership with providers (McCreadie & Tinker, 2005).

4.2.2 Issue 2: Dependence vs. independence

Robots have been shown to perform tasks like vacuuming and making coffee, while others have been deployed to assist disabled people (Helal, Mokhtari, & Abdulrazak, 2008). The benefit of performing tasks for other people is debatable. In some cases, it may be helpful while it might also encourage dependence (Magnusson et al., 2002). In addition, old people are expected to have different preferences. Some would be active users of technology while others would be passive recipients or somewhere in between (Pascale Lehoux, 2004). Therefore, the degree of independence ultimately experienced by the old person in an ACF could become a function of defined system design – a combination of preferences, functionality of the robot, institutional environment and rules defined by the healthcare providers – on which they depend to carry out various health-related tasks (Bosser, 1993). Therefore, the design needs flexibility to strike a balance between user preferences and level of frailty, where more independent people get to exert wider choices and gradually delegate more control to the robot as they decline in cognitive and functional capacities.

4.2.3 Issue 3: Joy vs. fear

Breazeal at MIT labs describes how her experiments with robots evoked emotions in people, and she recommends how to design robots that make people happy (Breazeal & Scassellati, 1999). However, in a large scale nationwide trial, Fazzi et al., observed that fear of equipment (31.1%) and intrusiveness of equipment (24%) were the two biggest reasons cited for patients refusing to use health monitoring technologies (Fazzi, Ashe, & Doak, 2007). These challenges are likely to be highlighted by a large, bulky, anthropomorphic robotic device where
conjectures from sci-fi movies and media are likely to affect their perceptions. Therefore, it is difficult to conclude whether healthcare robots would invoke fear or joy. Moreover, if older people feel that they are controlled by technology, rather than using it as a tool to remain in charge of their lives, then robotic fear is going to increase (Phillips & Zhao, 1993). Subordination to technology could become increasingly problematic as enabling technology is developed that exhibits increasingly intelligent behaviour (Gips, 1995). This can, of course, happen to everyone who uses such technology, but older people may be in a particularly vulnerable position due to the lower degree of control that they appear to exert.

4.2.4 Issue 4: Social isolation vs. enhanced communication
The success of companion robots in alleviating isolation seems to score in favour of technological intervention in aged care scenarios (Taggart, 2005). Conversely, Gips (1995) raises ethical questions around the appropriateness of delegating the care of older people with limited mental and limited emotional resources to a robot. This aspect of human dignity and the potential for robots to provide permission for family members to abdicate responsibility on the pretext that their elders have artificial company is a source of moral jeopardy. On the other hand, denying robotic assistance or removing the robots without replacing them with true human contacts is not necessarily an improvement (Hansson, 2007).

4.2.5 Issue 5: Reducing medical errors or introducing new ones
Introducing a system to keep accurate medication records, reminding users in time and reporting back to the physician is expected to reduce chances of error (Bates et al., 2001). Similar to any other technology in homes, robots would also be expected to conform to electronics, software and medical device industry standards. However, medication-related processes irrespective of robots have inherent chances of errors (Kohn, Corrigan, & Donaldson, 2000). Despite an assumption of increased accuracy and safety, some applications actually foster errors (Berger & Kichak, 2004), raising serious concerns of safe use of technology in a vulnerable elderly population. Moreover, the safety of keeping a robot in sloping passages, staircases, small rooms, especially bathrooms where the water and humidity may short-circuit or malfunction the device, is questionable (Boissy, Corriveau, Michaud, Labonte, & Royer, 2007a). Designing and implementing automated solutions will minimise the unintended consequences of obvious as well as subtle errors (Ash, Berg, & Coiera, 2004).
4.2.6 Issue 6: Organisational acceptance vs. rejection

According to the Technology Acceptance Model, (Davis, 2000), in order to be perceived as useful, robots must fit into the organizational workflows, ensuring buy-in from healthcare professionals and ACF staff. It has been seen earlier that information technology applications are not always accepted due to the perceptions of healthcare providers (Lu et al., 2003; Miller & Sim, 2004; Young, 1984). The acceptance of technology by healthcare professionals is a complex issue that needs to be addressed comprehensively (Chismar & Wiley-Patton, 2003; Patrick & Paul, 2002). It has been recognised that the implementation of innovative solutions can be a frustrating task in healthcare settings (Audit commission report, 2004; Khalil, Marinos, & Zahir, 2006; Ville, Dario, & Mikael, 2003). Professionals perceive changes as threats to their authority and autonomy, which has been a challenge in implementing safety measures and use of automation (Leape & Berwick, 2005). Moreover, the concept-reality gap described by Heeks as the gap between imagined high expectations and the actual clunky performance of the system, could be another cause of rejection (Heeks, Mundy, & Salazar, 1999), where expectations about the robot could be higher than the capabilities that current technology offers. Successful implementation should be supported by the development of a community of practice of users as well as an opportunistic approach to learning about the technology (Day & Norris, 2006).

4.2.7 Issue 7: Enhancing workforce capability vs. fear of losing jobs

Robotic assistance is expected to bridge the demand-supply gaps in the healthcare workforce by enabling the existing workforce to handle more clients and supplement their role; for example, by automatic handling of repetitive tasks and enhancing communication (Magnusson, et al., 2002). On the other hand, Elrod and Tippett (2002) describe predictable ways in which people respond when manual labour is complemented or replaced by automation. Usually, the organization passes through the initial fearful reaction of the existing workforce to the improved processes before the reduced work burden, enhanced skills and productivity brought in by the automated system is realised (Hammer & Champy, 2001).
4.2.8 Issue 8 – Expensive robots vs. reduced costs of care

The introduction of robotic assistance for older people is expected to be beneficial. Extrapolating lessons from home monitoring programmes (Barlow et.al 2007), it is possible that such a system might:

- Reduce the cost of institutionalization (by promoting ageing in place)
- Reduce morbidity and hospitalization (fewer adverse drug events and falls, better chronic disease outcomes leading to fewer visits)
- Contain manpower costs despite increasing demand-supply gap.

Even in many developed countries, the affordability of care for older people is limited. Financial support for the care of older people is mostly met by social security and public funding, and these crown agencies need to be convinced that there is a cost benefit to such interventions (Fuchs, 1998). Given these challenges, it is suggested that the design of robotic technology should be cost-conscious and tailored to areas of maximum cost-efficiency impact. An elaborate design may have advanced features but the incremental impact on solution robustness, quality of life and cost of care should be carefully justified in financial terms (Miskelly, 2001).

Being informed by these issues served as a useful starting point and stimulated thinking about the possible scope and features that could be included in the design. The next section describes the design and process of validation of a paper prototype.
4.3 First AR cycle: Field study with paper prototype

4.3.1 Objectives
The objectives of this phase of research were:

1. To seek expert opinion on an overall meta-cognitive model of the medication reminder module design
2. To seek feedback from representative elder users about any glaring or pressing issue/s
3. To develop the design elements to inform the automated medication assistant
4. To draw elements from the data to inform a theory-building process

4.3.2 Apparatus
The participants were shown the picture of the robot before the interview along with the screen on which the dialogues would appear. Followed by the image of the robot, the participants were shown four A4 size sheets of paper representing the screen states on the robot. Each of these sheets displayed a simple sentence which the robot would display and speak. The description of the robot and the paper representation of screens are shown in Figures 4.1 and 4.2 respectively.

4.3.2.1 ‘Cafero’ the robot (Healthbot)
The following image of the robot was shown to the participants:

![Figure 4.1: Cafero – the robot from Yujin Robotics](image)

Camera
Touch screen
Pan-tilt screen frame
Speaker and microphone
Blood pressure monitor
Tray
Hokuyo laser scanner
Rotatable body
Power and charging
Wheels
The robot was initially developed in Korea by Yujin Robotics for serving coffee in a coffee shop and it was therefore named ‘Cafero’. The details of hardware and software architecture of Cafero are described elsewhere; (Jayawardena et al., 2010, Kuo et al., 2011). The labelled image in Figure 4.1 depicts a mobile robot about 1.5 metres high. The robot has no arms or face but a touch screen mounted at the top of the torso and a tray in the middle. The tray was used to carry physiological monitoring apparatus. The base of the robot was composed of battery, navigation and mobility apparatus. The physical dimensions of the robot were derived earlier by other researchers in the team (Tamagawa et al., 2009). The dialogues for medication assistance would only be using the touch screen and speakers on the top.

### 4.3.2.2 Paper representation of dialogues

The participants were shown four sheets representing four screen states (labelled (a) to (d) in Figure 4.2). Each screen had the dialogue on the top and one to two soft button options in response to this dialogue at the bottom. Choosing an option (e.g. Yes/No) was equated to pressing a soft button. The next screen would logically follow according to the choice made. Answering ‘No’ to the dialogue (a) would lead to screen (c) and choosing either ‘Not feeling well’ or ‘Already taken’ would lead to screen (d). The flow of screens through either (a)→(b)→(d) or (a)→(c)→(d) is represented in Figure 4.2.

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**Figure 4.2**: Paper prototype of robot screen - displayed possible dialogues on a screen or spoken aloud to the participant. Images (a) – (d) are four screens and dotted arrows show possible movement from one screen to the next.
In the paper representation, a simple branching tree logic accounts for positive and negative scenarios. Whatever the response pattern is, the robot would log the information. The content for these dialogues was prepared after reflecting upon the findings of earlier work, where the ability to exert choice, engaging social communication and recording of user activities for the purpose of monitoring and feedback were considered important.

**4.3.3 Methods used in first AR cycle**

To briefly reiterate the methodological process, the first cycle of Action research followed the ‘Plan, Act, Evaluate, Reflect’ cycle. The planning phase involved reflections on previous work (i.e. the literature survey contextualized to this specific cycle) as well as interview consents and set times for interviews. The phase of acting involved creation of a paper prototype and conducting two sets of interviews with a wide range of respondents. The evaluation phase involved coding of interviewed data as well as participant feedback on the paper prototype. The reflection phase involved thinking more deeply through the open codes and allowing categories to emerge while finalising the data model and workflow design for the robot.

Figure 4.3 illustrates the steps in the AR cycle and also attempts to hint as to how other methodologies seamlessly interplayed to inform various phases of this AR cycle.

The development of the paper prototype and interactions with participants in the initial two steps reflects more of Participatory Design principles, whereas coding and analysis reflects more elements of Grounded Theory. Though Figure 4.3 separates the ideas for the purpose of simplified illustration, in reality these methods and processes are often co-mingled, conducted in parallel or iteratively moving ‘back and forth’ seeking refinement. For example, elements of PD dominated in the plan and act phases, they continued well over into evaluation where the
prototype was discussed with experts, and also during reflection where a design framework was created. Similarly, GT elements dominated the phases of evaluation and reflection, but the elements in the initial phases were forming while interviewing.

It may perhaps be useful to briefly digress a little at this stage and highlight the rationale of paper prototyping as part of the PD process, before continuing with the overall methods section.

4.3.3.1 Paper prototyping as a PD methodology

Design requirements can be elicited through site visits, workshops, story-telling, dramas, games or use of dummy prototypes (Muller, 2002). Ehn and Kyng (1991) describe the use of a paper prototype as an effective means of eliciting requirements and testing the initial ideas. It is a useful technique to encourage respondents to think about past experiences of technologies and unravel unique personal stories that contribute to the ways people shape and respond to imaginary scenarios with the help of a dummy prototype (Muller, 2002). The responses can even re-shape the design by highlighting important things a designer initially might have missed. The benefits of a participatory prototyping approach have been extraordinarily influential in informing designs across the globe (Druin, 2002; Druin, Bederson, Rose, & Weeks, 2009; Hutchinson et al., 2003; Muller, 2002). Paper prototyping techniques have also been successfully deployed for developing technologies for seniors (Massimi, Baecker, & Wu, 2007).

The benefits of using a paper prototype to elicit responses are:

- Enhanced communication and understanding through grounding discussions in a concrete artefact rather than giving hypothetical explanations
- Enhanced incorporation of new and emergent ideas through the ability of participants to articulate their expressions
- Enhanced working relationships through shared ownership of the resulting design
- Practical application with measured success to actualise a useful and practical output.

4.3.3.2 Conducting interviews

Proceeding with theoretical sampling, more data was collected from sources that could contribute towards building a wider context and add richness (Corbin & Strauss, 1990; Glaser, 1992; Dey 1999; Charmaz 2006). The second set of data collection was completed and again analysed using the open coding process, described in this chapter.
The planning phase of AR included preparing questions, obtaining further consents and scheduling interviews. Thereafter, a series of interviews were conducted over a period of two months. The interviews were covered by the ethics approval from UAHPEC. A phone call was followed by an initial appointment to explain the study, give the participant an information sheet and a signed consent was obtained as per ethics protocol. There were two sets of interviews during the first AR cycle.

1. Initially the actors identified earlier (in Chapter 3) who were involved in the medication processes within the ACF environment became the participants for the first round of interview

2. The data from initial interviews was felt insufficient in building enough categories, prompting *theoretical sampling* (see section 2.4.3) to choose a wider range of experts from diverse backgrounds for the second round of data collection.

The interviews of the actors involved (Table 4.1) were either in a one-to-one setting or a group setting depending upon the need for eliciting expression of deeper insights as thoughts bounce off during debates and discussions. The entire exercise was expected to make implicit ideas explicit (covering a wider context) and reveal nuances that could inform the design in a manner characteristic of participatory methods, as well as aid in theory building. The roles of actors and interview details are summarised in the table below.

<table>
<thead>
<tr>
<th>Actor</th>
<th>No.</th>
<th>Role</th>
<th>Interaction</th>
<th>Data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doctor</td>
<td>1</td>
<td>GM Medical services (GP at medical Centre)</td>
<td>Group discussion</td>
<td>Audio recording and transcript review</td>
</tr>
<tr>
<td>Pharmacist</td>
<td>1</td>
<td>Owner of pharmacy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caregivers</td>
<td>3</td>
<td>Assigned to Litchfield Towers</td>
<td>Interview</td>
<td></td>
</tr>
<tr>
<td>Managers</td>
<td>2</td>
<td>Manager clinical services</td>
<td>Group discussion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assistant manager independent services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residents of Selwyn Village</td>
<td>3</td>
<td>From two different buildings</td>
<td>Group discussion</td>
<td></td>
</tr>
<tr>
<td>Family members</td>
<td>4</td>
<td>Children of two of the interviewed elderly residents</td>
<td>Group discussion</td>
<td></td>
</tr>
</tbody>
</table>

In the second round of interviews a different set of people were interviewed who were not directly related to the earlier trial. These respondents could contribute to a wider range of themes and topics to enrich data categories. Table 4.2 lists their roles and locations.
In each instance, one to two hours were set aside for interview/discussion. During the interview, the researcher shared his experiences during process mapping (Chapter 3) and described what they observed. The introductions were followed by a reflective discussion about the image of the robot, paper prototype of dialogue flow (Figures 4.1 and 4.2) and possible robot behaviour scenarios. The respondents were encouraged to express how they thought and felt about them. Often, interesting arguments followed where opinions and ideas were shared. Finally, an open question was thrown in about the possible useful role of a robot for medication management assistance to the elderly.

Table 4.2: List of experts interviewed after theoretical sampling looking for more data (Data 2)

<table>
<thead>
<tr>
<th>Role</th>
<th>No.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geriatrician 1</td>
<td>1</td>
<td>Middlemore Hospital, Auckland</td>
</tr>
<tr>
<td>Geriatrician 2</td>
<td>1</td>
<td>North Shore Hospital, Auckland</td>
</tr>
<tr>
<td>Geriatrics researcher</td>
<td>1</td>
<td>University of Auckland</td>
</tr>
<tr>
<td>Social psychologist</td>
<td>1</td>
<td>University of Auckland</td>
</tr>
<tr>
<td>Clinical psychologist</td>
<td>1</td>
<td>University of Auckland</td>
</tr>
<tr>
<td>Health Informatics faculty</td>
<td>1</td>
<td>University of Auckland</td>
</tr>
<tr>
<td>Residents of Selwyn Village (not same as those interviewed earlier)</td>
<td>4</td>
<td>Selwyn Village</td>
</tr>
</tbody>
</table>

The interviews were recorded and transcripts of the recording obtained. All interviews were transcribed by a professional transcriptionist who had signed a confidentiality agreement as per the ethics protocol. The transcribed scripts were sent to the participants for them to edit or correct anything they might consider inappropriate or withdraw from subjecting to further analysis.

4.3.3.3 Analysis of data

Approximately 10 hours of recorded data were analysed using a grounded theory approach where the interview transcripts, video recordings and field notes were coded. The coded concepts were grouped into categories, after which relationships between these categories were identified through axial coding. Since the study was not large enough to use electronic coding, colour-coded post-it notes on a chart were used, grouping comments from each role to see what
pattern emerged. Reflecting upon these patterns, key issues were deciphered that could inform the design of a robotic medication assistant.

4.3.4 Results

4.3.4.1 Data collection and analysis process

Interview transcripts captured in the process of grounded theory (Figure 4.4 – data 1 & 2) were subjected to open coding of collected transcripts. The initial analytic process generated codes or concepts which are names given to a set of words or sentences or ideas that represent a phenomenon (Strauss & Corbin, 1998). These concepts were then organised into categories through an iterative, reflective process, being aided by memo notes. A category is discovered when concepts are compared to one another and grouped under a higher, more abstract order. These categories then were further analysed and organised into an initial set of themes.

Figure 4.4: Applying grounded theory. This reflects the constant comparison and verification of categories and themes that remain grounded in the original data

4.3.4.2 Open Coding 1

Open coding necessitates taking each code and ascertaining which category this code belongs to while constantly comparing categories with data. The interpretation and assignment of codes or concepts was then done not on the basis of literal or grammatical connotations but by focussing on the meaning of what was being said (see Chapter 2, Section 2.4.3). This meaning was abbreviated into a word, group of words or sometimes a short sentence to capture its
essence. These words or sentences now referred to as ‘codes’ were written on sticky notes of different colours. The blue sticky notes represent the clinicians (i.e. doctor and the pharmacist) yellow represented the managers, pink for caregivers, and green for residents (i.e. elders and their family members). These notes were then pasted over a blank sheet to ‘map the thinking’. Putting all the codes on a single sheet and colour coding them served a very useful purpose over and above other techniques of coding. A view of the entire data at a glance, coupled with reflective rearrangement of codes, brought interesting artful creativity to the process and fruitfully aided analysis until the initial set of categories became clear. After a few rounds of reflection and rearrangement of codes and organising them into common themes irrespective of the colour, the following picture emerged (Figure 4.5). The image shows a picture taken on the researcher’s desk after completing the coding process. Each circle represents a category that is labelled in the text box besides it.

Figure 4.5: The concepts emerging after arranging the codes

One could see at a glance colour dominating various categories, indicating that some ideas are important for some actors and not others. The dominance of each actor’s voice clearly stands out in the colour differentials, which would have been difficult to capture if we had used other methods of coding. These differentials were recorded as Memo Notes. The concepts and categories were then entered into an Excel spread sheet in tabular format for the sake of records and backup (Table 4.3).
Table 4.3: Initial open coding process, showing some of the categories and sample of codes collected from transcripts or data

<table>
<thead>
<tr>
<th>No.</th>
<th>Categories (1)</th>
<th>Concepts (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Contextual specificity</td>
<td>Varying dependency, multiple actors, varying processes, complex social network, pre-defined roles</td>
</tr>
<tr>
<td>A2</td>
<td>Non-compliance concerns</td>
<td>Missing doses, underreported, forgetfulness, choice, underlying psychological issues, clinically important, accumulating, unmet needs</td>
</tr>
<tr>
<td>A3</td>
<td>Data sharing</td>
<td>Cumbersome, manual, reconciliation, information silos</td>
</tr>
<tr>
<td>A4</td>
<td>Changing medications</td>
<td>Hospitalization, disease progression, flare-ups, complications, co-morbidities, generic substitutions, specialist prescriptions</td>
</tr>
<tr>
<td>A5</td>
<td>Emergency protocols</td>
<td>Call for help, wearable pendant, caregiver central, timeliness, staff response, ambulance, hoist</td>
</tr>
<tr>
<td>A6</td>
<td>Process complexity</td>
<td>Compliance packaging, OTCs/CAM, personalization, errors, expectations</td>
</tr>
<tr>
<td>A7</td>
<td>Robot requirements</td>
<td>Reminding, entertainment, carry stuff, call for help, emergency alarm, tele-presence, compliance summary, dashboard</td>
</tr>
<tr>
<td>A8</td>
<td>Information sharing</td>
<td>Language, respect, control, independence, irritation, medication names, reasons, side effects, competency, scheduling</td>
</tr>
<tr>
<td>A9</td>
<td>Provider feedback</td>
<td>CDSS, unstable patients, implementation delay, ownership</td>
</tr>
<tr>
<td>A10</td>
<td>Caregiver competency</td>
<td>Communication, information gaps, answering patient, skill gaps</td>
</tr>
<tr>
<td>A11</td>
<td>Memory needs support</td>
<td>Reminding, calendaring, distraction, appointments, refills</td>
</tr>
<tr>
<td>A12</td>
<td>Family involvement</td>
<td>Progress, symptoms, side effects, track events, problems</td>
</tr>
<tr>
<td>A13</td>
<td>Compliance packaging</td>
<td>Simplification, only for pills, crushable, multiple rolls</td>
</tr>
</tbody>
</table>

The initial attempt at coding is shown in Table 4.3, which lists concepts in the right-hand column and the categories in the left-hand column. The codes are the actual words or sentences written on the post-it notes, derived from the transcribed data, whereas categories are a meta-level understanding of what a group of codes is trying to convey. Contemplating on the list of 13 categories did not seem to contribute to a significant pattern that could be used to build a theory.

Striving to derive meaning and sense out of data, the researcher rearranged the codes with a deeper reflective analysis into a revised set of categories, shown in table 4.4. This exercise was
done by rearranging cells in MS Excel (each cell holding a code). Therefore instead of listing the actual codes, the cell numbers from the spread sheet holding the codes is listed in the table.

Table 4.4: Revised coding in categories on the Excel spread sheet, according to the source and numbered code

<table>
<thead>
<tr>
<th>No.</th>
<th>Revised Categories (1)</th>
<th>Code numbers in spreadsheet (1)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Setting and circumstances</td>
<td>D1-4, M 1-14, C 1-4, P 1-2</td>
</tr>
<tr>
<td>B2</td>
<td>Compliance packaging</td>
<td>D 5-13</td>
</tr>
<tr>
<td>B3</td>
<td>Data sharing issues</td>
<td>D 14- 20</td>
</tr>
<tr>
<td>B4</td>
<td>Non-compliance concerns</td>
<td>D 21-28, M 15</td>
</tr>
<tr>
<td>B5</td>
<td>Emergency protocols</td>
<td>M 16-20, C 5-7</td>
</tr>
<tr>
<td>B6</td>
<td>Administration process</td>
<td>M 21-29, C 8-18, P 3</td>
</tr>
<tr>
<td>B7</td>
<td>Medication administration problems</td>
<td>D 29, M 30, C 19-25, P 4-7</td>
</tr>
<tr>
<td>B8</td>
<td>Individual has preferences</td>
<td>M 31-32, C 20-23, P 8-10</td>
</tr>
<tr>
<td>B10</td>
<td>Place for a reminder</td>
<td>D 36-40, M 36-43, C 28-30, P11-14</td>
</tr>
<tr>
<td>B11</td>
<td>Memory support</td>
<td>P 15-18</td>
</tr>
<tr>
<td>B12</td>
<td>Patient info. needs</td>
<td>D 41-43, M 44-46, C 31, P 19</td>
</tr>
<tr>
<td>B13</td>
<td>Compliance packaging</td>
<td>D 44-52, C-32</td>
</tr>
<tr>
<td>B14</td>
<td>Personal Health Record useful</td>
<td>D 53-55, P 20</td>
</tr>
<tr>
<td>B15</td>
<td>Caregiver information needs</td>
<td>C 33-41</td>
</tr>
<tr>
<td>B16</td>
<td>Generic information not useful</td>
<td>D 56-60, P 21-22</td>
</tr>
</tbody>
</table>

*D= doctor and pharmacist, M=manager, C = caregiver, P = patient and family

Even after rearranging codes and revising categories no particular pattern seemed to emerge. Continuing the pursuit for meaning, another attempt was made to visualise data using a different creative process.
4.3.4.3 Looking for patterns

Corbin & Strauss (1990) recommend that the researcher should “play with the data” in an attempt to develop an in-close level understanding of the process, while being involved in the process at the same time as thinking about the data from a distance and developing conceptual and theoretical insights.

Another creative representation was achieved by converting the emphasis on categories into colourful bubbles, where the colour of the bubble reflected the speaker. The size of the bubble represented the emphasis on a certain idea. The results of this exercise converted the data into a visual image, indicating the attempts by the researcher to gain insights using visual imagery and invoking intuitive connections.

Evaluating the data in Figure 4.6, doctors and pharmacists place emphasis closer to ‘clinical’ dimensions, while patients and caregivers emphasis the ‘personal’ dimension. Interestingly, both groups (patients/family and doctor/pharmacist) emphasise ‘information’ although in different contexts, reflecting the concerns, language and preferences of each group. For example, doctors and pharmacists would highly value facilitating interoperability of data exchange between physicians, pharmacists and family and to observe patterns, which could give them sufficient clues to plan intervention.
“I want the ability to know what they’re taking and what they’re not taking because that then influences my assessment of them. So if they are taking 90 per cent of the medication correctly 97 per cent of the time, then I need that information to see what’s happening clinically. And if it’s just on Saturdays that they’re unreliable, because that’s when they go to the social event, then we can work around that.” (Doctor)

Physicians and pharmacists were also concerned about inducing new errors like double dosing or reporting false administration. Managers were concerned about processes and were well aware that many people actually need assistance but are somehow managing on their own.

“We know that people have been struggling with their meds but it’s too late after the fact is discovered by the doctor. ’Cause they’re independent, we don’t go and offer our services just like that.” (Manager)

When asked, patients expressed a desire to use something very easy which could assist their memory (especially in difficult patches like post hospitalization), or to help them cope with changed routine. They wanted to know what medication they are taking, how to take it, and why they are taking it. Sharing information with family members and doctors was also important to them.

“I need something simple for me to be able to use it. I need something that allows my doctor to take care of me and calls for help whenever I may need it.” (Resident)

The data pointed towards some important implications for design that will be described later. But for the purpose of theory building an attempt was made to tease out some general direction but the categories yielded very limited insights.
4.3.4.4 Open coding 2

A broader range of experts were interviewed including elderly residents and actors, both to discuss the paper prototype and to elicit deeper insights. The interviews were again transcribed and coded. The codes (2) were again arranged into categories (2) by the open coding process using the constant comparison, questioning techniques. This exercise was done using MS Excel and allowed a new list of categories to emerge (Table 4.5).

Some of the categories reached through this set of codes validated the views from literature, while others broadened the scope of design. Some categories were related to the process of medications (address variations, medication safety), while others could inform the design of a system (simplicity, user verification, support mistakes, fun factor, knowledge/education) and the way dialogues are worded (respect). Importantly, sensitive areas which might jeopardise design showed up (privacy, intrusion and surveillance), while other categories pointed to the need to address the requirements of the actors (prescribing in dark, caregiver needs, system improvement). Most importantly, a philosophical insight revealed symbolic meaning that might underpin implications of what we are attempting to do. These themes (emancipation, sovereignty, colonisation, relationships, embodiment, remote response) may not be directly related to the design process but forced the researcher to reflect on the direction and meaning of the whole design process. The addition of new streams of thought opened a wider perspective to the field of study and shaped the thinking in ways that were not expected in the beginning. The new challenge was now to design the application in a manner that aligned with these findings.

There was also some mismatch between the categories and clustering of codes therein, as the categories were carrying implications in reference to a prototype design. The codes fell into three broad sections – design ideas, healthcare system concerns, and user interests. Therefore, the analysis of categories came to depend upon these broad sections and tended to influence ordering of categories into themes.
<table>
<thead>
<tr>
<th>No.</th>
<th>Categories (2)</th>
<th>Concepts (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Simplicity</td>
<td>Not to overcomplicate a simple task, assist only when necessary, no clutter of information and buttons, short and precise dialogues</td>
</tr>
<tr>
<td>E2</td>
<td>Address variations</td>
<td>Different medication timings, dosage and forms, organization of medications, pharmacies, doctors, family interest, personalization</td>
</tr>
<tr>
<td>E3</td>
<td>Respect</td>
<td>Appropriate greetings, no judgmental remark in case of mistake, avoid ageism, allow them to say no, not patronizing, respect choice, avoid insisting</td>
</tr>
<tr>
<td>E4</td>
<td>Privacy</td>
<td>Ask before sharing info, allow to switch off reminder, set-up preferences, minimise intrusive nature of robot, clinical supervision, disturbance while resting, freedom to go out</td>
</tr>
<tr>
<td>E5</td>
<td>Knowledge/education</td>
<td>Know medications, know side effects, able to discuss with doctor, how many pills left, when to get refill, feedback on performance</td>
</tr>
<tr>
<td>E6</td>
<td>User verification</td>
<td>Recognition of right person, match right prescription, backup in case one method fails, self-identification</td>
</tr>
<tr>
<td>E7</td>
<td>Support mistakes</td>
<td>Assume success not failure, fumbling, comprehension issues, dropped pills, incorrect choice, prevent double dosing, prevent wrong medications, tripping over robot, lean on robot</td>
</tr>
<tr>
<td>E8</td>
<td>Support caregiver</td>
<td>Enable right assistance, bridge knowledge gaps, let them also see information, customise options; they can help users to set up, let them know if they are doing the right thing</td>
</tr>
<tr>
<td>E9</td>
<td>Comprehension</td>
<td>Dual output, font size, loudness of voice, clear visibility, not complicated screens, simple clearly marked buttons, gesture and voice recognition</td>
</tr>
<tr>
<td>E10</td>
<td>Emancipation</td>
<td>Knowledge as power, self-confidence, no more need to depend on others, build capability for self-care, ignorance and fear foster dependence, told what to do</td>
</tr>
<tr>
<td>E11</td>
<td>Sovereignty</td>
<td>Citizenship, medications not exclusive domain of experts, able to raise a voice, take responsibility, passivity leads to non-compliance, active engagement</td>
</tr>
<tr>
<td>E12</td>
<td>Colonisation</td>
<td>Pushing doctor’s agenda, pharmaceutical companies pushing compliance, ageing and resignation, self-disempowerment, docile body, rest home regulations, alienation</td>
</tr>
<tr>
<td>E13</td>
<td>Relationships</td>
<td>Robot alters existing relationships, relationship with the robot, likeability, long-term acceptance, bereavement if robot is taken away</td>
</tr>
<tr>
<td>E14</td>
<td>Fun factor</td>
<td>Avoid monotony, variations in dialogues, entertainment, avoid medicalisation of robot, humour, self-reflection</td>
</tr>
<tr>
<td>E15</td>
<td>Surveillance and intrusion</td>
<td>Disciplining role of invisible observer, personal space invaded by a representative of healthcare system, recording of personal activities</td>
</tr>
<tr>
<td>E16</td>
<td>Emotive response</td>
<td>Not only an intellectual response to information, people exhibit emotional reactions, need to manage emotional reactions, response to difficult emotions</td>
</tr>
<tr>
<td>E17</td>
<td>Embodiment</td>
<td>Anthropomorphism, mimic human behaviour, embodied agent, uncanny valley, pretending to be intelligent, pretension as hypocrisy inviting rejection</td>
</tr>
<tr>
<td>E18</td>
<td>Medication safety</td>
<td>Reconciliation of meds, verification of right medications, check double dosing, warn wrong use, keep prescriber and pharmacy in the loop, care with PRN medications, medication allergies</td>
</tr>
<tr>
<td>E19</td>
<td>Prescribing in dark</td>
<td>Prescriber knows very little about user behaviour, appropriateness of prescription, need to improve quality of prescription, tailoring for individual, knowledge of CAM use</td>
</tr>
<tr>
<td>E20</td>
<td>Send emergency message</td>
<td>Inform doctor, pharmacist/caregiver, how urgent, who should respond, nature of emergency</td>
</tr>
<tr>
<td>E21</td>
<td>System improvement</td>
<td>Learn about non-compliance, older people’s voice, discover patterns, support decision at the time of event, action at point of care</td>
</tr>
</tbody>
</table>
On analysing the second set of data some important and rich categories were derived, pointing towards a deeper understanding of underlying implications. For example Geriatricians were concerned about introduction of new errors and the need for a highly customised approach.

“You cannot assume that the generic information that the robot would pick up from a web page would apply for the person facing the robot. At times we deliberately do not reveal correct reason for medications especially in mental health patients; we often tell them that they are taking these medications (I am referring to antipsychotics here) for better sleep. Therefore when you think about automating education for my patients, I would recommend it should be handcrafted by my team.” (Geriatrician 1)

“One can understand help for routine medication, but how do we wish to approach PRN medications?...I think it’s best to carefully approach PRN medications simple reminding may increase PRN consumption or if you are probing with specific questions... let’s say the robot asks them ‘are you having pain or nausea’ and if the patient says yes and if the symptoms match then the robot can recommend PRN...” (Geriatrician 2)

On the other hand, social psychologists were concerned about the psycho-social implications of rolling a robot into an older patient’s residential apartment.

“...I can imagine living in a rest home and a big bulky machine with dominating voice, pretending to represent a doctor, telling me to do something that doctors and pharmaceutical companies want me to do, and if I don’t follow, sends a report... keeps an eye on me and begins to record what I am doing without letting me know... I wonder how friendly would I find it... but many who have resigned, feel disempowerment and institutionalised become a docile body, alienated... and simply accept everything or subconsciously resist everything that’s pushed on to them.” (Social Psychologist)

Elderly respondents also expressed their opinions that both saw the risk and value.

“...If the robot begins to move without a warning within my room it may be hazardous. I may not expect it, let’s say when turning around, and bump into it or fall...” (Resident 1)

“I should be able to control when it records or sends any information... and like to set it up according to my routine and the way I like it to behave with me... but I understand your point... it’s useful to know someone is watching the results and who can take appropriate action and ...umm... maybe make timely decision to keep me safe...” (Resident 3)
“We would like to know what a particular medication is for and maybe understand side effects... good to know if the problem we may have is actually a side effect (as it can be corrected) and not a new problem which needs more medication...” (Resident 4)

4.4 The design process

4.4.1 Requirements from the medication management module

The important issues identified in the literature about older people having problems with their medications (Lowe, Raynor, Purvis, Farrin, & Hudson, 2000; Ruscin & Semla, 1996; Ryan, 1999) are:

- Forgetfulness
- Change of medication schedule
- Confused by overwhelming number of instructions
- Overwhelming number of medications
- Taking medication at wrong times
- Confused by names of medication

In a systematic literature review of evidence-based interventions to improve medication usage (Petrilla, Benner, Battleman, Tierce, & Hazard, 2005), the greatest benefits were seen when the interventions were intensive, personalised and involved communications with healthcare providers. As compared to single intervention, a combination of interventions involving interactions with providers was particularly helpful because it could address multiple barriers and comprehension abilities at the same time.

As a result of this evidence, the design team chose to keep healthcare providers in the loop and designed technology to assist human interventions instead of designing a totally technologically driven passive reminder system (Pineau, Montemerlo, Pollack, Roy, & Thrun, 2003b). The design attempts focussed on a combination of interventions involving personalised reminding – allowing patients to express their choices and get help wherever they get stuck – and opening up the communication with healthcare providers so that the social network around medications is enriched rather than disrupted by the intervention.

Initially, the process of designing the first and foremost requirements were to comply with the safety and quality standards of the manual medication administration process, commonly termed as five rights: right patient, right medication, right dose, right route and right time.
The initial thoughts towards design were to meet these five rights by:

1. Right patient – user identification through biometric methods
2. Right time – programming the reminder using calendar and clock functions
3. Right medication – reading the electronic copy of the prescription from the GP’s computer
4. Right dose – reading the dose of each medication from the same
5. Right route – reading the form and linking it to route (e.g. tablet and syrup forms’ mean oral route) and constructing the reminder dialogue using the name, dose and route of medication from the electronic copy of the prescription.

However, it was soon realised that it was not simple to translate these ideas into an automated system because there are so many variables for a system to handle. For example:

1. Clinical status often determines parameters for the medication doses and frequency (e.g. Warfarin dose and frequency depends on INR readings, Insulin dose on blood sugar levels).
2. User preferences and location are not always constant (e.g. user chooses to wake up late in the weekends or goes down for lunch twice a week).
3. Prescribers and prescriptions are not constant either (e.g. three medications in one prescription given by GP while two more in another one given by the specialist; in another example three medications continue long term and one medication dose changed after three days).
4. Even names and forms of dispensed medications change (e.g. pharmacist substitutes brand name to generic drug or 60 mg tablet may be dispensed as 1½ tablet of 40 mg, and so on).

Moreover, during the process of mapping and interviews, we discovered more variables that influence the design of an automated system or medication management module (Figure 4.7).
Figure 4.7: The module requirements: variables that could possibly influence the function of the module

The list of requirements is large and varied. The medication management module on the robot should not only be able to record prescribed and dispensed medications but also self-prescribed nutritional supplements. It should be able to correctly locate the user, understand preferences in the way medications are organised (e.g. sachet), and tailor its behaviour according to the medication schedule (breakfast, bedtime or lunchtime), meal status (before or after food), and personalise its behaviour according to individual needs.

4.4.2 Medication variables and the module design

The clinical and mental status of the user determines the ability of the person to cope with the medication regimen, or the person’s need for closer personal attention. For example, it would be difficult to convince the doctor that a post-stroke patient with borderline cognitive functions would be able to self-manage Warfarin safely. It is the judicious balance between personal capability and complexity of the task that would determine whether a robot is suitable to support a person.

Similarly, some prescribed medications, such as injectable, would require personal assistance as a matter of course, or the physician may deem it necessary in other cases to recommend personal assistance. Those being assisted would use robotics differently (if ever) while others would require an architecture to parse dialogues that address frequency – using calendar and clock to determine when and how often a medication is taken – or interpret routes and forms to give appropriate instruction like ‘instilling’ eye drops, ‘applying’ a cream or ‘inhaling’ puffs, in addition to interpreting if pills are dispensed in bottles, strips or boxes.
Furthermore, a choice needs to be made when considering prescribed medication lists or dispensed medications to inform the robot dialogues. Assuming dispensed medications would most closely match the list of medications possessed by the user, it would be more logical to consider pharmacy information as preferred sources to inform dialogues. However, the nutritional supplements would not belong to any source other than the person themselves. Some medications require to be taken on an empty stomach while others are post meal, some are PRN (as and when needed), some half an hour before sleeping, while others are not to be taken with certain types of foods. To make matters more complicated, not all users organise their medications in the same way. Some use pill boxes with seven containers for the seven days of the week, while others use twenty-one containers (three times a day for seven days), and some are given blister packs, while others use labelled sachets.

In this first phase of designing, an attempt was made to identify basic components of the system. The design could then be refined over future iterations to handle these complexities around medication management. The next section presents the initial set of ideas that describe the design while aligning with the given hardware and research environment.

4.4.3 Conceptual model of medication information

On a conceptual level, it was important to make it clear exactly what we are trying to achieve. We are not only attempting to assist the older end users to cope better with their medications but also enabling the healthcare system to learn from user behaviours to tailor their response more effectively and efficiently. The proposed tool could be a potential platform to achieve this dual synergistic benefit.

The information about the nature of adherence is of common interest to prescribers as well as to researchers. Therefore, the first implication was to customize dialogues and behaviours of the robot as an information-gathering tool that aims to understand the medication process instead of merely enforcing compliance.

To deliver on this, it was clear that the robot needs to be wirelessly networked to send and receive information with healthcare providers. Therefore, a web-based engine that communicated with the robot on the one hand and with healthcare providers on the other became the central requirement. Moreover, the web-based engine needed to capture/present information from/to clinicians in their language and format while at the same time inform the robot to present/capture information in the lay user’s language. Therefore, the automated
medication assistant was conceptualised as consisting of a robot-installed system and a web-based system. The robot system would be a background software program that manages dialogues related to users and medications as well as generates a graphical user interface (UI or GUI) which responds to user actions. On the other hand, the web-based application would present a user interface for researchers to visualise/validate data as the information with the robot or external provider systems (e.g. pharmacy management system) is exchanged. Figure 4.8 shows the robot screen that is populated with various robot modules and details the basic components. These functionalities and hardware requirements have been elicited in earlier studies within the project (Boradbent, 2008). Being informed by analysis, the ideas evolved to incorporate a more complex design since most of the modules were conceived as native applications that would run independently on the robot. This automated medication assistant would also be referred to as a medication management module on the robot from here onwards. The early ideas from multidisciplinary teams were to keep the medication management module as a native application.

Figure 4.8: The plan for medication management module
4.4.3.1 Benefits of an integrated medication management module

Use of a social robot to offer reminders and serve as a medication assistant could be very usefully deployed with the help of twin components. The robot application could interact with the user while the web application could inform the providers, with the following benefits:

- Inform caregivers, family members, pharmacists and doctors about the medication administration events (Friedman et al., 1996)
- Improve timely correction of errors and safety
- Safe prescribing in addition to promoting adherence.

4.4.3.2 Application of the design framework

The two applications were envisaged to communicate with each other over web services. The following UML diagrams and data models made by the researcher were used to explain the ideas to software engineers. Unified Modelling Language (UML) diagrams are commonly used modelling techniques for describing software structure in a multidisciplinary group (Larman, 2004). UML is an industrial standard defined by the Object Modelling Group (OMG) for software engineering and has been widely applied (Fowler, 2004). It includes a large variety of graphical notation for visual representation of different aspects of a software system. UML diagrams can be roughly categorised into two sets: structural (class and object diagrams) and behavioural diagrams (activity and use case diagram) (Fowler, 2004). For example, class diagrams focus on hierarchical relationships between classes and their operations and attributes whereas activity diagrams (also called sequence diagrams or process diagrams) visualise sequence and timing of processes and inter-process messages.

In designing a robot service application, the goal of this categorisation is to encourage a brainstorming process within a group to design a robot’s main functionalities for a target service scenario. The initiation of communication between multidisciplinary teams is facilitated by a UML diagram; for example, where a clinical scenario – like medication management – has to be modelled in software functions yet the model might be completely different from a professional medical service but continues to be informed by it (I. H. Kuo, C. Jayawardena, E. Broadbent, & B. MacDonald, 2011). Such interactions can be effectively modelled and communicated in UML formats. The following description portrays a series of process diagrams, a UML activity diagram, logical data model and an activity flow diagram that were prepared by the researcher to communicate software design requirements to the team.
The process steps are:

1. The physician enters a prescription into the Practice Management System (PMS).
2. The PMS generates a printed copy.
3. The physician gives the printed copy to the elder.
4. The elder takes the prescription to the pharmacist.
5. The pharmacist enters the prescription into the pharmacy management system.
6. The system generates a printed sheet with instructions.
7. The pharmacist hands over the sheet along with medications to the elder.
8. The elder reports clinical progress/response/problems to the physician at the next visit, leading back to step one.

However, this routine process is altered when a person is physically assisted by a caregiver in Selwyn Village. Figure 4.10 shows the altered path of information flow.
1. The physician enters a prescription into the Practice Management System (PMS).
2. The PMS generates a printed copy.
3. The physician (medical centre) faxes a copy of the prescription to the pharmacist.
4. The pharmacist enters the prescription into the pharmacy management system.
5. The system generates a dispensed medication list.
6. A soft copy of the prescription is passed from the pharmacy management system to the packaging robot.
7. The packaging robot generates a roll of sachets/packaged medications that are labelled for the patient along with date and time when each sachet has to be consumed.
8. The pharmacist sends the packaged rolls to the physician (medical centre) in Selwyn Village.
9. The physician (medical centre) sends the packages to caregiver who is assigned to assist the person.
10. The caregiver physically takes the medications and administers them.
11. The patient reports issues to the caregiver; the caregiver collects the feedback and observations.
12. The caregiver reports back to the physician (medical centre) formally through the notes and also by telephone in case of emergency.
4.4.3.3 Information sequencing in the management module system

The design philosophy remains that a robot does not attempt to replace humans but to enhance human capability to improve quality, accuracy and safety of medication processes through systemised communication channels. Figure 4.12 shows an attempt to define the sequential flow of information using UML representation, to show how the module could possibly finds its fit into the system. In this figure, the packaging system has been excluded because the medication management module should be able to assist patients irrespective of requiring packaged or unpackaged medications. The web-based application interfaces between the pharmacy management system and the robot-based application whereas the robot-based application interfaces between the web-based application and the elder user.

![Figure 4.12: Process diagram – medication information flow as envisaged after intervention](image)

The steps in the process are:

1. The physician forwards the prescription to the pharmacist. Alternatively:
   a. The prescription is given to the elder user,
   b. The elder user takes the prescription to the pharmacy.
2. The pharmacist enters information into the pharmacy management system.
3. The medication list from the pharmacy management system is then forwarded to the web-based application of the proposed medication management module.
4. The web-based application processes it and forwards the information to the robot application at the right time, triggering an alarm of some sort.

5. The UI on the robot reminds the user to take his/her medications while inviting the user for an interaction.

6. The user informs the robot UI of the actions taken and/or the activity is logged.

7. The information is sent to the web-based application that logs and processes the information to decide on the next course of action including generation of a dashboard.

8. Based on the type of information and processing outcomes, the output of the web-based application is shared synchronously or asynchronously with the healthcare providers.

By comparing Figure 4.9 and 4.12, one can appreciate the degree of change. Initially sharing of information between actors was limited in existing practices (Figure 4.9), creating silos and gaps. The proposed intervention could open up the information channels and enrich the sharing of information (Figure 4.12). The nature, quality and quantity of this information and its presentation would need to be tailored to operational protocols and the information needs of each actor. Each actor would have certain preferences and objectives to interact with the medication management module.

4.4.3.4 Actors and their requirements form the system

The use case diagram representing the proposed scenario (Figure 4.13) shows that an elder user would like to use the system for being reminded as well as for seeking more information about their prescription and to communicate with other actors. The multiple arrows linking communication with all other actors have been omitted for the sake of keeping the diagram clear and simple. Family members and caregivers would like to be assured about the performance of the elder user while the caregiver could be sent an alert if something goes wrong. On the other hand, the goal of the GP and pharmacist would be to access the medication compliance summary, and the pharmacist would be expected to keep the drug information database up to date and personalised. In this diagram, the technical (robotics) service provider has been identified as an additional actor. The roles of technical service provider could be envisaged as the engineering support or the robotic company that would need to maintain the robot software and provide technical support wherever needed.
To ensure safety and quality, only a qualified and trained person should enter the medication data into the system (e.g. physician, pharmacist or caregiver). If possible, an electronic copy of prescriptions should be uploaded wherever possible to avoid manual process errors. Patient data preferably should not be stored on the robot system for security reasons. There should be the possibility of verifying medication data, updating changes whenever they occur, and viewing activity logs by a qualified professional who is responsible for patient care. These ideas could be incorporated into a logical data model to advise software architecture.

### 4.4.3.5 Logical Data Model

A logical data model is the next level of detail after conceptual modelling. Whereas conceptual modelling captures business processes and business requirements, the logical data model is meant to capture a high level view of what each component within the desired system is supposed to be performing. This model in turn informs the design of software architecture.
Figure 4.14: Logical data model in UML format

Figure 4.14 represents another view to the handling and processing of medication-related data. The prescription containing specific data fields is sent to the pharmacy management system (which processes the prescription) and sends through an export file to the ‘medication management module’s web-based system. The web-based system in turn offers a UI for handling of data and communicates over web services with the robot system. The robot system also has a UI with which the user interacts.
The data fields in the prescription identify the prescription, prescriber and the person for whom this is intended. These fields are unique identifiers including the NHI (National Health Identifier) number that recognizes each patient by a unique system ID unique to the New Zealand healthcare system and consists of three letters of the English alphabet and four digits in random sequence (e.g. HFP8501). Similarly, HPI (Health Practitioner Identifier) is a unique number allocated to each health practitioner in New Zealand. Each drug is then recognised by brand/generic name. More recently, the New Zealand Unified List of Medicines allocates a unique code to each drug sold in New Zealand; however, when this research was conducted, the system was still under development. Often the prescription printed by the GP bears a unique bar code as a prescription identifier for the pharmacist to scan and enter into their system; otherwise, the pharmacist manually enters the prescription into their pharmacy management system in order to generate labels and maintain an inventory, in addition to many other features. Toniq is able to generate an export file abbreviated as an ADS file which is essentially prescription information in XML format.

In the next chapter, we will explain how this desired functionality was actually achieved but the basic requirement features are being drawn and are further explained by a process flow chart in Figure 4.15. It highlights a few more design requirements, namely:

- The need for a robust user identification system that would establish the link between the user and his/her prescription.
- Matching the correct time to medications where for example breakfast-time medications are matched to the medications that need to be taken in the morning after breakfast, before uttering a dialogue.
- The readiness of the user (e.g. is free, has taken a meal, has a glass of water and so on) and availability of appropriate medications as there is no use reminding if the refill is overdue.
- The insurance that medications are not already taken, to avoid introducing accidental double dosing in case the user had forgotten whether he/she has taken them already or not.
- The prompting of a reminder and log task completion once these preconditions are met.
- The notification of a human caregiver in the case of any of the error conditions.
Figure 4.15: Activity Diagram
4.5 Discussion

In Chapter 3 observations of processes & practices at the aged care facility were noted. In this first cycle of AR, those earlier findings were presented to the actors along with a paper prototype. The data gathered during the discussions was open coded using the grounded theory method to arrive at emerging categories. The concepts were grouped into several categories around environmental issues, personal preferences, concerns and suggestions. A closer look at these categories revealed clinical, personal, information and administrative domains, with different actor groups predominating in one or more domains. It also became apparent that actors have different information needs, biases, knowledge gaps and trust issues (Tiwari, Warren & Day 2010). These observations were populated into initial memo notes which would be further refined in the next chapter. The second set of data collection involved academics and professionals from varied disciplines. Open coding of that data allowed categories to emerge around ethics, teamwork, psycho-social implications and clinically relevant issues.

Comparing the categories generated so far in two phases with the literature affirmed the findings presented earlier. There is a tension between autonomy and safety where doctors and pharmacists were concerned about the abilities of sick elderly patients – their ability to use medication correctly, adequacy of therapeutic response, risks, medication use patterns, refill due, expiring prescriptions and funding eligibility – whereas the residents (or patients) are interested in their quality of life, safety, prompt service and communication. The discussions with a social psychologist raised issues around imposition of medical power in the pretext of ensuring safety and converting patients into docile bodies who do not complain but do not necessarily follow instructions. The doctors and pharmacist understood the complexity of the medication regimen but the preferred solution was to reduce the complexity with compliance packaging, believing their patients would passively swallow them, whereas patients demanded to know more and be in control of what they were taking. The knowledge gap for doctors and pharmacists around ‘what do patients do and why they do so’ with their medications and knowledge gaps for patients exist around ‘why do they have to do what they have to do’ with their medications. Often patients ask caregivers about their medications and caregivers may not have enough knowledge to be able to answer them.

Tensions between dependence and independence were also highlighted in the data. The assumption of care providers that assistance is required for older people and the opinions from residents highlighting the need for information, timeliness of service, a desire to maintain independence and frustration with the inability to do so, show the underlying power struggle...
and compromise while living in an aged care facility. For example, caregivers are constantly striving to ensure that medications are in fact taken and will not trust the patient unless they see the medications actually being swallowed, whereas doctors and pharmacists have reasons to seek assurance that patients are complying and medications are correctly being administered. Such observations show an implicit assumption within caregiver and physician roles that elders will either not follow instructions or spit out the medications, and therefore need to be pursued till the task is completed – for their own good. Caregivers dealing with cognitively challenged, fragile and difficult-to-manage patients tend to believe medication administration is a difficult issue, but many of the independent living residents manage their medications by themselves, especially those who find it hard to afford an extra service despite their difficulties. An implicit desire to develop trust was also apparent within actors. Patients need to trust their doctor, pharmacist and caregiver, as well as the medications, to work for their benefit.

The tensions between joy and fear were apparent when some residents expressed their desire to interact with the robot and saw its value whereas some of them were concerned about bumping into a robot or being watched or their personal space being intruded into. The fear of a robot replacing the caregiver was expressed by some residents who expressed a strong opinion in favour of a human to help them instead of a machine. A caregiver’s visit was often the only social interaction many elders would have, and they did not want to lose it, especially as personal relationships had developed over a period of time. The fear of social isolation was visible and unless the value of a robot in enhancing communication was realised, there would be little reason to replace valued personal relationships.

The geriatricians raised concerns about introducing new errors or the automated assistant’s abilities to handle complex medication scenarios like PRN medications. The discussion with managers highlighted the organisational desire of monitoring medication intake, reducing falls and detecting them in time, where robots could serve a value to meet objectives of making the aged care facility safer. Caregivers and managers raised significant concerns about the fear of replacing jobs, prompting the researcher to communicate carefully during the trial period. In summary, the findings from the literature were mostly supported by the gathered data.

As we learnt more about aspects of the medication process in an ACF, our assumptions about the design of new technology began to change from designing just a simple reminder system to a more complex medication management system. It seemed naive to assume that simply issuing reminders would reliably yield compliance in this complex scenario. The design of a
proposed device needed to address the particular organizational context in addition to providing personal assistance. The question of being given a choice while being reminded, complemented by explorative reasoning, preferably informed by the immediate context (for example, has the patient taken food or is she sleeping?) could positively influence user behaviour over time. By capturing qualitative and quantitative information, it could be possible to penetrate the opacity of medication self-administration in the frail elderly.

It also became clear from the findings that regular feedback and coherence of the medication function is required between various actors. The issues also point towards the robot as an information-sharing portal. The information captured from older users could inform providers; as well as information from physician and pharmacy systems could be linked to inform the user about correct current medication lists and why they are prescribed. Links to consumer education portals could inform how to take medications and what to watch for. The robot could also relay some user behaviour information to the family members to keep them involved. By doing so, the new technology would not only help build trust, but also validate or challenge some of the biases that the actors carry.

Rich information from the context and actors along the principles of participatory design brought science into the art of useful designing. Involving potential users to articulate, clarify and inform the needs of themselves as individuals or even those they are connected to or responsible for was important. Such interactions between designers and potential users can challenge assumptions and/or create new ideas which emerge though negotiations, co-creation of identities, working language, understanding, relationships and poly-vocal discussions (Spinuzzi, 2005). The data models presented in this chapter used UML conventions to draw information flow patterns. The information flow diagrams captured the existing patterns of data flow and, reflecting on the requirements gathered, it was considered desirable to open the information flow across actors and across silos of information. It also became clear from the findings that regular feedback and coherence of the medication function is required between various actors.

To enable collection and sharing of information while maintaining strict integrity of prescription information and accuracy of dialogues uttered by the robot a system having two components was envisaged: one on the web and the other on the robot. The details of converting these design blueprints into a prototype will be explained in the next chapter.
4.6 Chapter summary

This phase of research aimed to seek feedback from representative elder users and experts to develop a meta-cognitive understanding of the medication management module design in light of the literature. A rich set of categories was obtained by analysis of interview data and open coding. It also aimed to develop the design elements for the module which was achieved through modelling techniques in UML. This phase of action research revealed that the medication process in an ACF happens in a complex context. Qualitative data analysis identified an implicit need for a support tool that could address existing problems while serving some useful purpose for each stakeholder. An understanding of needs was derived in the second AR cycle and a model was represented for designing software for a medication management module. The design models presented in this chapter needed to be converted into a working dialogue system delivered through the touch screen on the robot. This dialogue system needed to be informed by a web-based electronic medication record. Thereafter, the prototype so developed would need to be iteratively refined and tested with the participants as part of the participatory design process, which is described in the following AR cycles.
Chapter 5: AR Cycle 2 – Usability testing of initial prototype

5.1 Introduction
The earlier chapter presented the reader with a grounded theory methodology used to develop categories that helped formulate the themes underpinning the design. It also demonstrated documentation of conceptual design requirements using UML representation. This chapter describes the first attempt to convert those design requirements into a working prototype of an automated medication assistant while progressing with the theory building process. The process of seeking answers to two research questions concerning the theoretical implications of automated medication assistance and the actual design of a medication management module continued to unfold. In this chapter, the description is focused on:

1. Literature survey on automated dialogues design and their use in healthcare
2. Literature survey on Human Robot Interaction (HRI) in healthcare
3. The process of arriving at the overall system design for a medication management module and its two components, namely a web-based electronic medication record and the robot-based dialogue system
4. The field testing of the initial prototype with 10 residents of Selwyn Village.

This phase of research was completed between April 2010 and August 2010. Defining the software framework and lab testing were essential before taking it into the field for potential users. Once again, the entire process followed the process of action research while using principles of participatory design and grounded theory. The chapter concludes with reflection on the implication for future developments that would in turn inform the next iteration presented in Chapter 6.

5.1.1 Role of the researcher
Given wings of imagination, potential users tend to generate requirements that often exceed the ability of systems or even the current state of technology itself (Lubars, Potts, & Richter, 1993). Managing requirements for software designing is difficult and not all requirements can be addressed in the first iteration. Hence, the researcher’s contribution was to scale down the requirement ambiguity and complexity to bare essential needs, identify design constraints and point out valid alternative possibilities for executing a working prototype. The researcher needed to translate the insights derived in previous exercises for team members to start coding. Later in the design process, the role of researcher morphed into an ‘alpha tester’ of the desired functionalities and performance of the system.
5.2 Literature survey

5.2.1 Automated dialogue systems

Friedman et al. (1996) have shown the value of automated prompting and monitoring for correct medication administration to significantly improve medication adherence. Another systematic literature review found automated voice prompts to have a significant impact on adherence due in part to reminding in case of forgetfulness; however, the same review discovered that education and social support equally impact on outcomes (van Eijken et al., 2003). The early systems used telephones using Interactive Voice Response (IVR) to deliver dialogues that supported a wide variety of conditions: a script was read by a voice artist before loading on to a system, and the system took a branching logic based on what the patient/user said (Migneault, Farzanfar, Wright, & Friedman, 2006). Nonetheless, automated dialogues have been developed and tested in many domains including tutoring (Litman & Silliman, 2004), (Georgila, Henderson, & Lemon, 2006), command and control (Paek & Chickering, 2007), smart homes control (Möller, Gödde, & Wolters, 2008), telecare and symptom management (Finkelstein & Friedman, 2000), and companionship (Field et al., 2009). A dialogue system for medication support to the elderly was rigorously tested on a robot by Pollack et al. (Pineau, et al., 2003a) using complex AI algorithms.

In a review of these dialogues systems – particularly in the context of older adults – it was found that both older users’ abilities and older users’ performance are more variable than those of younger users (Georgila, Wolters, Moore, & Logie, 2010). Turkle (1982) has explained how computing devices alter identities, values and meanings. People tend to form relationships with such automated systems and project their emotions like guilt, love and ambivalence (Kaplan, Farzanfar, & Friedman, 2003), while others have shown how seemingly neutral dialogue actually pushes the agenda of the doctor and healthcare system on to the users (Forsythe, 1996; Kaplan, 1995). These implicit projections have a potential to exaggerate in either direction, given the power of embodiment and anthropomorphism that an agent such as a robot presents (Conrad, 1985).

The clinical effectiveness of automated dialogue systems in healthcare has also been researched widely. The studies on automated dialogues delivered to patients using telephonic support found that personalization and tailoring of dialogues based on principles of behavioural psychology improves acceptance and delivers optimum clinical results (Migneault, et al., 2006). Bickmore and Giorgino (2006) have identified several characteristics applicable to dialogues in healthcare such as criticality, privacy, continuity, empowerment and initiative.
which support patient safety and respect. The structure of the dialogues for this study was designed incorporating the above in addition to special emphasis on motivational support and providing freedom of choice at every step of the reminding process. More specifically, it was important to find answers within the literature to three broad questions that define automated dialogue design:

1. What to say and why to say it?
2. How to say it and when to say it?
3. What makes a difference in healthcare?

Answering the first question, Migneault et al. (2006) recommends that one should understand and define the objectives clearly (medication management, in our case) and the people who will be using it, their values, culture, limitations, literacy and expectations (elder residents of an ACF, in our case). They have also suggested the process of creating automated dialogues for a computer after their experience with hundreds of patients on Telephone Linked Care (TLC) model. They believe effective systems are based on dialogue that has several important qualities (Migneault, et al., 2006), including that the dialogue:

1. Is optimized for spoken communication with lay people
2. Endows the systems with human-like characteristics to resemble real conversations
3. Is personalized to the individual user
4. Maximizes interactivity
5. Balances repetition and novelty of content
6. Mixes system and user control of the conversation

The content of the dialogue is strongly recommended to be well based on theoretical grounds (Bickmore, Gruber, & Picard, 2005; Migneault, et al., 2006). Synthesizing many theories on self-efficacy and stages of change, Prochaska and colleagues propounded the trans-theoretical model as a comprehensive reference to behaviour change theories (Prochaska, Redding, & Evers, 1997). Assessing the motivational readiness of the user, enhancing knowledge, personalizing cognitive support, and ipsitive and iterative feedback to the user are some important principles highlighted in this model which informed the design process. In addition, the theory of mixed initiative interfaces (Horvitz, 1999) as well as autonomous adaptive agents
– as described by Maes (1993) – would find application in the context of this research. One common challenge in writing dialogue systems for behavioural change interventions is how to manage the complexity of the potential conversations. This can be managed to some degree when flow diagrams are used (Migneault, et al., 2006).

Attempts to find answers to the second question revealed the importance of personalisation and tailoring. The dialogues can be generic (e.g. *Please take your medication*), personalised (e.g. *Mr Smith, please take your medication*), targeted (e.g. *Mr Smith, this medication is important for you to take now*) or tailored (e.g. *Mr Smith, please take these three pills with a glass of water this morning*). It has been shown that personally tailored messages are more effective than other forms of messages (Revere & Dunbar, 2001). Bickmore and Giorgino (2006) have described some important pragmatic issues in healthcare dialoguing as:

1. Sensitivity to context
2. Respect for autonomy: power & negotiation
3. Social, emotional & relational issues
4. Continuity over sessions
5. Language change over time

Regarding the designing of the dialogue system, the third question referred to the factors within the dialogue design that relate to clinically significant impact. Some reasonable answers could be found in the literature on automated healthcare dialogue (Duffett-Leger & Lumsden, 2008; Revere & Dunbar, 2001). These researchers meta-analysed studies (including RCTs) and found following characteristics of an automated healthcare dialogues to be linked to clinical efficacy (Duffett-Leger & Lumsden, 2008):

1. Theory-based design of dialogues
2. Tailoring of dialogue
3. Repeated interactions
4. Multi-strategic interventions
5. User collaboration during design process.

Therefore, being well-versed by this information, this research attempted to incorporate as many of the pragmatic features and clinical success factors as possible into the design. Also the state transition network process was chosen as the preferred method, given its possibility within the available resources and a good balance between functionality and programming.
complexity. It is common practice in dialogue design methods to use flowcharts as a systematic way of informing the engineering efforts (Young, 2002). The dialogue schema was drafted and communicated by the researcher as flow charts described later.

### 5.2.1.1 Psychosocial considerations

The dialogue was initially conceived according to the mental schema that older people are known to carry around their medication usage (what to take, how to take and why to take) (Morrow, Von, & Andrassy, 1993). Also, seven variables known to independently and significantly influence medication use were acknowledged (Lorenc & Branthwaite, 1993). They are: accurate knowledge of regimen, belief in the importance of taking medications exactly as prescribed, low resentment of time spent waiting to see the doctor, less fear of illness, ability to read the label on the bottle, understanding what the doctor has said and living with a relative. Some other behavioural theories have been widely accepted, such as health belief model (Becker & Maiman, 1975) that attempt to predict determinants of compliance to healthcare related instructions and theory of planned behaviour and variation (Ajzen & Fishbein 1980) that helps in understanding attitudes and predicting social behaviour of patients and providers.

Keeping the user in a primary position and building skills while carefully avoiding medicalisation was important. In the view of healthcare providers, a good user is a compliant patient. However, people who assume responsibility- apply their own initiative, becoming active and reasonable medication users (Lumme-Sandt & Virtanen, 2002). Increasingly, patient empowerment and engagement are seen as components of the mechanisms that support compliance (Sabete, 2003).

Humans tend to harbour egalitarian motives, making it difficult to take instructions from a machine, especially those pretending to be intelligent (Dawes, Fowler, Johnson, McElreath, & Smirnov, 2007). These factors are more likely to be pronounced in older people, given the chances of higher computer anxiety (Laguna & Babcock, 1997) and more apprehension, which are proven to affect less competent outcomes (Morrow, et al., 1993). Social stimuli can arouses strong emotions that need to be managed appropriately (Frith & Frith, 2006).

In professional communication, a bidirectional sense of empathy is often communicated through a process of self-reflection and self-criticism (Charon, 2001) as opposed to patient alienation caused by expression of ‘knowledge-power’ and ‘professional domination’, the two Foucauldian concepts (Petrilli, 2003). In this light, the dialogue system could express and
invoke empathy by admitting that it might have the wrong information and remain subject to correction. Also, this process could serve as a safety net in case an error has been made by the machine; the human is given a chance to correct it.

5.2.2 The talking computer: Human-robot interaction in eldercare

5.2.2.1 Should a talking computer behave like a human?
While most of the dialogue systems described earlier was delivered using desktop computers or handheld devices, scientists imagined the next version of a talking computer that looked and behaved like a human (Reeves & Nass, 1996). Pollack et al. (2005) demonstrated the use of complex Artificial Intelligence (AI) algorithms to drive dialogues and interaction between a robot and an older person. In a robot-based reminder system (Figure 5.1), they designed a robot that attempted to understand and predict the user's needs and communicated using voice and display. It was called a “Personal Cognitive Orthotic” (reminder) and generated a dialogue informed by the “Plan Manager” (that stores all the planned activities and schedules) and client modeller (that records that the activities have been performed). For each instance of interaction a context-specific dialogue was synthesized (Pollack, 2005).

At a glance, it may appear that increasing the complexity and sophistication of dialogue automation to generate more intelligent dialogues would have a higher influence on users. On the contrary, many intelligent dialogues tend to have a paradoxical effect. The ‘uncanny valley’ was a term used by Mori (Mori, 1970) which described the user’s perception of a machine as it achieves greater similarity to a human. It may become more appealing to the observer at an emotional level; however, when it becomes very close to mimicking human behaviour, speech or looks, there is a very strong drop in believability and comfort (Figure 5.8).
In the context of automated dialoguing, a similar phenomenon applies. Raising user expectations for the system to behave like a human and then not delivering fully on it raises user dissatisfaction (Migneault, et al., 2006). As seen in Figure 5.2, the effect is higher for a moving (or talking) machine than it is for a static one.

5.2.2 Input-Output devices – Why use a touch screen on a robot?

The appropriateness of input devices and user interfaces for older people has been studied widely. Older people are reported to deal better with gesture-based and touch screen systems than with standard keyboard mouse systems (Hollinworth, 2009; Tobias, 1987). Familiarity with gestures has been reported to improve usability (Stöbel, Wandke, & Blessing 2010) and touch screen systems have been shown to have better usability for older people (Fisk, Rogers, Charness, Czaja, & Sharit, 2009). Touch screens make the interaction simple, directed and goal oriented (Murata & Iwase, 2005). Older adults have also been reported to prefer multimedia presentations over simple text display (Ogozalek, 1994). Routine use of ATM machines by residents of Selwyn Village makes them familiar with a touch screen-based user interface and this could be leveraged.

The fundamental basis for proposing a robotic solution is not the robot’s mobility or performance of physical tasks; rather, it is an attempt to harness the robot’s influence of physical embodiment (or anthropomorphic presence) that builds a shared social context. This shared social context with the user adds an interpersonal element to inform, empower and support older users and also leverage formation of an affective or social relationship (Looije et al., 2010). These relationships are not only with the robot but the people that this robot
represents, as a key for time-extended support for relatively isolated older people, especially those with special needs.

A robot cannot only identify and invite users to interact but can also serve as an extension of the remote caregiver through telepresence. As shown in Figure 5.3, just as touch screens extend the usability of standard computers, it can be hypothesized that the information presentation capabilities of a touch screen-based user interface can be extended on a robotic platform for successfully engaging older people. Though this research did not test the influence of the caregiver’s telepresence component, it could be a possible direction for future iterations.

![Figure 5.3: The incremental usability and likeability of computers for older people](image)

The current literature on social robotics in healthcare does not satisfactorily address implications around intrusiveness, domination, disempowerment and medicalization (Joyce & Loe, 2010) that could be imposed by social robots in healthcare and limit their potential use. Moreover, the medication management module design described in the thesis is influenced by the mention of robots but has also attempted to conceptualize the module to run on any touch screen or mobile device, irrespective of its robotic operation. Measuring the exact value that a robot adds to a touch screen-based medication management system remains a subject for future research.

### 5.3 Objectives of this AR cycle

The main objectives of this phase of research were to:

1. Collaborate and develop a working prototype of medication management module
2. Test safety, efficacy, functionality and usability of medication reminder system mounted on the robot
3. Collect user feedback on the dialogue flow/sequence, appropriateness and content
4. Test connectivity and data transfer between robot and remote server.
The apparatus developed and used and methodologies followed to achieve these objectives are described below, followed by the results and discussion.

5.4 Apparatus

This section describes the design of software to enable a robot-mounted medication management module. There were two main components of this software as envisaged earlier – (see Figure 4.8); first, the web-based application, called Electronic Medication Record (EMR) in this initial version, that included a database and a graphical user interface. The second component was an application running on the robot computer with its own user interface. Figure 5.10 illustrates these components of the module. It also shows the developments within the overall Healthbots project, which in collaboration with other research teams had planned other modules that would run side by side with the medication management module. Some of these modules were already developed and tested (e.g. the vital signs module), the results of which are published elsewhere (Kuo et.al, 2008).

The prescription data was obtained in electronic format from the pharmacy management system (Toniq) of the pharmacy that serves packaged medications to residents of Selwyn Village. The lack of electronic connectivity and the standalone systems working in silos meant that the researcher had to manually collect the file on a USB drive. The file format was .ADS which had to be read by the web-based component of the module, the idea being that, in future, web connectivity between the robot system and the pharmacy system would eliminate the manual process. ADS is a systematic format which arranges medication lists in a tabular form. Each row of this table is assigned to a medication name and the columns are assigned to the date and time of day when this medication is supposed to be taken. A simplified depiction for one medication over two days is shown in Table 5.1.

<table>
<thead>
<tr>
<th>Medication name</th>
<th>Date/ month/ year</th>
<th>Date/ month/ year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Breakfast</td>
<td>Lunch</td>
</tr>
<tr>
<td>Tablet XYZ 20 mg.</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
As presented, it does not contain any further granularity about instruction on how to take the tablets. Currently the .ADS file is used in the pharmacy to transfer data from Toniq to the packaging robot that generates labelled sachets of medication. An attempt was made to enable Toniq’s web connectivity with our module, but the disproportionate costs and time involved in working with a proprietary system made it unfeasible.

Figure 5.4 captures the essential design elements of the architecture. As described earlier in Chapter 4 (Figure 4.8), the module was envisaged as having web-based and robot-based components.

5.4.1 Web-based application

In the light of requirements gathered earlier, a central repository of patient medication data was required, where data from all patients could be stored, manipulated and used to inform individual robot interaction. Requirements from a web-based system were:
1. The ability to hold data about as many patients as required in a single place. Each patient should have a unique profile with his/her personal details, a picture and personal prescription.

2. The web-based patient profile should accurately link to the same patient who may be using the robot in the field.

3. Each prescription should have all the necessary details to inform a meaningful and accurate medication dialogue prompted by the robot.

4. The web-based electronic record should be able to read the .ADS file and populate the medication list automatically under the patient profile

5. The researcher should be able to create a new patient, upload the ADS file, and verify/change this medication data against the paper prescription to avoid any technical errors.

6. Whenever the patient interacts with the robot, the exit point of the dialogue (e.g. taken medication or refused medication and so on) should come back to the EMR and populate a log entry. This will inform how many times the patient has taken his/her medications.

The summary of requirements was shared with team members and the researcher participated with software engineering researchers and colleagues to develop an initial database schema in MS Access that was refined and developed into the application that is described separately. The database in turn was linked to a data access layer for creating a graphic user interface (GUI). The user interface allowed the researcher to manually upload the ADS file from a computer in the lab and manipulate the missing data elements. The database and GUI were linked to an EMR library that linked the patient information to the prescription information.

5.4.2 The robot software environment

5.4.2.1 The user interface
The touch screen presented with a resting state menu that displayed all the modules available to the user at any given time as shown in Figure 5.5. The service application layer was already designed and consisted of several application modules, developed in C++. The application front end was written in Flash and Action Script 2.0 that generated the GUI with soft touch buttons and icons.
The main screen was designed by the larger Healthbots team pursuing multiple research objectives. It is shown in figure 5.5 as background information. Only the user interface for the medication management module (accessed by pressing the button [Medicine] on the home screen) was specifically conceptualised by the researcher in alignment with other existing modules in order to maintain perceptual continuity between all applications.

Figure 5.6 shows a simple, uncluttered screen with the dialogue displayed prominently in the centre of the screen in high contrast and large easy-to-read font. Being informed by well-known criteria for usability of computers (Nielsen, 1994), it has not more than three clearly visible large buttons with unambiguous choice and clear indication of touch recognition. The screens give the ability to backtrack or exit from the top button and generate speech that matches exactly with the written word. These features were specifically designed to keep the needs of older users in mind as they informed us while discussing the paper prototype (Chapter 4). Each screen followed state transition with a branching tree logic explained below.
5.4.3 Dialogue system design

Although each alternative has its trade-offs, the nature of the challenge necessitated a user interface (UI) dynamically informed by an XML dialogue manager as the main component of the software architecture. In this version of the robot, all dialogues were pre-defined in text form and synthesised in real time using a festival speech synthesiser as each dialogue state was evoked by the XML dialogue manager. Once a dialogue was initiated, the robot screen prompted the user in a deterministic manner, synchronising the spoken dialogue with what was displayed on each screen. The user could indicate his/her choice/response by pressing one of the soft button options. We preferred the use of touch inputs over speech recognition given the current status of Automated Speech Recognition (ASR) technology. As summarized in a recent literature review (Young, 2010) ASR has been shown to pose serious limitations for ambient voice recognition of older people.

Such limitations could potentially make the interaction not only frustrating but also error prone – an unacceptable variable in a medication management module. Therefore, it was decided to forgo the voice input option for this study.

The simultaneous display of dialogue text with option buttons with spoken dialogue reinforces cognition if people have visual or hearing deficiencies. This dual presentation of information or instructions makes it easier for older adults to comprehend and respond appropriately. The visual display is simplified to present a single piece of information or instruction at a time (per screen), thereby minimizing the cognitive burden with respect to attention and memory (Hawthorn, 2007). The system driven by Adobe Flash programming displays in bold letters against a bright contrast followed by not more than three large, clearly labelled soft buttons to improve the clarity of choice selection and reduce the response time, compensating for motor skill limitations (Murata & Iwase, 2005). The soft buttons use action script to show their responses. Every touch makes them change colour and makes a distinct sound confirming haptic input. The audio reproduction of the displayed dialogue allows for adjusting to a relatively loud volume. Additional support to physically disabled users becomes possible by mounting the screen on a mobile robotic platform. In an ideal situation the robot would be able to drive itself close to the person (as well as to a self-charging station), carry medications in its tray and take the initiative to start interactive sessions by virtue of mixed-initiative design. In the future, integration with other smart home technologies could also be attempted. Despite the
robot being able to locate and self-navigate to the user in its final design, it was manually
driven for this trial.

Being informed by earlier studies, a schema of dialogues was prepared (shown in Figures 5.7
and 5.8). The schema went through a few iterations, starting with a complex scenario and later
scaled down to the simplest possible sequence that could adapt to the engineering limitation on
any given software platform (Figure 5.9).

An effective medication dialogue system would probably attempt to address some of these
factors by providing knowledge, building confidence, making it easy to communicate with
doctors and pharmacists, reading labels, and explaining information, while providing useful
companionship. In this light, the dialogues strategy intended to encompass the following (but
did not necessarily deliver on all of them at this stage):

1. A reminder function
2. A strategy to promote users to engage with their medications (e.g. actively
   seek medications, read labels and inform themselves)
3. An ability to handle errors and allow users to confirm instructions rather
   than asserting responsibility and inadvertently making a mistake
4. A choice at each stage to promote interactive dialoguing and show respect
5. An opportunity for education-promoting quality use of medications
6. An ability to inform the healthcare providers about their choices and
   satisfaction.

In Figure 5.8, the dialogue starts with the concept of time – Is it now? (where ‘now’ means the
time to take medications). Patients take different medications at different times. The system
recognised four times: breakfast, lunch, tea and bed, and each ‘time’ is linked to a particular
list of medication/s. These four time slots are not only conventional medication-taking times
but also link with the ADS file coming from the pharmacy management system. In that file,
the prescription is tabled in a calendar format and each medication is allocated a day and a
time. The robot system was programmed arbitrarily to read the time as follows:

1. Breakfast time: 5am – 10.59am
2. Lunch time: 11am – 2.59pm
3. Tea time: 3pm – 5.59pm
4. Bedtime: 6pm to 9.59pm
If the interaction was started on any given day between these times, the robot would only invoke a list of medications from EMR that was linked to that particular day and time. This list, in turn, would inform the reminder dialogues. The system can fix a particular time to suit each individual preference within this range. In case there were no medications listed for a particular time or the time is not reached, the robot machine would rest in an idle state, displaying the general menu (Figure 5.7).

The touch screen computer is wirelessly connected to an EMR server that holds relevant personal and clinical information in a secure manner. The information is released only after the confirmation of user identity and appropriateness of schedule (e.g. right information at the right time, as indicated by the prescriber). The user ID is confirmed in this stage by requesting the user to enter their first name and last name on the touch screen using a virtual keyboard. The dialogue, being essentially a reminder, takes a neutral stance without issuing an instruction but rather invoking interaction (Stößel, C., H. Wandke, et al. 2010).
Figure 5.7: Dialogue flow when the time to take medications is reached

The system would respect the autonomy of the user to refuse taking medication but gently attempt to elicit the reason behind the ‘declined’ decision in order to learn about user behaviour and possible reasons why people say no to medications.
Initially, the researcher attempted to construct a dialogue based on individual medication, but soon realized the complexity of the varied forms and organizations would be very hard to handle at this initial stage. Therefore, *medications* were treated as a single unit, whatever it may mean to the user. In the branching tree logic, there were multiple exit points depending on the status and choice of the user in relation to his/her medications. The flowchart in Figure 5.8 shows scenarios before now and after now.

![Flowchart showing dialogues before and after scheduled time](image)

**Figure 5.8: Dialogues when a user interacts before and after scheduled time**

In the scenario of the person interacting with the robot after the preferred time (*after now*), the possibility of already having taken the medications and forgetting that experience is significant. On the other hand, interacting with the robot and completing the task before the scheduled time (*before now*) opens the possibility of taking the medication unsupervised once again in future.

### 5.4.4 Simplified version

The ideas generated by context analysis were discussed with the team for converting into a dialogue system. The limitations of screen size on the computer and the complexity of logic expressed by the researcher in flowcharts was considered difficult to implement by the engineering colleagues. These discussions and further iterations led to a simplified flow chart.
that team members mutually agreed upon. Figure 5.9 shows the complexity of the logic of medication assistance dialogue and exit routes are significantly reduced, resulting in the dialogue size being made smaller to fit the screen while retaining their utility. This stripped down version was then taken to implementation.

This scenario was limited to people who are already on compliance packaging, reducing the plurality of medications to a single pouch. These pouches are labelled to clearly display the patient’s name, date and time, making it easy to construct the short and safest possible dialogue. Also, this would match with the context of Selwyn Village where we followed the caregiver on her medication rounds and observed her dispensing these packaged medications to high-risk patients. Some of the respondents in the evaluation phase (described in the next section) were actually part of the process mapping.

This chart was then documented in XML script by the researcher (Figure 5.10). The dialogue manager on the robot used action script that was informed by dialogue schema in XML format to maintain the flexibility of changing dialogues. If it was hard coded in C++, then it would be
difficult for the researcher to request changes. The dialogue words and structure kept changing frequently as the discussions evolved and insights were gained. The initial part of the XML schema is demonstrated below:

```xml
<xml version="1.0"/>
<dialog_module author="Priyesh Tiwari" date_last_updated="03 Nov 2009"
first="initial_questionnaire">
  <Dialog name="check_medication_time" back="false" quit="true">
    <Button next = "usually_takes_now" log="The person usually takes medicine now">This is medication time</Button>
    <Button next = "takes_later" log="The medication time is coming later">Medication time is coming later</Button>
    <Button next = "takes_before" log="The medication time has passed">Medication time has passed already</Button>
    <say text="Please select the correct option."></say>
  </Dialog>
  <Dialog name="usually_takes_now" back="false" quit="true">
    <Button next = "not_now" log="The person declined that this is medication time">No</Button>
    <Button next = "correct_now">Yes</Button>
    <say text="I believe you take your medication now, is that right?"></say>
  </Dialog>
  <Dialog name="not_now" back="false" quit="false" exit="true">
    <say text="sorry I may have some incorrect information, I will recheck."></say>
  </Dialog>
  <Dialog name="correct_now" back="true" quit="true">
    <Button next = "already_taken" log="The person has already consumed medication">Yes</Button>
    <Button next = "check_medication_possession">No</Button>
    <say text="Thank you for confirming #Name#. Have you taken them already?" ></say>
  </Dialog>
  <Dialog name="already_taken" back="false" quit="false" exit="true">
    <say text="Excellent, that is very good"></say>
  </Dialog>
  <Dialog name="check_medication_possession" back="true" quit="true">
    <Button next = "check_ready_now">Yes</Button>
    <Button next = "can_take_later">No</Button>
    <say text="Okay, do you have them with you now?" ></say>
  </Dialog>
</dialog_module>
```

Figure 5.10: Partial XML schema of dialogue system

VoiceXML was an alternative possibility for coding the dialogues. It is a specific standard to mark-up speech for Web browsers e.g. to add inflection and pauses. While VoiceXML may have been useful at a certain level, our higher level dialogue specification included the complete logic of the dialogue (e.g. branching), not just the words. We could have specified the whole thing as a web page with JavaScript branching, but our part was really at a higher level – word rendering and the GUI presentation were separated from our dialogue design. Ultimately, the decision of using a particular technology remained out of the scope of researcher where the larger multi-disciplinary team had speech scientists developing and synthesising a voice and were pursuing their own specific research questions.
5.5 Methods

As explained in Chapter 3, the cycles of action research blended grounded theory and participatory design. In this second cycle, we designed and tested the first prototype. Figure 5.11 summarizes the important steps during this iteration.

The planning phase included the literature survey and the prototype designing as described earlier. The coding assistance was provided by software engineering colleagues. The planning step also involved seeking approval from the ethics committee for experimenting with human participants (University of Auckland Human Participants Ethics Committee protocol approval 2010 / 032). Thereafter, interview consents from independently living elder residents of Selwyn Village were taken and an appointment was set up for testing.

The acting phase took the robot to the participants in their apartments and tested the appropriateness of intervention. Out of 19 participants who responded to the flyer in their mailbox, we randomly chose 10 participants. After an initial discussion, two participants declined to continue, so two more participants were randomly picked from the remaining group that agreed to participate. The reason for choosing relatively independent and capable participants was to seek active feedback to improve the design (PD), which would have not been possible if we had chosen high dependency or cognitively impaired subjects. Moreover, the ethics committee was concerned about the risk of testing an unproven technology on vulnerable participants.

After sharing the participant information sheets and signing of consent forms, the current prescription data was collected from the respective pharmacies. The prescription information
was collected as a hard copy printout as well as a soft copy (as an export file) from the pharmacy management system. The software file was intended to be read by the robot software and its contents translated into a meaningful dialogue. On an appointed day, the researcher and the team of engineers reached the apartment of the participant at their preferred breakfast medication time early in the morning.

The evaluation phase involved a field study. The study was a one-off interaction to test the usability of the application. Ten elderly residents of Selwyn Village were exposed to the designed prototype. During the interaction video recordings were made and the researcher took field notes. Post interaction a questionnaire was served, and a semi-structured interview was conducted. Audio recordings of the interviews were then transcribed. Transcribed data was then coded and triangulation with field notes, video recordings and questionnaire responses was carried out. Table 5.2 summarises the data collection methods and tools used in this phase of study.

<table>
<thead>
<tr>
<th>Aims of the study</th>
<th>Measurement tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 To test safety, efficacy, functionality and usability of medication reminder system mounted on the robot</td>
<td>Qualitative observation and usability testing data analysis - time taken, paths, backtracking, ease of use, getting stuck &amp; recovery</td>
</tr>
<tr>
<td>2 To collect user feedback on the dialogue flow/sequence, appropriateness and content</td>
<td>Semi-structured interview and questionnaires</td>
</tr>
<tr>
<td>3 To test connectivity and data transfer between robot and remote server</td>
<td>Reliability scoring &amp; technical feasibility e.g. connectivity issues, error rate, type of errors, and their resolution</td>
</tr>
</tbody>
</table>

Finally, the reflection phase involved thinking more deeply through the maturing categories and allowing themes to emerge via axial coding. Concurrently, the documentation to inform the refinement of application design was prepared. The main data collection methods were: during testing – video recordings of user interaction and field notes; and post interaction – questionnaires and semi-structured interviews. This data was then analysed using GT to inform the categories. The field testing also intended to elicit participation, collect feedback and gather further requirements in PD fashion to refine the prototype design. In parallel, the data from the
field notes, interview transcripts, questionnaires and log records was triangulated following a GT approach to further develop the categories during the theory building process.

5.6. Results of the usability study in AR Cycle 2

Adhering to participatory design methodology necessitated taking this design back to the potential participants and letting them test the system, while collecting subjective and objective feedback. This section presents the results of usability testing of the system. It presents the methods used and their outcomes, namely video recording of user interaction, the post-interaction questionnaire, and a semi-structured interview. The results from this study were presented at Australasian User Interface Conference (Tiwari, Warren & Day 2010).

5.6.1 Participant profile

As shown in Table 5.3, the 10 participants were distributed across four different independent residential blocks in the ACF, and ranged from 69 to 94 years of age, with half of them above 80 years and mean age 80.5 years. The evenly distributed five males and five females included two couples.

Table 5.3: The participant profile

<table>
<thead>
<tr>
<th>Patient</th>
<th>Location*</th>
<th>Age in yrs.</th>
<th>Gender</th>
<th>Pharmacy**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BS</td>
<td>73</td>
<td>Female</td>
<td>i</td>
</tr>
<tr>
<td>2</td>
<td>LT</td>
<td>79</td>
<td>Female</td>
<td>iii</td>
</tr>
<tr>
<td>3</td>
<td>RA</td>
<td>77</td>
<td>Female</td>
<td>ii</td>
</tr>
<tr>
<td>4</td>
<td>RA</td>
<td>80</td>
<td>Male</td>
<td>ii</td>
</tr>
<tr>
<td>5</td>
<td>RA</td>
<td>69</td>
<td>Male</td>
<td>ii</td>
</tr>
<tr>
<td>6</td>
<td>LT</td>
<td>77</td>
<td>Female</td>
<td>i</td>
</tr>
<tr>
<td>7</td>
<td>LT</td>
<td>94</td>
<td>Male</td>
<td>ii</td>
</tr>
<tr>
<td>8</td>
<td>BS</td>
<td>87</td>
<td>Male</td>
<td>ii</td>
</tr>
<tr>
<td>9</td>
<td>LT</td>
<td>87</td>
<td>Male</td>
<td>ii</td>
</tr>
<tr>
<td>10</td>
<td>LT</td>
<td>82</td>
<td>Female</td>
<td>ii</td>
</tr>
</tbody>
</table>

*BS, LT & RA are abbreviated names of 3 multistorey buildings within Selwyn Village (Bishop Selwyn, Lichfield Towers, Randerson Apartments)
** i, ii and iii are 3 geographically separate pharmacies

Being a usability study, it was conceived that a small sample size should give us the insights to guide our further solution development directions. A formative approach was more appropriate than a summative approach which pursued a larger number of respondents at this stage. The participant profiles might contribute a selection bias because the voluntary expression of interest in participation could draw more interested and capable people. In fact four out of 10 participants had already participated in earlier trials conducted under the same project. However, this was not a psychological study of human-robot interaction as before, and none of the participants had earlier been exposed to medication management modules.
5.6.2 Video analysis
Since the issue of medication is sensitive to the patient’s safety, the researcher not only explained the process while supervising and supporting the users during the session but also took notes throughout the session and noted areas needing improvements, reasons for getting stuck or backtracking and reasons for errors. The recordings were made of users interacting with the robot as it moved into their living quarters at the scheduled time. The users had agreed not to take their morning medications earlier but instead took them when prompted by the robot.

To keep the interview time short and not cause significant delay in medication intake, the researcher made subjective observations about their cognitive status and suitability of the robot for these people from a general clinical perspective. Retrospectively, an objective assessment of the cognitive status could have been made but a mini mental-scoring-type quick clinical observation with simple questions relating to orientation and performance during introductory conversation seemed sufficient at that stage. None of them seemed to have clear symptoms of dementia, although three participants appeared to fumble with repetition and recall of names and they were categorized as average.

Table 5.4: Results of video analysis

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Medications organized as</th>
<th>Cognitive Status</th>
<th>Computer literacy</th>
<th>Previous participation in robot trial</th>
<th>Errors made by user</th>
<th>System errors</th>
<th>Backtracking</th>
<th>Total time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73</td>
<td>Pouch</td>
<td>Average</td>
<td>None</td>
<td>No</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>79</td>
<td>Bottles</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>77</td>
<td>Packaged</td>
<td>Average</td>
<td>None</td>
<td>No</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>Pill box</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>2.3</td>
</tr>
<tr>
<td>5</td>
<td>69</td>
<td>Bottles</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>77</td>
<td>Bottles</td>
<td>Average</td>
<td>None</td>
<td>No</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>9.3</td>
</tr>
<tr>
<td>7</td>
<td>94</td>
<td>Bottles</td>
<td>Good</td>
<td>Yes</td>
<td>No</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>4.7</td>
</tr>
<tr>
<td>8</td>
<td>87</td>
<td>Pill box</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>2.7</td>
</tr>
<tr>
<td>9</td>
<td>87</td>
<td>Bottles</td>
<td>Good</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td>10</td>
<td>82</td>
<td>Pouch</td>
<td>Good</td>
<td>Yes</td>
<td>No</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The results of video analysis showed that although all users were able to complete the interaction successfully, irrespective of age or cognitive status, the presence of the researcher and his prompting was an influencing factor in this exploratory study, and we are not sure how the sessions would have progressed unsupervised. We took the approach that to learn the most about areas for improvement the researcher would prompt the users through sticking points, after noting the nature of the error that caused the problem.
Table 5.5: List of errors recorded

<table>
<thead>
<tr>
<th>Errors made by users</th>
<th>System /design errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typographic errors</td>
<td>Confusing options</td>
</tr>
<tr>
<td>Medication identification errors</td>
<td>Voice generation errors</td>
</tr>
<tr>
<td>Inappropriate choice of option</td>
<td>Soft button (touch screen) errors</td>
</tr>
<tr>
<td></td>
<td>Pronunciation errors</td>
</tr>
<tr>
<td></td>
<td>Inappropriate utterance</td>
</tr>
</tbody>
</table>

There were two types of errors: one made by the user and the other made by the designers. The major set of errors was observed when users were attempting to type their name for self-identification. The user misidentified the medication that was prompted once, while the users chose options that were not consistent with their goals twice. The system design errors were mainly related to errors in the dialogue construction, pronunciation of medication names, and slow response of soft keys to the touch of the user. While attempting to analyse the relationship between errors and user profiles, there was no significant relationship observed between the occurrences of errors or time taken to complete the session in relationship to age, computer literacy or previous exposure to the robot. This observation highlights the fact that, in this study, mild cognitive impairment and/or unfamiliarity with computers or robots did not impair the medication reminder function’s usability.

One relationship that stands out was the way medications were organized and the errors generated, as well as time taken. Unsurprisingly, users who had medications loosely arranged in bottles and strips (five out of ten), took almost twice as much time as those who had them organized in pouches or blister packaging or used pill boxes: the mean task completion time was 5.7 minutes compared to 2.8 minutes. The same group was almost twice as likely to encounter errors as those who had their pills organized in pill boxes, sachets or blisters (64.6% of total errors were made by those taking medication in the bottles and strips group compared with 35.4% errors in others).

The results may not be surprising, but the reasons were variable. The main problem was related to the screen design, where designers had categorized methods of pill organization, and the user could choose only one option. For example, if the user was on sachets (packaged medication), then the dialogue proceeded along those lines. Most users had loose pills in addition to sachets and were confused as to which option was most appropriate to choose. We
had failed to anticipate this as we had been informed that use of the robotically packed sachets was the norm in Selwyn Village.

Mainly, there were problems with typing names into the text box using the soft keypad, the inability of the robot system to handle ‘null or error’ values entered into the web-based EMR (e.g. wrong name or wrong timing), and some were processing failures including voice generation problems and soft button miss strike. Most of the system or design errors were perceived by the engineering teams as simple to correct in the next iteration.

5.6.3 Questionnaire analysis

The participants who used the system were asked to respond on a five-point Likert scale to the questions after the interaction. The questionnaire was modified from a System Usability Scale (Bangor, Kortum, & Miller, 2008) and the responses are shown in Figure 5.12. The X axis shows participant number (total of 10) and Y axis the question. On the Likert scale, 1 indicated strong agreement and 5 indicated strong disagreement. The responses were grouped into three categories namely: Agree = (Strongly Agree and Agree), Equivocal = 3, Disagree = (Disagree and Strongly Disagree).

The questions tend to explore commonly known elements of usability like learnability, functionality, practicality, and satisfaction. There may be trade-offs among these criteria while designing where some may be more important than others in particular situations.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I may like to use this robotic reminder system frequently (whenever I need it)</td>
</tr>
<tr>
<td>2</td>
<td>System would be easy to understand and use by people like me</td>
</tr>
<tr>
<td>3</td>
<td>It would be easy to practically use this system in our living quarters</td>
</tr>
<tr>
<td>4</td>
<td>I would need the support of a technical person to be able to use this system</td>
</tr>
<tr>
<td>5</td>
<td>Various functions in this system were appropriately designed</td>
</tr>
<tr>
<td>6</td>
<td>Such a medication support system would make us feel confident about our health</td>
</tr>
<tr>
<td>7</td>
<td>I would imagine that most people would learn to use this system very quickly</td>
</tr>
<tr>
<td>8</td>
<td>I found the system very cumbersome to use</td>
</tr>
<tr>
<td>9</td>
<td>I felt very confident using the system</td>
</tr>
<tr>
<td>10</td>
<td>I needed to learn a lot of things before I could get going with this system</td>
</tr>
</tbody>
</table>

Figure 5.12: Responses to modified system usability scale
The small sample size failed to provide any clear association between age, type of medication packaging, pharmacy or residential location and the responses. The responses lead to two important conclusions. Firstly, the assumptions about the appropriateness of the user interface design for the older people were affirmed, and the system was well received. Most users found the system easy to use, appropriately designed and felt confident about using it. Secondly, the results were mixed with respect to whether the users would like to use the system regularly, regarding the practicality of a robot moving around in their living quarters and whether it would build confidence about their health. They were also not sure if their other peers would learn it easily, probably because respondents were aware of the varying degree of cognitive capability in their peers in the facility.

5.6.4 Semi-structured interview

Further along the lines of participatory design, a semi-structured interview was conducted to elicit the overall impressions of the users and identify some of the design implications for future developments. The responses were coded using grounded theory to be able to infer definitive direction.

Figure 5.13 shows the question asked in semi structured interview and makes an attempt to classify the subjective answers as affirmative, negative or neutral. The answers given by 10 participants are illustrated in the bar diagram where x axis represents the number of participants saying yes, no or may be to the questions numbered on y axis.
1. Would you like us to build in the dispensing function as well?

2. Would you prefer a moving machine like this or a static small device that has the same features sitting on your dining table?

3. Would you like the robot to ask you from time to time if there was any possible side effect, or the medications are working as they should – and inform your pharmacist or doctor?

4. Would you ever like to ask the robot the details of your medication and the information that is usually on the leaflet?

5. Would you like the robot to quiz you or pop bits of information about your medication to keep you better informed?

6. Would you like the robot to send a message to your pharmacist or doctor when you actively ask it to seek clarification about your medication?

7. Would you like the robot to display if there was any message sent to you from your pharmacist or doctor?

8. Would you like the robot to prompt you or automatically schedule refill appointments when your medication/s are getting overdue?

9. Would you like the robot to tell you how other people on the same medication as you are responding to it?

10. Would you like the robot to inform your family member or caregiver in case there is some problem with the medication?

11. Would you like the robot to display your other health records (e.g. lab values, appointments, discharge notes, recommendations etc.)

12. Would you feel better about taking your medications if we replaced the robot’s voice with your doctor, pharmacist, nurse, caregiver’s or family member’s voice?

**Figure 5.13: Responses to Semi-structured interview**

### 5.6.4.1 Design implications identified:
The data specify some themes which could be considered important indicators for future design work. The respondents tended to be strongly opinionated one way or the other as seen in the data showing minimal ‘Maybe’ responses.

1. Most users were in favour of the automated dispensing function and not just being limited to reminders.

2. There was almost unanimous desire for a smaller static device instead of the large moving robot, given the practicality of this in a small living space such as the ACF apartments, as well as relatively good mobility of respondents and obtrusiveness of the robot. Moreover, we are not sure if the same response would be valid for a multifunctional robot as opposed to a single application as tested in this study.

3. Most respondents definitely wanted some form of educational component and side effect surveillance system, because many of them have had side effects from their medications.
medications where they were not sure what was happening and even the doctors failed to detect them for months. A few patients reported coming across side-effect information somewhere and asking the doctor specifically. Only then was it recognized and addressed.

4. Refill reminding was another big issue, where the users indicated that they would benefit greatly from being reminded in advance. It was reported prescribers often take a long time to give appointments and some of them come to the clinic on specific days. If the residents forget the exact day, then they may have to wait without medication till next week for the doctor to become available at the ACF clinic.

5. There was almost unanimous desire by the respondents to keep their family members and/or caregivers in the loop about the medication processes. They indicated that this was not only for the sake of keeping family informed but also to ensure that someone is there to respond in case something went wrong.

6. On the other hand, the users did not like the idea of being quizzed or being pursued about remembering details of their medications.

7. They were also less interested in knowing about other residents who are on the same medication and how they were doing, the main argument being that each person has a different reason for taking a particular medication and there is no reason why private information should be shared.

8. The respondents almost unanimously disliked the idea of changing the mechanical robotic voice to a more familiar human voice (e.g. voice of a family member or of their pharmacist).
5.7 Developing grounded theory through open and axial coding

As shown in Figure 5.14, this cycle of action research builds upon the information gathered earlier. In this phase of research, the data from this study was not only open coded but also triangulated with other data sources (questionnaire) and also with codes gathered in earlier cycles. The constant comparison with data and triangulation was used to further develop categories and perform axial coding to arrive at themes that emerged in the process.

![Diagram of the coding process](image-url)

**Figure 5.14: The coding process (applying grounded theory)**
5.7.1 Open coding – moving from codes to categories

The data from the semi-structured interviews was subjected to open coding in the first instance. Chapters 2 and 3 explained open coding as the process of breaking the data down into concepts by reading them and each sentence or group of sentences were condensed into a concept depending upon what was being said. Table 5.6 shows nine categories that emerged from the data collected in semi-structured interviews.

Table 5.6: Categories emerging from open coding of data

<table>
<thead>
<tr>
<th>No.</th>
<th>Categories (3)</th>
<th>Sample concepts (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Convenience</td>
<td>Dispense, easy to find, organized, in one place, easy to reach, joint pains,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>scissors to open, breaking tablets, like a caregiver</td>
</tr>
<tr>
<td>D2</td>
<td>Practicality</td>
<td>Space issue, lean over, drop, spill liquid, technical support, charging, parking</td>
</tr>
<tr>
<td></td>
<td></td>
<td>when idle, cleanliness, might break it</td>
</tr>
<tr>
<td>D3</td>
<td>Communication</td>
<td>Family interest, supervision, assistance, confidence, professionalism, interaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>easy, queries</td>
</tr>
<tr>
<td>D4</td>
<td>Knowledge</td>
<td>Medication information, side effects, timing, correctness, at right time,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>language, easy</td>
</tr>
<tr>
<td>D5</td>
<td>Safety</td>
<td>Problem detection, warning, support, call for help, prevent mistakes, trip over</td>
</tr>
<tr>
<td>D6</td>
<td>Privacy</td>
<td>Sharing personal info, need based,</td>
</tr>
<tr>
<td>D7</td>
<td>Medical domination</td>
<td>Voice, mannerism, impersonal, likeability, authority, control, fun, machine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>as machine</td>
</tr>
<tr>
<td>D8</td>
<td>Embarrassment</td>
<td>Testing, asking, ability to use,</td>
</tr>
<tr>
<td>D9</td>
<td>Other reminders</td>
<td>Appointments, refills, time delay, missed often, self-programmable</td>
</tr>
</tbody>
</table>

In this cycle, some of the categories that emerged further reinforced the categories previously identified (e.g. safety, privacy, communication, knowledge). The two additional categories were *embarrassment* and *domination*. Residents were asked: ‘How about the robot quizzesing you about your medication knowledge?’ and most of the respondents voted against the idea. One resident said: “I wouldn’t want the robot asking me questions. It is not going to be here to test me but to help me, I would suppose.” Some residents might feel that they know about their medications, but they are not confident about it or they may be embarrassed if the robot actually discovers how much or how little they know about medications. People feeling embarrassed in the presence of a robot reflects the power of its anthropomorphic presence (Bartneck, Bleecker, Bun, Fens, & Riet, 2010).
Another respondent was concerned that she might break the robot and one was very concerned how she would be able to handle this machine on her own if it starts moving in her apartment. She said, “Holy Lord, what if this robot begins to move on its own in the middle of the night, what I will do?” In all three instances presented above, users felt challenged about their ability to handle the robot and its behaviour on their own. This conclusion does not fully corroborate with their response to the questionnaire where they expressed how easy they found it to use. It may perhaps be related to usability of dialogues on the touch screen being easier to respond to but, overall, handling the robot in the larger context might have raised their concerns.

Once they were led to imaginations about the robot speaking in the voice of their doctor and asking questions about medications, some deeper issues became explicit. There is some literature to show that assigning social identity to a robot improves obedience (Yamamoto, Sato, Hiraki, Yamasaki, & Anzai, 1992). From the perspective of adherence or compliance to medications, this might have been a desirable condition. Making the robot sound like an authority (e.g. representing a doctor) may translate into better compliance with tasks. However, respondents of this study unanimously rejected the idea. For example, a resident expressed his view on what the robot might symbolise and how that symbolism might impact how much they liked the robot:

“I wouldn’t want the robot to sound like my doctor. I like this voice as it is, let the machine be a machine, something we can have fun to play with.”

These words seem to reflect both a rejection of the idea of medicalization as well as a desire to have control over the technology; to derive pleasure from it as opposed to being expected to conform or be obedient to it. Many IT systems to assist older people in the future are likely to be funded by pharmaceutical companies or healthcare providers that might attempt to build powerful levers of expectation to conform to desired behaviour. They might work in the short term but run the risk of rejection by users in the long term. However, this phenomenon of user empowerment versus user conformity as a long-term engagement strategy needs to be studied further.

Also, since the users saw the robot for the first time in their apartment, two issues came to the fore: firstly, the imagination of convenience where the robot would help them take their medications just like a caregiver helps some of their colleagues. To quote:
“You see, my fingers can’t do much because of this pain of arthritis. Can it help me open my packet and bring me the medication every time?”

Issues around the practicality of having a robot in their apartment were expressed: maintenance, cleaning, charging itself, as well as to how it will live, move and occupy space. One participant said:

“Oh, where is this robot going to sit the whole day? There is hardly any space in my apartment for it to move. Maybe I have to get rid of this coffee table.”

Another expressed her diligence:

*I will need to keep it clean, are you sure it won’t go bad if I clean it with a wet cloth?*

The discussion above illustrates the grounded theory method of open coding and the constant comparison of concepts/codes with the original data as well as with the literature. Having gained more insights, the researcher proceeded to compare these concepts with those collected in earlier phases of the research, and attempted to derive a meta-level understanding through axial coding.

5.7.1 Axial coding –moving from categories to themes

The categories identified through open coding of the transcript were organised into themes by axial coding. In grounded theory, it is considered a useful way to scale up the analytic process as well as a strategy to organise qualitative data. This deeper meta-analysis of concepts enables gaining a higher, more abstract overview of the data (Miles & Huberman, 1999). To get an overview of categories and synthesise them into a higher level of abstraction, they were collected in a single Excel sheet. Table 5.7 shows a list of categories collected in AR cycles 1, 2 and 3.
Table 5.7: List of all categories collected so far

<table>
<thead>
<tr>
<th>No.</th>
<th>Categories (1)</th>
<th>No.</th>
<th>Categories 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Contextual specificity</td>
<td>C1</td>
<td>Simplicity</td>
</tr>
<tr>
<td>A2</td>
<td>Non-compliance</td>
<td>C2</td>
<td>Address variations</td>
</tr>
<tr>
<td>A3</td>
<td>Data sharing</td>
<td>C3</td>
<td>Respect</td>
</tr>
<tr>
<td>A4</td>
<td>Changing medications</td>
<td>C4</td>
<td>Privacy</td>
</tr>
<tr>
<td>A5</td>
<td>Emergency protocols</td>
<td>C5</td>
<td>Knowledge/education</td>
</tr>
<tr>
<td>A6</td>
<td>Process complexity</td>
<td>C6</td>
<td>User verification</td>
</tr>
<tr>
<td>A7</td>
<td>Robot requirements</td>
<td>C7</td>
<td>Support mistakes</td>
</tr>
<tr>
<td>A8</td>
<td>Information sharing</td>
<td>C8</td>
<td>Support caregiver</td>
</tr>
<tr>
<td>A9</td>
<td>Provider feedback</td>
<td>C9</td>
<td>Comprehension</td>
</tr>
<tr>
<td>A10</td>
<td>Caregiver competency</td>
<td>C10</td>
<td>Emancipation</td>
</tr>
<tr>
<td>A11</td>
<td>Memory support</td>
<td>C11</td>
<td>Sovereignty</td>
</tr>
<tr>
<td>A12</td>
<td>Family involvement</td>
<td>C12</td>
<td>Colonization</td>
</tr>
<tr>
<td>A13</td>
<td>Compliance packaging</td>
<td>C13</td>
<td>Relationships</td>
</tr>
<tr>
<td></td>
<td><strong>Revised Categories (1)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>Setting and circumstances</td>
<td>C14</td>
<td>Fun factor</td>
</tr>
<tr>
<td>B2</td>
<td>Compliance packaging</td>
<td>C15</td>
<td>Surveillance and intrusion</td>
</tr>
<tr>
<td>B3</td>
<td>Data sharing issues</td>
<td>C16</td>
<td>Emotive response</td>
</tr>
<tr>
<td>B4</td>
<td>Non-compliance concerns</td>
<td>C17</td>
<td>Embodiment</td>
</tr>
<tr>
<td>B5</td>
<td>Emergency protocols</td>
<td>C18</td>
<td>Medication safety</td>
</tr>
<tr>
<td>B6</td>
<td>Administration process</td>
<td>C19</td>
<td>Prescribing in dark</td>
</tr>
<tr>
<td>B7</td>
<td>Medication administration problems</td>
<td>C20</td>
<td>Send emergency message</td>
</tr>
<tr>
<td>B8</td>
<td>Individual has preferences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B9</td>
<td>Feedback in flux</td>
<td>D1</td>
<td>Convenience</td>
</tr>
<tr>
<td>B10</td>
<td>Place for a reminder</td>
<td>D2</td>
<td>Practicality</td>
</tr>
<tr>
<td>B11</td>
<td>Memory support</td>
<td>D3</td>
<td>Communication</td>
</tr>
<tr>
<td>B12</td>
<td>Patient info. needs</td>
<td>D4</td>
<td>Knowledge</td>
</tr>
<tr>
<td>B13</td>
<td>Compliance packaging</td>
<td>D5</td>
<td>Safety</td>
</tr>
<tr>
<td>B14</td>
<td>Personal Health Record useful</td>
<td>D6</td>
<td>Privacy</td>
</tr>
<tr>
<td>B15</td>
<td>Caregiver information needs</td>
<td>D7</td>
<td>Medical domination</td>
</tr>
<tr>
<td>B16</td>
<td>Generic information not useful</td>
<td>D8</td>
<td>Embarrassment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D9</td>
<td>Other reminders</td>
</tr>
</tbody>
</table>

The set of ‘Categories 1’ and ‘Revised categories 1’ were collected via open coding of data collected in AR Cycle 1 described in Chapter 3. Similarly, ‘Categories 2 and 3’ were derived in AR Cycles 2 and 3 respectively (described in Chapters 4 and 5) The applicability of the organising principle becomes clearer at this stage of analysis, as there were many categories.
discovered later that are not too dissimilar from categories observed earlier. Such similarities reflect that saturation of categories was beginning to emerge.

Deliberating further on these categories into higher levels of abstraction and generalisation, common themes begin to emerge from the collated data. For example, categories A7 (robot requirements), C1 (simplicity), C7 (support mistakes), C9 (comprehension), C14 (fun factor) and D1 (convenience) all refer to the design requirements and its appropriateness to meet the needs of elder users in one way or another. Therefore, they could be all grouped into one theme: *appropriate design*. Similarly, other categories could be organised and compressed into common themes that bound these categories together – a process of axial coding. Table 5.8 shows the serial number of categories in the right-hand column taken from Table 5.7. The left-hand column shows the ‘Theme’ that binds these categories together.

<table>
<thead>
<tr>
<th>No.</th>
<th>Themes</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Useful and usable</td>
<td>A7, C1, C7, C9, C14, D1</td>
</tr>
<tr>
<td>T2</td>
<td>Appropriate to context</td>
<td>A1, A6, B1, B6, C2, D2</td>
</tr>
<tr>
<td>T3</td>
<td>Share information</td>
<td>A3, A8, A9, A10, A12, B3, B9, B12, B14-16, C5, D3, C19-20</td>
</tr>
<tr>
<td>T4</td>
<td>Privacy and security</td>
<td>C4, C6, D5, D6</td>
</tr>
<tr>
<td>T5</td>
<td>Medication safety</td>
<td>A2, A5, A4, A13, B2, B4, B5, B7, B13, C6, C18, D5</td>
</tr>
<tr>
<td>T6</td>
<td>Respect sensitivities</td>
<td>B8, C3, C16, D8</td>
</tr>
<tr>
<td>T7</td>
<td>Support performance</td>
<td>A11, B10, B11, C21, C19, D9</td>
</tr>
<tr>
<td>T8</td>
<td>Not disempowering</td>
<td>C10, C11, C12, C13, C15, C17, D7</td>
</tr>
<tr>
<td>T9</td>
<td>Build capacity</td>
<td>B12, B15, C5, C8, D4</td>
</tr>
</tbody>
</table>

Another advantage of grouping categories into themes was to allow a further comparison with data on the one hand and the literature on the other. Further, these themes could now be used to observe saturation or deviation of the data elements, as we would continue to gather more data in future iterations of action research.
The emerging categories affirm the direction of design aiming towards a practical, useful and usable system that aligns itself with the ACF environment and its workflow, but also one that enables sharing of information across the actors. We would need to consider safety issues and address the possibility of a range of errors which could compromise safety. An important observation that emerges from the analysis is the users’ desire to remain in control, maintain respect for their privacy and security of information, personal choices, variations, support and build their capacity to self-manage instead of being treated as dependants in need of robotic assistance.

5.8 Discussion

Significant research has been done on automated dialoguing in healthcare and several guiding principles are highlighted in the literature. It is desirable that interactive dialogues be informed by the theory of behaviour change, be personally tailored, engaging and evolve over interactions. User collaboration during the design process is also recommended.

A talking pill box or automated dispenser may be good as reminders and organisers but are insufficient to offer an engaging interaction. In contrast, a well-designed automated dialogue system could provide detailed instructions/education, invoke affect and social support, cross check accuracy and safety, troubleshoot errors, and report and call for human help in real time – functions which many older people often need. In order to invoke user engagement and participation an agent needs to build acquaintance, suggest options, present information in logical sequence, offer choices and allow user to indicate preference. The literature presented evidence that an interactive dialogue system could be an effective means of achieving these design objectives. The cognitive limitations are addressed through dual output, i.e. displayed information as well as spoken dialogue so that if a user has limited eyesight or hearing deficits, one could compensate for the other. In this system the user could interact through haptic feedback only (i.e. through soft touch buttons), but in future more reliable and sophisticated means of interaction could be possible. To give personality to the robot an interactive dialogue seemed a logical choice as the required technology was already available.

A robot-based interactive module could offer opportunities and options that were not available with standalone reminder devices and pill management systems. The use of a touch screen interface could support a well-structured dialogue sequence as well as usability for older people, who might find mobile phone-based or desktop-based solutions cumbersome to use.
Very few instances of social robots and home monitoring equipment currently being studied and deployed attempt user identification. This research identified and highlighted the importance of user identification while designing healthcare and medication management solutions (Kuo et al. 2010). Various options for user identification were considered by the larger ‘Healthbots’ team. Face recognition was given particular consideration because of the possibility of a seamless interaction mimicking that of a caregiver. This research could have benefitted from a parallel work comparing various options as the technology used did not deliver its promises as expected. The topic remains open for future research.

The second AR cycle presented an attempt to design a module based on these principles. Reading current pharmacist dispensing data through EMR and informing the robot accordingly ensured consistency between dialogues spoken by the robot and the dispensed medication. If the prescription changed, the dialogue would also change, making accurate and appropriate dialogueing possible. Without a web-based component it would be extremely difficult and error prone to update the robot every time a prescription changed. The situation would be worse in real life situations, assuming multiple robots in multiple locations reminding patients who would be served by multiple pharmacies. Moreover, prescribed medications often get changed or substituted by the pharmacist (e.g. from branded to generic). A discrepancy between the medication name being displayed and medication in hand could provoke significant anxiety and user dissatisfaction. Therefore dialogue for reminding specific medications needs to be carefully designed.

Positive user recognition assures that the robot is interacting with the right person at the right time. The intention of using face recognition did not serve as useful a function as we hoped, thus falling back upon manual name entry by the user to confirm his/her identity. ADS file export from the Toniq system (proprietary software used by most New Zealand pharmacies) was only able to inform the medication name, dose and the time of interaction (breakfast, lunch, tea and bedtime), did not inform how the pills were presented (in bottles or blisters) or organised (pill boxes vs. loose pills), and did not directly indicate forms (puffs to be inhaled, lotion to be applied). These variables need another layer of fine-grained individual customization. The researcher performed this task but it would need to be delegated to a nurse, caregiver or a family member in real life application.

A usability study was conducted with ten participants having an average age of over 80 years. The results of this study found the system to be usable as well as useful. The ability to
complete the interaction and rating favourably on user friendliness of the system supports the hypothesis that older people can successfully navigate through a touch screen-based system to assist them with a complex self-care task like medication intake. The participants made very few errors, with most of the errors being attributed to an incomplete design or to the stability of the software environment. Many lessons were learnt during this study and from the feedback collected thereafter. It was apparent that not all elders would be able to use such a system independently, especially those on the fringes of cognitive competence. The system did promote better understanding and engagement with medication (such as reading labels and following instructions correctly) which might contribute to building people’s self-management capability over a longer period and enhance the quality use of medications. An important insight came from observing a respondent who was cognitively impaired but was able to complete the interaction with progressive improvement in performance. Such behaviour suggests the possibility that the use of robots may enhance cognitive performance and could train users for skill building, instead of making them more dependent on assistive technology. This needs to be studied further, but has wide implications for the use of technology in elder care.

Allowing participants to refuse to take medication was an option but was not exercised by any participant during the testing. It was presented to enable choice instead of enforcing compliance and also to elicit the need for further intervention if they were not feeling too well. The feature could be further refined to probe ‘intentional non-compliance’ in similar situations. A possibility for penetrating the opacity of medication self-administration in the frail elderly could be opened and issues relating to compliance or the lack of it could be uncovered. It could also be possible to identify errors in a timely fashion and inform appropriate decision-making.

The limitations of passively parsing the pharmacy data to inform the dialogue process were realised. The information available was not enough to drive a meaningful dialogue. A manual process would be involved to update the missing elements such as medication organisation and relationship to meals. The observation may be important to note in case one assumes that data from CPOE or PHR would be enough to drive a successful and complete user interaction of an automated assistant. Such attempts may lead to disappointment unless one takes into account the user’s context and preferences. The dialogues would become non-meaningful if the data elements were missing from the source. It would, therefore, be essential to resolve ambiguities in the face of missing data or system failures to avoid confusing vulnerable users.
These observations were noted in the current cycle and issues were left to be addressed and resolved in the next iteration of the application development. The users’ strong desire for issuing refill reminders, keeping family members and caregivers in the loop, minimizing obtrusiveness and for development of modules for active screening of side effects would also need consideration. Grounded analysis of data also presented corroborative findings that showed participant’s desire for making the functions useful, usable and appropriate to context. Triangulating the data from questionnaires and video analysis affirmed the need for keeping the interaction fluid, rich and smooth. Sharing of medication information while respecting privacy and security was highly valued by respondents. Pooling of categories from previous iterations and coding them axially reaffirmed a robust process for handling errors and integrity of information to maintain safety. To make medication usage safe, early detection of undesirable effects, timely reporting of side effects and close observation by healthcare providers to infer trends would be ideal.

The emerging themes strongly indicated the desire by the elder respondents for sovereignty and freedom and retaining a sense of control. They expect the assistant to respect sensitivities and personal preferences. Instead of ‘assuming lack of capability’ and ‘telling them what to do’, it would be more desirable to assume that the users are capable of self-managing their medications; they just need some support to improve their performance, share knowledge and build capability.

This is probably the first time touch screen-based robotic applications have been studied in the context of medication management for older people (Tiwari, Warren & day 2010). The AR cycle informed the application of user interface design principles for older people and pointed to where errors may happen. The implications discovered in this study are limited by the small number of respondents, lack of randomization and the partially researcher supported interaction. However, iteratively testing, reaffirming and building on previous knowledge gives it the robustness of a valid design research.

5.9 Chapter summary

The objectives of this phase of research were to collaborate and develop a working prototype of a medication management module, to test safety, efficacy, functionality and usability of a medication reminder system mounted on the robot, to collect user feedback on the dialogue system and to test connectivity and data transfer between robot and remote server.
This chapter surveyed the literature around automated dialoguing in healthcare. It described the development of a prototype of a web-based EMR that converted prescription information from a pharmacy export file to a scheduling system, which in turn informed the native application running on the robot to utter meaningful reminder dialogues. The EMR application was running from a local server on the laptop along with a face recognition system database. The laptop server connected over a wireless network and web services to the flash application on the robot. The flash application was informed by an XML schema of dialogues and generated a user interface with simple display of dialogues and simple soft response buttons. The robot application was customised for each instance of interaction according to the data on the web-based EMR to maintain accurate matching between the patient ID and the correct medications for the date and time of day. The system was then taken to ten representative elder users who performed the usability testing. The interactions were video-recorded and a post-interaction questionnaire survey and semi-structured interviews were conducted.

The objectives were satisfied by developing a successfully working prototype in collaboration with engineering researchers. All users successfully completed the interactions and found their IDs correctly matched to the prescribed medications which were appropriate for the day and time. The web-based EMR successfully informed the robot-based dialogue system over web services in every instance; however, many data elements were found to be missing and needed manual intervention. The users shared a rich set of information that was both encouraging and informative. The users’ participation in the design defined the scope for new dialogues and corrections in the current design. Grounded analysis of interview data revealed another set of categories which, when viewed in light of those generated earlier, helped derive more abstracted and focussed understanding of themes, on the basis of which a grounded theory could be developed. The development of theory and iterative refinement of prototype would continue in the next two cycles, unfolding the interesting story of this research journey.
Chapter 6: AR Cycle 3 – Supervised testing over multiple interactions

6.1 Introduction

In the previous chapters initial attempts at designing a medication management module including usability testing during a single interaction with the robot were presented. Chapter 5 also demonstrated the software design framework and the branching tree logic underpinning the dialogues. Finally, it presented the evaluation results to inform and develop the next version of the medication management module on the robot as well as the development and saturation of categories after coding of collected information. This chapter attempts to address the issues and design requirements identified in Chapter 5, and informs the next version of the prototype. The process of seeking answers to the research question concerning the theoretical implications of automated medication assistance reached a stage where collection of categorised data from 34 respondents interviewed (the total of those described in Chapters 4-6) was pooled and analysed to arrive at nine themes. Having discovered partial answers to the two research questions, this AR cycle proceed with an aim to further refine the prototype and formulate the theory.

Description of next the steps in the research process presented in this chapter focuses on:

1. Literature survey of patient education about medications and side effect monitoring
2. Further refinement and development of branching tree logic in an automated dialogue system to include side effect monitoring and medication education dialogues
3. Field testing of the refined prototype over multiple interactions over a period of time while collecting feedback in participatory design fashion
4. Open and axial coding of data gathered during interviews conducted
5. Constant comparison of evolving categories with data as well as against the literature, triangulation of evaluation results, field notes and interview transcripts followed by selective coding of saturated categories in light of new evidence, contributing to the theory building process.

The chapter concludes with a description of emerging themes to inform the theory of an automated medication assistant along with reflection on implications for future design developments.
6.2 Literature survey

6.2.1 Medication education

Doctors tend to overestimate patients’ comprehension levels and their ability to follow instructions or accurately interpret information about their illnesses and patients (especially older patients) are too embarrassed or intimidated to admit that they don’t understand information given (Kaldy, 2011). Haynes (1999) has shown that increasing medication complexity actually reduces patients’ measured knowledge about their medications, and medication complexity amongst the elderly tends to be high (Conn, et al., 1991; Corsonello, et al., 2009). Literature documents patients having a sub-optimal level of knowledge about their medications and in older patients knowledge washes out with time instead of building up (Hill, Bird, Hopkins, Lawton, & Wright, 1991; Monane, Bohn, Gurwitz, Glynn, & Avorn, 1994; Williams, Baker, Honig, Lee, & Nowlan, 1998). This lack of knowledge may be one of the factors underpinning older people’s concerted decisions about taking their medications differently than prescribed, not disclosing these modifications to their physicians, and not recognizing the potential dangers to their health (Lee & Dey, 2010). In addition,

An association between education intervention and increased knowledge of older people is well supported (Cantrill & Clark, 1992; Furlong, 1996; Opdycke, Ascione, Shimp, & Rosen, 1992; Taira, 1991). Though an association between medication knowledge and medication compliance seems to be relatively weak (Esposito, 1995), improved knowledge ultimately does impact on motivation, engagement and self-efficacy (Proos et al., 1992) and improves clinical outcomes, hospitalisation and even mortality rates long term (Haynes, et al., 2002; Pinnock et al., 2010). Education programmes likely to be successful include personalized and tailored information that is provided orally and reinforced either by repetition or in writing (Borne, 1998). Park et al. (1994) demonstrated that older people (even without dementia) have considerable difficulty inferring information from given labels and drug sheets, but they comprehend explicit, simple, direct instructions better. This limitation in inferential reasoning may affect patients’ medication-taking behaviour in two important ways. Firstly, it suggests that older adults may have difficulty self-monitoring their medication-taking behaviour and their adherence to their medication regimen. Secondly, patients (especially if cognitively impaired) may have difficulty determining, in advance, when to refill a prescription or to make an appointment with their physician to obtain a new prescription (Park, et al., 1994).
This is an ideal situation, where all older patients would receive adequate medication education according to their knowledge and skill gaps; however, this is far from being achieved in real life situations (Malhotra, Karan, Pandhi, & Jain, 2001). Medication education provided by healthcare professionals adds significantly to the workload and consumption of nursing time (Webb, Addison, Holman, Saklaki, & Wagner, 1990), costs (Windsor et al., 1990) and faces access barriers (Subramaniam et al., 2002).

To address these limitation, automation of patient education has been suggested as an effective alternative (Krishna, Balas, Boren, & Maglaveras, 2002). The positive impact of automated educational dialogues has been reported for a wide variety of conditions, including medication management in older people (Friedman et al., 1996b; Leirer, Morrow, Tanke, & Pariante, 1991; Milch, Ziv, Evans, & Hillebrand, 1996; Stricklin, Jones, & Niles, 2000). A variety of technologies have been deployed to deliver these messages including telephones, mobile text messaging, computers and, more recently, personalised DVDs (Lapane, Quillian, Goldman, Eaton, & Zayas-Cabán, 2010). Commonly, repetitive, personally tailored messages of short duration that interactively engage the user are most effective. Automation of patient education not only offers a cost-effective option (Friedman, et al., 1996b) but also, almost equally powerful, intervention to improve patient knowledge and comprehension (Morrow, Leirer, Carver, Tanke, & McNally, 1999), leading to improved medication management and reduced chances of adverse events (Krishna, et al., 2002; Piette et al., 2000).

6.2.2 Side effect monitoring

While educating patients about the procedural and beneficial side of medications is uncontested, educating patients about side effects remains controversial (Boulet, 1998; Malhotra, et al., 2001). More than half the patients carry some concern or worry about their medication and its side effects (Berry, et al., 1997). But often find fine print too small to read (Smith & Smith, 1999) and patients are also reluctant to raise their concerns with their doctors. Consequently, they often stop taking the medications without informing anyone about their decisions (Assumpta Ann, 1999). Black and colleagues (1987) confirmed these findings in a roundabout manner. They found their patients self-reported 100% compliance with medication as prescribed, but when a pill count was done by the researchers, 74% of patients had a mismatched pill count.

Therefore, it appears that older patients are less likely to know about side effects, less likely to ask and be informed about side effects, and even less likely to report them if they occur.
(Shrank, et al., 2007). Moreover, even if they report them, physicians may be reluctant to pay attention. Hence, it may also be concluded that expecting elderly patients to learn about side effects and self-report them would be a somewhat overambitious goal. Rather than educating and expecting older people to report side effects, a direct automated query about a specific symptom could be considered logical. In fact, assisting hypertensive patients and diabetic patients with automated calls to understand and report side effects has had some encouraging results (Friedman, et al., 1996; Piette, et al., 2000), but the details of the dialogue construction or approach taken was not well described in available publications.

Physicians remain concerned about questions regarding side effects as they wish patient anxiety or contribution to non-adherence to be avoided (Berry, et al., 2002). There may be some validity to this concern with inappropriately constructed automated dialogues. Moreover, such an attempt runs a risk of inducing a nocebo effect. Opposite to the well-known placebo effect that contributes towards the positive effects of medication, a nocebo effect is linked to higher probability of adverse side effects when patients believe so. Patients’ expectations of adverse effects and inducing a conditioning by repetitive questioning may make vulnerable patients believe they are having side effects (Barsky, Saintfort, Rogers, & Borus, 2002).

**6.2.3 Politeness in automated dialoguing**

In the field of pragmatics and sociolinguistics, politeness has been explored as a communicative strategy to promote and maintain social harmony in human–human interaction. One of the most influential theories of politeness by Brown and Levinson (1987) is based on the notion that each individual has positive and negative ‘face wants’. The negative face wants to be unimpeded in one’s actions, the basic claim to territories, personal preserves and rights to non-distraction (i.e. freedom of action and freedom from imposition). On the other hand, the positive face wants to be approved of itself, desiring that self-image be appreciated and approved of.

Each utterance or instruction (by a human or by a machine) carries a potential threat to another person’s face (either or both of positive face or negative face). It is also pointed out that the seriousness of this threat depends upon the power equation (authority), social distance (or closeness) and the ranking of imposition involved in the face threatening act (Brown & Levinson, 1987). Politeness is used as a strategy to mitigate this risk. Non-interruption and allowing the other person to do what he/she wants with the given information saves his/her negative face (negative redress). On the other hand, positive feedback, encouragement,
appreciation (and even flattery) saves positive face (positive redress). The polite behaviour may also be direct, to the point, and neutral (bald), or could be being indirect (off-record) by expressing uncertainty about the situation itself (e.g. saying ‘it’s too cold in here’ – implicates ‘can we close the window?’ without saying so). The analysis of application of these principles to automated dialogues has shown some interesting results (Wilkie, Jack, & Littlewood, 2005). The bald strategy received significantly more positive responses in terms of being shorter, less long-winded and containing more relevant information. The positive face-redress, on the other hand, was found to be significantly more manipulative, patronizing and intrusive. Though negative face-redress might seem the most appropriate design choice, it was shown to be judged as lengthy, long-winded and was perceived to be too apologetic and formal (Wilkie, et al., 2005).

The issue is far more complex in the context of the institutionalised elderly and needs to be carefully considered. This work deployed a mix of strategies while generally keeping the dialogues polite, where users were greeted, encouraged and thanked amply (negative redress) but were given some bald instructions about medications and also had the freedom to indicate their choices (positive redress) in a non-coercive manner.

6.2.4 Objective verification of subjective reporting
False reporting to automated dialogues remains a concern where users may simply press the button without actually taking the medications and mislead the clinical decision-making, which makes data from compliance assistive devices and pill boxes unreliable (Rivers, 1992) or inappropriate (Gould, Todd, & Irvine-Meek, 2009). Therefore, obtaining an objective record of medication intake is felt necessary. There have been some attempts at automating detection of medication intake including camera vision to detect association of hand, face and medications (Bilodeau & Ammouri, 2011; Huynh, Meunier, Sequeira, & Daniel, 2009; Valin & Meunier, 2006); rapid frequency identification device (RFID) enhanced sensors (Su & Shih 2011; Takacs & Hanak, 2008); agent-based technology (Haigh et al., 2004); remotely monitored dispensers (Patil & Gale, 2006); and ingestible RFID antennas (Rajagopalan & Rahmat-Samii, 2010). We chose not to get into these complex methods at this stage in research, rather sticking to simple video recording of medication ingestion and letting a healthcare provider assess user performance logs.
6.3 Objectives of AR Cycle 3

In AR Cycle 2, we discovered that users have difficulty in entering names or the variation in their medications, plus a variety of technical errors in our previous design. We also saw users interacting with the robot, and we collected their feedback and suggestions in a participatory design fashion. We learnt what was working and where we needed to improve. The main objectives in this phase of research were:

1. To refine the design incorporating requirements gathered in AR Cycles 1 and 2.
2. To determine hidden design inconsistencies and usability problem areas over repetitive interactions within the user interface and content areas. For example, navigation errors (failure to locate functions, getting stuck, backtracking and failure to follow instructions), presentation errors (dialogue comprehension and labelling ambiguities), or control usage problems (improper button or command usage).
3. To evaluate over-repeated interactions psychomotor performance of older people and time taken for task mastery.
4. To evaluate:
   a. Additional sub-modules of side effect monitoring and medication education as part of the system,
   b. Complementary role of other modules on the medication management module in a multifunctional robot.
5. To elicit design implications, assessing ‘fit to environment’ and discovering breakdown points that could impact long-term performance.
6. To evaluate the web-based component (Robogen) and test the feasibility of real time communication between the web-based server and robot system in a real world situation.
6.4 Refined apparatus

The previous phase informed us that the users had problems entering their names into the system for the purpose of identification. This necessitated some form of automation; and it was agreed to start working on a face recognition system that identifies the user automatically. Secondly, the users validated the need for dynamic communication with healthcare providers and family members. Users also appreciated the need for education and side effects monitoring to keep them safe and better informed. Keeping these requirements in mind, designing additional modules was attempted. In AR Cycle 2, a range of errors during field evaluation were discovered, most of which came from two sources:

1. Technical stability of the robot’s computer and software applications installed on it
2. Inappropriate dialogues due to incomplete information in the EMR and inability of the robot dialogue system to handle a wider range of scenarios.

To address these conditions, colleagues from the software engineering team needed to debug the system by thorough testing, and the branching tree logic also needed to be refined to accommodate new learning. The EMR had to be redesigned to add information that could inform a wider range of accurate dialogues. The new EMR was named ‘Robogen’. To address communication and information sharing needs of actors, Robogen was conceived to be a ‘web-based’, ‘real time’, ‘information-sharing’ portal. For this purpose, a dashboard screen was developed that enabled people (i.e. doctors and pharmacists) to log in from any location to update medication lists as well as observe the user behaviour by noting the updated information in real time. A deliberate decision was also made to drop dependence on ADS files coming from the pharmacy, for two primary reasons:

1. The information gave bare essentials only and felt inadequate to inform a range of preferences and scenarios
2. It was limited to proprietary software and we could not dedicate our developmental efforts to fit with a particular system.

Though the new EMR (Robogen) was designed to be independent of ADS files, it enabled reading electronic information from any authorised system that could export XML script. This time, instead of carrying the EMR on a Wi-Fi enabled laptop, the University of Auckland’s IT services were requested to allocate some server space to host Robogen. This server would then be enabled to communicate over web services to the robot in real time.
6.4.1 Face recognition system

It is essential to establish the identity of the person as the first step in the medication management module. Out of the five ‘rights’ of the medication administration process, it is not only important to ascertain the identity of the right patient but also to match the prescription information stored on Robogen to this specific person. It is difficult to automate this process, but it can be achieved using methods of biometric identification including finger prints, palm prints or voice prints (Jain, Hong, & Pankanti, 2000). In this research, face recognition technology was chosen because of its availability from our research collaboration with the Electronics and Telecommunications Research Institute (ETRI) in Korea. Cafero had a built-in camera at the top of the screen, the touch screen could tilt back and forth, and the entire robot body could rotate, giving the camera freedom to locate the face in three dimensions. On detecting a face, the robot computer sent signals over web services to a webserver that hosted a database of facial images of all potential users. These facial images were taken in advance to populate the database. The facial images were stored associated with respective user names. The incoming image from the robot was matched with all the faces and most probable match was determined. The recognition results were then returned from the database back to the robot, and a human affirmation of the computerised process was made mandatory. A dialogue prompted the user (both display and voice) to confirm their identity – “Could you please confirm if you are “Mr XYZ” by pressing the button in front of your name.” Face recognition is an evolving technology and is not always accurate. If the results are not verified and medication information is invoked then one might introduce a new medication error of reminding the wrong person with the wrong medication. Moreover, an additional dialogue also becomes a form of interaction that allows the user to engage with the machine.

In case of failure of the recognition process the robot would fall back on a self-recognition process requesting the user to enter their name using the soft keyboard. The details of the architecture and processes involved in face recognition are published elsewhere (Kuo et al., 2010).
6.4.2 Robogen

In the previous version of EMR, the limitations were noted in the capability of the system to address a wider range of variables. The ADS files and extracting information from them was more suited to packaged medication served in the form of a sachet. The need to address other forms of medication organisation (loose, pill boxes, blisters), to incorporate the ability to display log reports on a single dashboard, and the need for anywhere anytime access led us back to the drawing board. The next version was conceptualised as a more detailed and comprehensive web-based medication record. That was named Robogen. The site map of Robogen’s web site is shown in Figure 6.1.

![Site map of Robogen](image-url)

**Figure 6.1: Site map of Robogen**

The features list of Robogen were prepared and presented by the researcher and collaboratively refined with the help of multidisciplinary team members. The coding was done by engineering colleagues in C sharp and HTML while attempting to address a requirements list generated by the researcher.

The home page presented a secure ‘log in’ web portal. This was primarily for the researcher/s to log in and manage the medication-related data for the entire list of patients enrolled in the study (Figure 6.2). The user name and password are assigned by the system administrator. The password could be changed from the ‘Other’ tab in the navigation menu. In this section the
word patient is used instead of older users/users to prevent confusion between user of Robogen (usually the researcher or healthcare provider) and user of robot (older person).

Figure 6.2: Robogen log in portal

The four tabs at the top of the Home page lead to the entire list of enrolled patients and their personal preferences in terms of preferred name, NHI number, preferred medication time, and how medications were organised (loose, pill box, sachets or blister packs).

On successful login, the home page was displayed (Figure 6.3) where only the patients registered under a particular provider who logged in with a unique ID and password (the researcher in this case) would be displayed. On clicking details hyperlink the patient page would open displaying the list of prescribed medications for that particular patient. Theoretically, this mechanism would allow multiple providers to have customised view of their patients in future. In the current phase, since the researcher was the only intended user (in addition to the system administrator), all enrolled patients were displayed on the home screen.

Figure 6.3: Patient list and prescription list
Figure 6.4 shows a screenshot of the drug database, where all the drugs, prescribed for all enrolled patients, are entered. The brand name, generic name, form and link to drug monograph was posted.

Figure 6.4: Drug database – a list of all medications across all patients containing their brand name, generic name, dose, form, and link to external information source

Figure 6.5 shows the monitoring parameters which are essentially subjective questions to find out presence of undesirable drug effects. Each of these questions could be manually composed and edited by a clinician and was presented to the patient in one of the three ways randomly.

Figure 6.5: Monitoring database – a list of questions that were programmed to seek more information about possibility of side effects and adequacy of symptom control
The compliance summary page (Figure 6.6) provided a dashboard of a patient’s activity throughout the monitoring period. It displayed the list of medications on rows and day-by-day record of logged information in columns where the patient indicated having taken or refused each medication.

![Compliance summary](image)

**Figure 6.6: Compliance summary**

On the same page, patient responses to monitoring questions were also displayed, whether they responded affirmatively or negatively to each question on a day-to-day basis. This was envisaged to give the clinician a snapshot of the patient’s use of his/her medications and subjective response to monitoring questions. A fine grained view of what was going on could allow a clinician to draw conclusions that might affect the clinical decision making around medications; e.g. if the person reported dizziness or bleeding gums on an everyday basis and was on sedatives, then it might indicate the need to reduce the dose of sedatives or Warfarin, and so on.

### 6.4.3 Refined dialogue system

The dialogues in the previous trial were limited to a simple scenario. During earlier field trials, a wide range of possible scenarios was discovered, leading to expansion of dialogue states and resulting in revised design specifications.
The initial dialogue sequence used in the previous iteration was altered to include error scenarios (like getting stuck or getting distracted), and dialogues were added to provide opportunistic medication education, considering that during the medication administration process, the users might open up to a learning moment and be receptive to information provided (Russell, 2006). After rounds of internal discussion, a dialogue schema was streamlined and new scenarios were added.

A scenario for packaged medications was tested in an earlier trial, but after analysing the results of field testing it was considered worthwhile to include other forms of medication organisation. For example, if the user said he/she was on loose medication, then the dialogues would guide the user medication by medication. If the user indicated being on packaged medication, the assumption would be that patient has limitation in cognitive ability to process a large volume of information. In that case, the robot would just prompt them to take ‘medications’ (as a singular entity) and later show them the list of medications in their pouch or blister, if they so desired.

Further, some information about medications could be provided through the dialogue system to promote self-efficacy and enhance quality use of medication. This issue was addressed by giving a button linked to a screen that stored detailed drug information if the users wanted to visit it. Side effect monitoring questions were incorporated into the system. The challenge was to avoid raising anxiety or inducing a nocebo effect. The dilemma was addressed by saying: “The doctor would like to know something about your medication safety.” If they agreed to it, then they would be asked a leading question: “Do you feel nauseous or dizzy?” instead of saying: “Do you know this could be the side effect of this medication?”

The users may make mistakes during the process if left completely on their own. Also, they may be distracted by other events (e.g. a phone call or visitor) when they are in the middle of the medication process and forget to continue. A failure to respond to a question despite three repetitions, or taking too long to complete the session (time out), would trigger an alert message. It was also felt necessary to build some real time information support so that at least a caregiver could promptly respond to problems and save a potential error situation. This was achieved by asking the user in case of difficulty (not progressing beyond a screen, or reaching a branch where a clear problem is reported). Once the user confirms there is a difficulty and indicates a desire for help, then a message could be sent to the caregiver. However, providing an alarm feature was difficult to achieve technically during this iteration.
Ethical considerations must form an important part of any interventions as intimate as those involved in aged care and in light of the vulnerability of this population. It is possible to design a technological intervention in the healthcare domain to become intrusive and disempowering to the users by virtue of passive monitoring and delivering instructions expecting compliance (Tiwari, Warren & Day, 2010). This ethical concern is addressed by careful choice of dialogues that build skills instead of encouraging dependence (e.g. the dialogue would say: “Please read the label on your bottle and confirm if it reads...”, instead of issuing a direct instruction: “Please take your pills now”). The presentation of information empowers users to make a choice at each stage, putting the patient in the position of control (e.g. saying: “Would you like me to inform you about...?” instead of dumping information: “Please read...”).

Finally, resolving the ambiguities around initiation and course of dialogue needed to be resolved. A mixed initiative interface as described by Horvitz (1999) often enables users to initiate interaction and achieve their goals. For example, the user should also be able to self-initiate and complete the medication task even without invoking the reminder function. Considering that as a possibility, the robot reminding again would possibly introduce a source of potential error. Therefore the dialogue should first check if the user has already completed the medication task by asking: “Have you already taken your medications?”

Figure 6.7 illustrates a flow chart of dialogues which attempt to address most (but not all at this stage) of the above mentioned requirements. This flow chart was converted into an XML schema which in turn was used to manage the dialogue screen logic on the robot touch screen. The medication management module is initiated once the scheduled ‘time slot’ (breakfast/lunch/tea/bedtime) is reached, followed by an introductory greeting drawing the attention of the patient to the robot. Thereafter the patient ID is confirmed and personalised information is invoked, before displaying the first dialogue. In the flow chart illustrating branching tree logic, the white boxes represent the dialogue and grey ones represent the choices linked to each dialogue. The red border box that reads ‘read label prompt’ is detailed further in Figure 6.8.
Figure 6.7: Flow diagram of final dialogue system design
Figure 6.8: Expansion of read label prompt process (red box in Fig. 6.7)
Figure 6.8 details the process of ‘read label prompt’. In screen 4a, four types of dialogues are shown corresponding to four different ways in which medications could be organised.

The forms could be pills (strip/bottle/box), syrups, puffs, lotion, cream, eye drops and so on. For each form, a separate action is required (e.g. pills are taken, syrup is poured, puffs are inhaled, lotions and creams are applied, eye drops are instilled). Each of these are dosed and each dose is represented by a number in singular or plural forms (such as one pill, two teaspoonful, three puffs, two drops).

The association between the entered information in Robogen and spoken dialogue was customised for appropriateness. For example, entering the following information in Robogen required:

1. Drug (name): Tablet Furosemide 40 mg
2. Form: pill (bottle)
3. Medication type (organisation): loose
4. Dosage: enter number ‘1’ in the box corresponding to breakfast time
5. Drug name as dispensed: ‘Generic’

The resulting dialogue generated at breakfast time by this input would be: “Please take out one pill from the bottle that reads Furosemide 40 mg.”

To give an example, if the number changed to ‘2’, form would change to syrup and if the name choice changed to brand name, then the dialogue would be: “Please pour two teaspoonfuls from the bottle that reads Lasix 40 mg.” Note the word pill became bottle; take out became pour; number of pills became number of teaspoonfuls and the generic name Furosemide changes to the brand name Lasix.

Similar rules would apply to syrups that need to be poured, creams that need to be applied drops that need to be instilled and puffs that need to be inhaled, with corresponding connotations for quantity, timing and method. All of these variations and possibilities were meticulously tested for accuracy of spoken dialogue and a need was felt to add some extra words within Robogen for special conditions (e.g. “Swallow whole. Do no crush or chew” for sustained release tablet formulations).

For each type of organisation, the utterances are appropriately tailored. If the patient is organising his/her medications in a pill box, then he/she is prompted to locate the container. For
blister packs, the appropriate pack has to be located and the pouch bearing the name, date, day and time needs to be verified by the user prior to self-administration. Therefore, the dialogue has three steps.

1. Verifying the right medication for the time and day (screen 4a) and possibility of learning more about the medication (screen 4c)
2. Opening and collecting medication (screen 4b)
3. Administering medication by the right route (screen 5).

At any stage, patients have the option of indicating difficulty or asking for help. Also, there are quit and back buttons on the top to help them revert back to their own unassisted method or navigate and correct themselves. Most dialogues ended with a prompt to choose one of the options on soft buttons displayed below the dialogue (e.g. press the ‘done’ button when finished) in order to resolve ambiguity around action planning by the patient. By clearly mentioning the features and options available to the patient up front and guiding in the face of mistakes, the system is intended to minimize patient anxiety about what is expected of him/her at each stage. The presented information or task during a session assumes success of completion but builds redundancy for failure (e.g. “Have you already done...? If not, then press...”). The system attempts to correct unintended errors and encourages the patient to continue interaction (“Oops! There seems to be some problem. Would you like to try... again?”).

The dialogue schema was prepared in XML by the researcher and refined by software engineers before implementing it on the robot. With an eye to future maintainability and flexibility, the dialogue script on the robot was maintained in XML to allow editing by someone without a software engineering background (such as the researcher). XML’s human readable coding schema facilitated fine-tuning and last-minute changes without having to modify the code.
6.5 Methods

In this iteration, an attempt was made to address previously identified issues and refine the design. This AR cycle was informed by the results and observations of AR Cycle 2. Figure 6.9 summarizes the important steps during this iteration.

In the **planning** phase, alternative methods of user identification were discussed. Redesigning the EMR was also a priority as many errors were observed to be originating from there. Making the robot system more stable, adding modules on side effect monitoring, and sharing more education about medications were important considerations. The description of changes and refinements was informed by a literature survey to discover what we can learn from previous work done around elder’s medication safety and competence building through the use of automated agents. The software development was done by collaborating team members to incorporate design requirements.

The **acting** phase involved taking the robot for participant interaction at Selwyn Village. While sharing the participant information sheets and signing of consent forms, the researcher explained the schedule of multiple visits over two weeks with the residents, and that they had a choice to opt out at any time. An approval to collect current prescription data from their pharmacies was obtained in the consent form. The form was faxed to the pharmacy and the pharmacy faxed back their current prescription, as for the previous trial. The researcher manually populated the prescription into the Robogen database. (The web-based EMR application was hosted on the university server this time, accessed by the robot computer through a USB port mobile device using 3G internet connection).
On the first day of the trial, the researcher (along with other team members) served the pre-test questionnaire and explained the system. A guided walk was given through multifunctional robot modules. Thereafter, participants were invited to ‘give it a go’ and become familiar with the operations. During the rest of the trial, the robot-participant interaction remained mostly unsupported, and the researcher merely supervised for medication safety and took field notes. This time, refraining from providing any instructional support was deliberate – leaving the patient unaided – while measuring the impact on psychomotor performance over time. At the end of every session with the medication management module, the robot presented a short survey of how they would rate today’s experience of taking their medications with the robot. The entire session was videotaped for all participants over two weeks when they interacted with the robot. After two weeks of interactions, a post-test questionnaire was served and a semi-structured interview conducted.

In summary, the methods used were:

1. Video recording of each session
2. Field notes taken by the researcher
3. Robot delivered evaluation survey
4. Post-trial questionnaire and interviews

The evaluation phase involved analysing questionnaires, coding of interviewed data and participant feedback, and triangulating it with field notes, video recordings and questionnaire responses.

The reflection phase involved deeper consideration of the maturing categories, to allow themes to emerge. Concurrently, the documentation to inform the refinement of application design was prepared.

The role of the researcher in this process was to prepare the requirements list, document dialogue contents and flow charts, and conceptualise schemas for information presentation and interaction through use case scenarios in UML. During the design process, the researcher did not do any of the software programming; rather, he collaboratively supported and validated/tested applications within the lab. After the design was felt satisfactory, the researcher conducted the entire field study as a primary lead while being supported by multidisciplinary team members.
6.5.1 Preparing for the field trial

After obtaining the ethics approval, the researcher approached the CEO for his consent to conduct the research within Selwyn Village. The participants were then scheduled as described in the earlier. They were served a pre-test questionnaire, collected their preferred name and preferred medication time for the morning (the scope of this trial was only once-a-day reminding for not more than two weeks). Further, names and contact details of their pharmacy and GP were collected along with a signed consent to access their health records. During initial sessions, we also collected facial images for the purpose of populating the face recognition database.

During the process, some discrepancies were discovered which affirmed our reason to move away from solely relying on pharmacy output (see ADS files described in Chapter 4) to inform the medication management application. The researcher actually had to perform medication reconciliation and manually enter the reconciled medication list (including nutritional supplements being used) into Robogen for it to be accurate and safe. The medications that were not in the Robogen database were updated into the drug database and then each prescription was customised with required parameters described in section on Robogen (section 6.4.2). The side effect monitoring parameters were discussed with the GP and narrowed down to one or two high suspects that could inform the clinical decision-making. Also, medication education data (the purpose of this medication and consequences of stopping) was manually entered into the corresponding fields as this is the highest ranked question in older people’s minds while taking multiple medications (Barat, et al., 2001).

Once the data was loaded on Robogen and the internal ID generated on Robogen, XML files on the robot were configured to read corresponding prescriptions linked to specific patients. The face recognition (or self-identification) confirms positive identification of a person from the front end client. It results in a query to the server database for relevant information. Thereafter, the robot and Robogen will communicate prescription information belonging only to this particular person to personalise and tailor the interaction.

Having databases updated and making these connections, it was important to lab test the integrity of the system for safety purposes. The researcher spent two days going through each and every scenario in the dialogue system with each enrolled participant’s data. Wherever gaps were detected, the data was updated, dialogues were reconfigured and minor debugging procedures were carried out by software engineers. Simultaneously, other researchers carried
out testing of other modules (entertainment, brain fitness, and vital signs) and set up interlinks between these modules. It was agreed that during the trial the sequence of events would be as follows (Figure 6.10):

The trial sequence was aligned to the preferred medication timing of the participant. The other components on the robot were contributing to the overall safety and skill building of the participant to improve quality of care. For example:

1. Medication administration prompt
2. Querying symptoms and side effects
3. Drug information & tailored education
4. Alerts and call for assistance
5. Vitals signs monitoring

Figure 6.10: The planned sequence of actions during the trial
6.6 Results of the field study in AR Cycle 3

Table 6.1 shows the profile of the participants. Their age ranged from 83 to 92 years, with a mean of 86.6 years, out of which 50% were males and 50% females. Half the participants used pill boxes to organise their medications while others used loose pills. One participant who did not complete the study was on sachet-based compliance packaging. None of the participants received personal assistance from a caregiver for supervised administration of medications.

<table>
<thead>
<tr>
<th>No.</th>
<th>Age in yrs.</th>
<th>Gender</th>
<th>Medications organized as</th>
<th>Caregiver assistance being given</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>87</td>
<td>F</td>
<td>Pill box + Loose</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>86</td>
<td>F</td>
<td>Sachet + Loose PRN</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>92</td>
<td>F</td>
<td>Loose</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>M</td>
<td>Pill box with 3 compartments</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>83</td>
<td>M</td>
<td>Loose</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>88</td>
<td>M</td>
<td>Pill Box</td>
<td>no</td>
</tr>
</tbody>
</table>

The users were chosen to interact with the robot within their apartments over a two-week period. They could opt out for any of the day/s during this period. Most participants took a weekend off, and some attended to other social commitments. One participant discontinued the trial after the fifth day due to aggravation of a health condition, which was not considered related to the intervention. Therefore, the participants averaged seven to nine interactions out of a total 14 possible overall (Table 6.2).

<table>
<thead>
<tr>
<th>User No.</th>
<th>Total number of interactions (out of 14)</th>
<th>Success of medication intake (out of total number of interactions)</th>
<th>Correct prompting (appropriateness of dialogue to actual process)</th>
<th>Backtracking, getting stuck or needed assistance</th>
<th>Yes to side effects question</th>
<th>Medication information accessed / demonstrated</th>
<th>Non-technical errors observed at any point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>9/9</td>
<td>8 †</td>
<td>day 1</td>
<td>1</td>
<td>1‡</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>5/5</td>
<td>4§</td>
<td>day 1, 2, 3</td>
<td>1</td>
<td>1§</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>8/8</td>
<td>8</td>
<td>day 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>8/8</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>1‖</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>6*⁄7</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>6*⁄8</td>
<td>8</td>
<td>day 1</td>
<td>1</td>
<td>1¶</td>
<td></td>
</tr>
</tbody>
</table>

*Had taken meds already
†Taken before breakfast medication earlier
§Unclear to user when to swallow
‡ Loose medication was in the pillbox
‖Missed supplements
¶promoted name of brand was different
Out of 45 logged interactions, 42 were successfully completed. In these three instances, the participants had already taken their medications as usual without waiting for the robot to arrive in the morning. On assessing the relationship of displayed instructions to user behaviour, in 43 out of 45 instances of interaction the users interpreted instructions correctly and responded appropriately. On one occasion, the participant felt confused between *take your medication* (took them in hand) where the instruction was *swallow the medications*. On another occasion, the participant had taken some morning medications *before breakfast* on an empty stomach, whereas the instructions on the robot assumed that all morning medications are always to be taken *after breakfast*. Here we discovered something new, *before breakfast* scenario, which was not a part of typical pharmacy assumption of four medication timings that we had been pursuing do far. The morning medications that are supposed to be taken on an empty stomach were being taken earlier or *before breakfast*. There was no way in the current system to address this scenario, given the robot would not visit the same person twice in the morning.

The distribution of participants across four floors of Litchfield Tower during the trial meant driving the robot from one room to other through the corridors and lifts to meet their particular timing preferences (figure 6.11). Luckily, it just worked out that the participants’ preferred times staggered in such a way that researchers had sufficient time to finish a session in one room and run to the other, set up the wireless connection, and drive the robot into another room. Roughly at the rate of half an hour per participant, it took us more than three hours each morning to cover six participants. It became clear that it would be nearly impossible for a robot to self-navigate from room to room and assist multiple people with their medications in a real life situation.
The participants had some difficulty on the first day of interactions because they were not sure how or which button to press and the researcher had to prompt them. However, they were able to use it successfully without prompting from the next day onwards, with the exception of one participant who struggled due to physical limitations (severe arthritis of the fingers) and lack of confidence, and prematurely dropped out of the trial.

Out of 45 interactions, queries for side effects were raised 15 times (as the robot was programmed to ask every three days) and only one instance of a side effect was reported (in the patient who was struggling). This person with an unstable clinical condition might have benefitted from closer monitoring but unfortunately they were finding it too challenging to use this technology.

While mapping the correctness of medication information shared with the participant during the trial, we observed that people change their medication organisation – sometimes keeping them in the bottles, and putting them in pill box at other times. Brand names of dispensed medications change and people start and stop nutritional supplements on their own, making it difficult to automate dialogues correctly every time.
6.6.1 Psycho-motor performance and user rating

Analysis of psycho-motor performance and user rating during the trial is shown in Table 6.3 from day 1 to day 14 of the trial. The timing (T) here means the time taken to complete the total interaction with the medication management module in minutes and seconds. This does not include time taken for face recognition or by other features and functionalities. This time was calculated from the log records of the robot post trial. J or jumping indicates where the users anticipated the dialogue and jumped ahead of instructions without reading or paying attention to the dialogue. This was used as a surrogate for task mastery and user familiarity. The value is 0 or 1. The day the participant skipped or jumped the action ahead of instructions, the value changed from 0 to 1. Finally, R or rating means the rank participants gave to their satisfaction with the interaction with the medication management module only (not the entire robot session).

Table 6.3: Analysis of psychomotor performance from robot activity logs and time stamps

<table>
<thead>
<tr>
<th>User no</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.52</td>
<td>0</td>
<td>3</td>
<td>1.10</td>
<td>0</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>3.50</td>
<td>0</td>
<td>2</td>
<td>3.40</td>
<td>0</td>
<td>3</td>
<td>4.19</td>
</tr>
<tr>
<td>3</td>
<td>2.29</td>
<td>0</td>
<td>3</td>
<td>1.20</td>
<td>0</td>
<td>3</td>
<td>1.18</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.30</td>
<td>0</td>
<td>4</td>
<td>4.08</td>
</tr>
<tr>
<td>5</td>
<td>2.23</td>
<td>0</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>.15</td>
<td>0</td>
<td>2</td>
<td>.18</td>
<td>0</td>
<td>2</td>
<td>3.59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>User no</th>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
<th>Day 11</th>
<th>Day 12</th>
<th>Day 13</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.11</td>
<td>1</td>
<td>3</td>
<td>.35</td>
<td>1</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.59</td>
<td>1</td>
<td>3</td>
<td>.49</td>
<td>1</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>3.13</td>
<td>1</td>
<td>4</td>
<td>2.50</td>
<td>1</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0.25</td>
<td>1</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.58</td>
<td>1</td>
<td>3</td>
<td>.47</td>
<td>1</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

T = Time taken to complete the medication session, J = Jumping ahead of instructions (0 = No, 1 = Yes), R = Rating the experience (1=Poor, 2= Acceptable, 3= Good, 4= Excellent)

The tabular data from Table 6.3 was then converted in a graphical format (Figure 6.12).
The figure illustrates that the most participants progressively improved the speed of task completion, except the one that continued to have problems and dropped out of study (participant two). X Axis represents the 1st to the 14th day of interaction, and Y axis represents total time taken to complete the session in minutes.

![Graph of timings](image)

**Figure 6.12: The graph of timings**

The dotted lines indicate the days when the participant chose not to invite the robot to his/her apartment, usually over the weekends. The aberrant peak for participant six on the third day appears due to forgetting about the visit and querying a brand of his medication. Similarly, on day four, participant two got confused and our program had failed to capture the scenario for PRN medications. That led to a delay in completing the interaction.

As seen in Table 6.3, the point at which the users showed signs of task mastery is indicated by jumping ahead of the task. They were marked as jumping ahead when they anticipated the instructions and jumped ahead of the task by pressing the response button before the dialogue was finished or took their pills before the dialogue was finished. It can be seen that five out of six participants did this and it took them anywhere from two to four sessions to master the task and predict the behaviour of the technology.

At the end of each session, the participants were asked to rank the experience as one of four options displayed on the robot screen (1= Poor, 2= Average, 3= Good and 4 = Excellent).
Figure 6.13: The graph of module rating

In Figure 6.13 it can be seen that user ratings improved as the task was mastered and people felt more confident and comfortable using the system after two to four interactions.

6.6.2 Post-trial questionnaire analysis

The questions asked and the answers given by the six participants are summarised in Table 6.4.

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Was your morning medication list correct every time the robot came to remind you?</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2  Did you access more details about your medications on the robot?</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>3  Did the robot have correct educational information about your medications?</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4  Would the robot help you to remember your medications?</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>5  Did the robot ask you about the side effects of your medications</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6  Did you find the side effect monitoring questions helpful?</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>7  Would you like to change the number of steps or instructions being given in the medication management module</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

The first question queried if the medication list entered in Robogen correctly informed the robot dialogue, in the opinion of the users. Five out of six confirmed the accuracy of system design by affirming the names of medications on the robot reminder matched with the medications that they had in their hands. One respondent who was not sure was on packaged medications and she said:

“I was told to take all the medications in the pouch, but really not sure what do you mean by the list of medication?”
The answer reflects the need to rephrase the question to elicit information from people using different ways of organising their medication.

Another interesting observation was around the medication education component. When the medication name was displayed, there was a clear button at the bottom – ‘Tell me more’ – indicating that the user could choose to access more information. But none of the users pressed that button, simply wanting to get on with the process. Unsurprisingly, most users did not find it useful except one who remembers the first time when the educational content was demonstrated by the researcher. Most of the participants exclaimed, asking the researcher while answering this question if there was any education content. However, the findings are consistent with the literature where healthcare providers tend to underestimate the information needs of older patients (Berry, et al., 1997). They simply failed to acknowledge that the content was available or thought they did not need to know more about it. One of them said:

“Oh, I wished I could read more about my medication, but you know I really missed it”

While another one said

“Well, I have been on … (the name of medication) for a few years now. I already know what it is for and what it does to me…nothing dreadfully serious.”

One regretted noticing its relevance:

“I wish I could remember where all that information was that you are asking me about. I never noticed it; if I had, I would have liked to read the details.”

Another one said:

“I thought it was quite well done but to find out more about the actual medications would have been helpful.”

Question 4 attempted to elicit if this way of reminding would be useful to participants over the long term. The word reminding becomes an oxymoron when the person has an appointment, keeps his/her medications ready, and waits for the robot to come. Moreover, for safety and ethics compliance purposes, research was conducted on relatively fit people who volunteered to test the robot. None of the participants felt that they were forgetful, hence saw little value in the robot functioning merely as a reminder. One of them offered a useful insight:
“I have been taking my medication for years now, you see, without any robot or any reminder buzzing on my door and hope to be able to continue the same way. If it so happens that there comes a day when I can’t remember, then I can see how this machine could be of help to me.”

Finally, five out of six participants did not remember if the robot asked them about the side effects, despite being asked on multiple occasions. Since most of the participants did not acknowledge being asked, they were not sure about its helpfulness. However, the one who remembered the question about side effects found it helpful.

6.6.3 Semi-structured interview – open coding

The interview data was subjected to open coding, where the transcripts were analysed and broken down into codes or concepts as summarised in Table 6.5.

<table>
<thead>
<tr>
<th>No.</th>
<th>Categories (4)</th>
<th>Sample concepts (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Customisation</td>
<td>Expertise, confidence, desirable, variable, before breakfast, as needed medications, personal preferences, for a couple</td>
</tr>
<tr>
<td>E2</td>
<td>Practical usefulness</td>
<td>Name entry, face recognition, intrusive, bulky, trip over, multifunctional, do chores, dispense, vigilance</td>
</tr>
<tr>
<td>E3</td>
<td>Appropriateness</td>
<td>Sufficient, no change, adequate, good design, thoughtful dialogue, timely prompt, as it should be, well supported</td>
</tr>
<tr>
<td>E4</td>
<td>Access to information</td>
<td>Desire to know, failed to access, more direct, readily available, not monotonous, very useful</td>
</tr>
<tr>
<td>E5</td>
<td>Communication</td>
<td>Useful, novel, calling a relative, video call, messaging, family appreciative, caregiver on call, doctor in loop, comforting</td>
</tr>
<tr>
<td>E6</td>
<td>Fun factor</td>
<td>Desire to own, engaging, enjoyable, multifunctional, entertaining, makes more useful, likeable, acceptable, keep us sharp, popularity</td>
</tr>
<tr>
<td>E7</td>
<td>Other reminders</td>
<td>Doctor availability, automatic refill, inform management, to-do lists</td>
</tr>
</tbody>
</table>

In this cycle, some of the categories that emerged further reinforced the categories known earlier (e.g. fun factor, other reminders, communication, practical usefulness). This iteration of action research allowed the users to interact with a variety of features installed on a multifunctional robot. In earlier trials, only the medication management module was presented for testing. The additional features did add to the likeability of the robot (especially the brain gym, Skype calling and music videos), but they did not add much to the formulation of concepts and categories. One of the participants said:

“I have enjoyed it immensely – cannot speak too highly of its wide applications, and am desirous of having one myself”, while the other said: “My grandsons think
it's a hoot that grandma's doing robot research. I found it quite entertaining; I looked forward to the interview each morning.”

The users also appreciated the fact that the robot came to them and attempted to help them; for example, one said:

“I thought it was very good that you brought the robot to my apartment; that meant no interruptions, and the engineers were just around the corner if it wasn't going the way they wanted.”

This observation led the researchers to think about the situation in real life where the robot would be left alone with the user and researchers are not always going to be present. How will the user be assisted in that case? Therefore, the need for real time assistance informed the design of instant text messaging to the caregiver and more robust consideration of error situations.

The only two new categories that came up in this iteration were customisation and access to information. Regarding customisation, the variety of ways in which users organise and administer their medications was baffling and despite two rounds of observations, once again we discovered new patterns. Unsurprisingly, the literature affirms the variations in medication use that are difficult for doctors to predict (Barat, et al., 2001). The users indicated a need for customising the programmed reminder dialogue to suit their personal medication organisation and administration method as it was not exactly accurate every time. At the same time, they expressed a lack of confidence in their own ability to customise the robot. There could be two implications to this observation. Firstly, it should be very easy to change the personal preferences and secondly, only minimal and essential features be delegated to users for customisation. The majority of the customisation for complex features should be system driven. For example, a participant said:

“… that’s a good question you ask. I should be allowed to reset my own robot if I wish to wake up late on a Sunday morning. I would rather like that without having to call anybody up.”

Another participant commented:
“I can understand what you are trying to explain, but I am not sure if I have the ability to set up the robot. It sounds like a big thing for an 86-year-old lady, don’t you think?”

6.6.3.1 Saturation of axial codes

The codes and categories generated in this cycle were then compared to other codes collected earlier. The codes had been grouped earlier into themes (Chapter 5). It was then relatively easy to see the relevance of newly collected codes to earlier codes arranged into themes in Table 6.6. All the categories from Table 6.5 (bolded) found their place in the thematic hierarchy without the need to create any new theme. The beginning of saturation of categories is an indication to stop the process of data collection and engage in reflective thinking about the emerging theory (Charmaz, 2006).

Table 6.6: Further saturation of themes in axial coding. The new categories populated into themes are highlighted in bold letters. As can be seen, they found a matching place every time

<table>
<thead>
<tr>
<th>No.</th>
<th>Themes</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Fun, useful practical and usable</td>
<td>A7, C1, C7, C9, C14, D1, <strong>E2, E6</strong></td>
</tr>
<tr>
<td>T2</td>
<td>Appropriate to context</td>
<td>A1, A6, B1, B6, C2, D2, <strong>E3</strong></td>
</tr>
<tr>
<td>T3</td>
<td>Share information</td>
<td>A3, A8, A9, A10, A12, B3, B9, B12, B14-16, C5, C19-20, D3, <strong>E5</strong></td>
</tr>
<tr>
<td>T4</td>
<td>Privacy and security</td>
<td>C4, C6, D5, D6</td>
</tr>
<tr>
<td>T5</td>
<td>Medication safety</td>
<td>A2, A4, A5, A13, B2, B4, B5, B7, B13, C6, C18, D5</td>
</tr>
<tr>
<td>T6</td>
<td>Respect sensitivities</td>
<td>B8, C3, C16, D8</td>
</tr>
<tr>
<td>T7</td>
<td>Support performance</td>
<td>A11, B10, B11, C21, C19, D9, <strong>E7</strong></td>
</tr>
<tr>
<td>T8</td>
<td>Not disempowering</td>
<td>C10, C11, C12, C13, C15, C17, D7</td>
</tr>
<tr>
<td>T9</td>
<td>Build capacity</td>
<td>B12, B15, C5, C8, D4, <strong>E1, E4</strong></td>
</tr>
</tbody>
</table>

6.6.3.2 Selective coding

The process of selective coding identifies the themes with the maximum number of categories and develops them further to arrive at a theoretical construct. As seen in Table 6.6, the data from the previous three iterations and the concepts/codes generated therein represent a total of 40 transcribed and analysed interviews. (Chapter 4: 24 participants, Chapter 5: 10 participants, Chapter 6: six participants). This data had so far been categorised into 72 categories and those
categories in turn were condensed into nine themes (T1-T9 in Table 6.6). These themes were matched or triangulated with the results from the questionnaires, field notes, and video analysis results to understand patterns.

Reflecting further on the themes in the light of other pieces of information, literature and the immersive experience of researcher, these nine themes appeared to circle around four major themes (Table 6.7):

1. Appropriateness and usability of the system for older users (usability)
2. Building ability to communicate, share information and facilitate collaboration between actors (collaboration)
3. Making the system safe to use, preventing errors and accidents, not introducing new errors and enabling quality use of medication (safety)
4. Empowering the users to stay in control, build their capacity to engage with their medications and providers, without undermining their capacity for self-care (empowerment)

Table 6.7: Themes emerging

<table>
<thead>
<tr>
<th>No.</th>
<th>Themes</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th1</td>
<td>USABILITY</td>
<td>(T1-2) Appropriate to context, fun, useful and usable, practical</td>
</tr>
<tr>
<td>Th2</td>
<td>COLLABORATION</td>
<td>(T3) Share information</td>
</tr>
<tr>
<td>Th3</td>
<td>SAFETY</td>
<td>(T4-5) Privacy and security, Medication safety</td>
</tr>
<tr>
<td>Th4</td>
<td>EMPOWERMENT</td>
<td>(T6-9) Respect sensitivities, Support performance, Not disempowering, Build capacity</td>
</tr>
</tbody>
</table>

These core themes seemingly emerged from the categories and it was considered important to validate them against the data before making conclusive opinions. To achieve this, open codes that populated the categories were revisited. In addition, transcripts were re-read to reflect on the meaning of codes and what the participants said. Then the codes were placed against each of the elements of thematic construct as shown in Table 6.8. At a glance, it could be seen that they appeared in perfect alignment.
The codes tended to fall in alignment with the emerging themes, legitimating the emerging themes to inform the formulation of a theoretical construct. There may be a possibility of some inconsistency in the codes in Table 6.7. However, it is pertinent to note here that codes are mere symbolic abstraction of what the participants were intending to convey, which in turn inform the higher level of abstraction of themes. For example, it may be argued that the code of OTC/CAM should belong to the category of safety (given their risk of medication interaction) and not to usability. Referring back to the data, however, the code comes from the older person’s point of view that they would like to be reminded about OTC/CAM as well as prescription medications.

Referring to the dynamic interplay between the thematic elements and the system design, there has already been some synchronicity evolving. Usability testing of the apparatus informed the research process: how users found the system through questionnaires as well as interviews, data logs and video analysis about the user experience and vice-versa.

In the process of selective coding, to select the central theme of theoretical construct, Strauss and Corbin (1998) recommend looking at the theme with the maximum number of categories or codes. At a glance, looking at Table 6.7, it becomes evident that the maximum number of codes and categories in this construct seem to populate the theme of Empowerment. Here,
empowerment was conceived to encompass the four aspects that emerged earlier from the categories; respect for sensitivities, supporting performance, not disempowering or appearing to hold power over users, and building their capacity to engage better with their own health and medications in particular. Potential users not only demand privacy and dignity, but also express the need for encouragement and being allowed to make independent choices at each step. The system should enable users to engage effectively with the self-care task by bringing reminders, knowledge, medications, monitoring equipment and surveillance close to the patient, and maintaining user friendliness. Therefore, providing knowledge, providing motivation, and offering users the power of choice at each stage was summarised under a single theme of empowerment. In the literature, empowerment has been considered an important aspect of enabling older adults to engage in self-care (Shearer, Fleury, Ward, & O'Brien. 2012). Computers can not only empower patients to engage in self-care but also empower doctors to provide better care (Slack 2001).

The theme significantly informs the underpinning direction of design and development of eldercare technologies. It shows that most independently living elderly desire to be enabled instead of being made to feel incapacitated or dependent of the healthcare as long as avoidable. The healthcare system’s preconception of limitation, disability, inability or dependence that needs to be addressed tends to arise from a view of ageing-as-a-problem (Richardson, et al., 2005). The result of this study point in the opposite direction of ageing-as-a-decline, and in fact sees an older person being no less than a fully capable person given his/her cognitive/physical limitations are bridged.

In the context of medication management, increasing availability of and access to resources may partly be fulfilled by addressing usability. Although the usability of the system would need to match the capability/limitations of the users, older people are able to access information, be reminded and get assistance whenever needed by making the system easy to use, making it fun to use, useful, functional and practical to fit with their day-to-day lifestyle in a way that is appropriate to the context, wherever they choose to reside. Although people with severe dementia or high needs would be more dependent on human care those relatively independent and capable people would be more likely to be engaged with their own care.

Creating an empowering environment for the safe and effective use of medications requires healthcare providers to collaborate (in a closed-loop system) and incorporate as many safety protocols as possible into the system design that prevent the user from making an inadvertent
mistake that may have serious consequences. Collaboration here means sharing of information with the older person about an accurate list of medication to be taken at any given point of the day (or night) and also with healthcare providers about how the person is responding, both in terms of adequacy of symptom control and early detection of any undesirable effect.

The thin line between sharing and privacy of information is also captured by the thematic analysis (Table 6.7). What to share, how much to share and when to share is preferably kept under the control of the user, except in case of urgencies that may compromise the safety of the person (Whiddett, Hunter, Engelbrecht, & Handy, 2006). Taking medication was described not just as a routine task but also as socially contextualised, where patients, family members, caregivers, pharmacists, GPs and specialists were all part of the process and needed to know what each other was doing (Tiwari, Warren, & Day 2010). This opens the opportunity for healthcare professionals (all using different information systems with different interpretations of the person’s EHRs) to use the EHR for better communication about their patients. Importantly, there was a need to create a safe system that is robust, does not introduce new errors, helps its users in timely identification, and reports adverse events. In summary, selective coding arrived at usability, empowerment, collaboration and safety as four major design themes as shown in Figure 6.14 and can be summarised as an overarching outcome of the functionality of the module. Thus an automated medication assistant should engage older people in an empowering manner so that they can collaborate and manage their medications safely.

![Figure 6.14: Representing the theoretical elements](image)

Empowerment, engagement and enablement aim to enhance functioning (beings and doings) within an agency for the purpose of enhancing capability and experiencing emancipation (Sen, 1993). An ability to build internal capacities and capabilities, increasing availability of and
access to resources and creating an empowering environment are an integral part of the process of capability enhancement (Ruta, Camfield, & Donaldson, 2006). Other themes namely “safety, engagement and collaboration” were in a way indirectly supporting user empowerment. For example, improving a usability of a device enables or compensates for disability thereby supporting empowerment. Collaboration between users, their families, caregivers, facility managers, pharmacists and doctor indirectly empowers the user to establish balanced relationships. An elder person who lacks confidence and is apprehensive about taking self-responsibility is more likely to take charge if he/she feels assured that the system has a safety net and any mistake or problem is going to be detected and well supported by others. Therefore, out of the four, empowerment appeared to be the central theme.

The above analysis attempts to build a relationship between the themes and highlights the central nature of the selected theme. The analysis also attempts to draw parallels with the literature and the data to propose elements of a theory of automated medication assistance for the elderly. The alignment, relationships and fit between categories and themes seems to be a sensitising device to arrive at the theoretical construct.

6.7 Discussion

This chapter described the third cycle of action research, where the lessons learnt in previous iterations were incorporated into a refined design of a system. The two main components of the system were the web-based electronic medication record called Robogen, and the robot-based dialogue system that was informed by Robogen in real time. To define the content of these dialogues, three elements were incorporated. Firstly, a highly personalised and fine grained dialogue to support robot-assisted self-administration of medications; secondly, some education about medications and, thirdly, monitoring of side effects were designed. The literature review supported the importance of these elements. Knowledge about medications is not only important for older people but it also improves outcomes. Best results are obtained if information is tailored and shared interactively, but providers are busy and reluctant to spend time given a possibility of increasing workloads without added incentives; also, patients are hesitant to ask. In such circumstances, automated and repeated sharing of tailored information in interesting and standard format seems valuable. Similarly, side effects of medications are often ignored by both physicians and patients, making a case for automated querying. However, the manner of eliciting such information needs consideration, to prevent undesirable consequences. Equipped with the information, the researcher made an attempt to design
dialogues and impart the corresponding capabilities to Robogen, before taking the system for field testing.

Assessing the results of the field testing, the intended goals of successful intake of medication – while being prompted by the automated dialogue system – were affirmed in the study, where 42 out of a total of 45 interactions were successfully completed. The prompts were correctly delivered 43 times out of 45, while being sequentially relevant and contextually appropriate. Medication side effect monitoring dialogues were delivered 11 times, out of which one was reported positive. It was presented that the intended goal of building medication knowledge by providing detailed medication information as an option was not successful in the current design. Despite being made available as an option and being demonstrated in the beginning, the users neither accessed it nor remembered it at the end. The web-based Robogen correctly collected and displayed the session outcome logs as intended.

Future development requires the dialogues to be crisper and clearer about the actions being prompted. It would be useful to develop the entire module as envisaged, including text messaging, interaction video logging and clinical collaboration through Robogen log report sharing. It is useful to think about an evolutionary dialogue that matches the skill mastery and becomes more brief and precise over the long term. More educational information would escalate the medication skills to the next level.

Corbin and Strauss (1990) describe two canons and seven criteria for judging a grounded theory that have been revisited by Glaser (1992). The first is the Canon of Reproducibility where Corbin and Strauss (1990) recommend that if another researcher using the same methods does an analysis, the same theoretical explanation should be arrived at. Glaser (1992) considers this to be an overstatement where each theory continues to evolve with relevance different contexts, making a full reproduction of grounded theory difficult given its fluid and changeable nature. Moreover, the theoretical sensitivity of a different researcher might allow or disadvantage the other researcher to view things and situations the way they were in this research. With a hope that the observational capability of future researchers matches or exceeds the current work, the theory remains open to evolutionary expansion.

The second Canon of Generalizability states that a grounded theory study is generalizable to specific situations only. Glaser (1992) extends the scope of generalizability of a theory given other situations match the context in which it was conducted. He called it a theory’s ability to fit, work and be relevant in a process context. Since this study looks at the process of
automating medication assistance to older people, it may not remain limited to just medication processes, but given the matching situations, it might become generalizable to the wider context of developing technologies that promote self-care practices in the elderly.

**Criterion 1: Are concepts generated?** – The criterion refers to the grounded nature of analysis, where themes are grounded in the data and a systematic process of coding before arriving at themes. This study has followed the prescribed process and stands true to this criterion.

**Criterion 2: Are the concepts systematically related?** – The analysis presented in this study clearly draws the links between codes/concepts and categories and themes. It presents a clear chain of analysis as well as dynamic interplay between a central theme of empowerment with other themes of collaboration, safety and usability re-enforcing the central theme.

**Criterion 3: Are there many conceptual linkages and are the categories well developed? Do they have conceptual density?** – This criterion checks the linkages between categories and subcategories and if they were theoretically dense in terms of their properties. The open coding process and axial coding resulted in categories of dense properties. A theoretical saturation was achieved in subsequent iterations and generations of new categories that aligned with the themes. Therefore, a rich subset of thematic construct was arrived at which was dense with a large number of codes.

**Criterion 4: Is much variation built into the theory?** – This criterion requires that a grounded theory specifies variations and establishes more than a few conditions, actions and consequences related to the phenomena under study. Clearly, the concepts and categories were not only collected from a wide variety of data sources over multiple iterations but also theoretical sampling was used to venture into areas that are not conventionally explored. Therefore, a wide variation of possible categories was carefully pursued. Secondly, the data was manipulated in multiple ways to look for patterns and allowed the themes to emerge from a wider variety of codes. The theory is probably able to explain the implicit need for any one of any age to be empowered, independent and self-deterministic, while at the same time remaining safe and able to participate in a wider collaborative social network.

**Criterion 5: Are the broader conditions that affect the study built into its explanation?** – This criterion specifies that the analysis should not just remain limited to a microscopic scope but should also address ‘macroscopic’ sources such as trends, social movements, cultural
values and so forth. The study aligns itself with the emerging trends of emancipation, person-centric models of healthcare, and anywhere-anytime access to relevant information, as well as a futuristic application of technology. The emerging concepts are not only relevant for today but empowering technologies may become the trend of future developments.

**Criterion 6: Has process been taken into account?** – This criterion perhaps refers to social phenomena that are more related to environment than to a process and attempts to address relevance to everyday life. This study fulfils the criterion by being linked to the process of medication management.

**Criterion 7: Do the theoretical findings seem significant and to what extent?** – This criterion attempts to prevent a situation where a grounded theory study fails to produce significant findings. In this study, grounded theory procedures are applied with sensitivity, imagination and insight after fully understanding the requirements of the research. Demonstration of analytic ability, theoretical sensitivity, sensitivity to the subtleties of the interaction, and sufficient writing ability to convey the findings has been attempted. The data was fully drawn upon and data collection was sufficient to show saturation of categories. One measure of the significance of the research findings is the degree of recognition by the academic discipline to which they are attached. The findings at each stage of iterative cycle have been published and presented at peer-reviewed conferences and were well received (Tiwari, Warren, & Day, 2010, 2011; Tiwari, Warren, Day, MacDonald, et al., 2011; Tiwari, Warren, Day, & MacDonald, 2010). One of the papers even received the best student paper award at a national level conference (Tiwari, Warren, Day, & Datta, 2011). This achievement is significant and could be regarded as parsimonious, relevant and of considerable importance.

A legitimate question arises at this point that subjects the original two research questions to scrutiny. Considering the core category to be a dimension of the research problem, should development of the core category inform reformulation of the questions? The answer is definitively a yes. In qualitative research, there are moments when developments of new insights force the researcher to redefine the problem and successively refine the research question (Dey, 1993). An answer to the research question: *What is the theoretical framework for designing automated medication management solutions that appropriately meet the needs of older people?* overrides the answer to the first question: *Can an information technology-enabled solution successfully be developed to support this framework using available robotic platform?* Dey (1993) remarks that questions vaguely formed at the outset may be considerably
redefined and reformulated by the time the final stage of analysis is reached. The research question could perhaps be better phrased as: Can an application be designed that empowers its users to engage in self-care that is practically usable, builds safety and facilitates collaboration?

6.8 Chapter Summary
This chapter presented results from literature survey around patient education about their medications, importance of monitoring of side effects. Literature survey also indicated importance of politeness while conveying information and looked at implications for objective verification of vital signs in addition to subjective reporting of symptoms. This chapter described the refined version of dialogue flow and the new structure of web based EMR, namely “Robogen”. The testing of refined apparatus over repeated interactions showed patterns in task performance. The chapter also analysed the qualitative data, demonstrated selective coding to derive a theory of automated medication assistance.

As evident from the results presented earlier, the application was usable to a fair extent, but a stage was not reached where the robot could be safely left with the users. Research had also not tested the aspect of collaboration (though the design had sufficient capability to) and most importantly, the aspect of empowerment remained to be established. In the next iteration, a step forward in this direction will be described. The researcher’s attempt to redesign the application and fulfil the conditions will be explored as to how research led to further refinement of features and test if these statements remain valid once a robot is left unsupervised with an older person over a relatively prolonged time. It would also be worthwhile testing the rigour of newly developed theory with another AR cycle, to see whether the elements continue to hold their validity or not.
Chapter 7: AR Cycle 4 – unsupervised long-term testing

7.1 Introduction

In the previous chapter, the highlight was on the usability and performance of the system over multiple interactions. Chapter 6 also demonstrated the process of building a refined version of the EMR (Robogen), in addition to refinement of reminder dialogues and augmenting it with side effect monitoring and medication education dialogues. The known ways to address challenges in medication adherence, as pointed out in the literature, indicate the primacy of the manner in which patients internalize the expert advice and personalise it into their daily routine and are supported to manage it on a day-to-day basis. The research was intending to explore the utility of a robot-mounted touch screen with an appropriate dialogue system, as an enabling tool to achieve these objectives over a series of experiments. Earlier, the reader was presented with the testing and evaluation results that pointed out important gaps in the design, ability to handle error situations and need for a more robust and secure system. Cafero with its touch screen and the dialogue system were acceptable and usable for the medication support function but it was necessary to accommodate the logistical requirements of the complexity and plurality of medication events. The logistics of moving one robot around would be difficult in real life to serve multiple enrolled residents who require medication support at least three to six times a day, on occasions on both sides of the meal (e.g. before and after breakfast), at night or at random timings (PRN medications).

AR Cycle 3 (Chapter 6) dealt with the final stages of grounded analysis to derive a theoretical framework that redefined the research question. Having discovered the theory of automated medication assistance to older people, the actual prototype seemed significantly short on delivering all the requirements. The answers to the two research questions were now appearing somewhat divergent. On the one hand, the complex needs of the users were being understood and derived, but on the other hand, there were significant shortcomings in the prototype design to meet many of those needs.

This chapter presents the story of challenging preconceived ideas, believing in the data and negotiating iterative refinement and improvements of the process. The following sections attempt to address how the design of the medication management module was adjusted to accommodate challenges noted in the previous cycle around PRN medications, before breakfast medications, refill and appointment reminders, access to the educational component and enriching communication with healthcare providers. The mobility of the robot appeared
more of a hindrance than a useful purpose. The value of the robot seemed to be more around user engagement rather than physical mobility. In this phase, therefore, the larger mobile robot was substituted with a smaller static robot and it was left with the users without the researcher being physically present. Moreover, two robots were simultaneously put to action with two users living in two apartments, to learn how Robogen handles multiple users in real time. In order to learn about leaving unsupervised robots in people’s apartments, a less intrusive robot would be a safe starting point.

This phase of research was completed between April 2011 and October 2011. The ethics approval was taken in November 2010 as we had planned to move earlier but got delayed by procurement and programming tasks. In this chapter, the reader will be presented with details of setting up and testing a smaller static robot.

7.2 Literature survey

7.2.1 User empowerment – what does it mean?

The concept of empowerment has also been well researched in the social sciences, organizational behaviour, nursing and health promotion literature. From a social perspective, empowerment is seen as a process of personal growth and development, with an individual’s beliefs, views, values and perceptions being key factors (Bradbury-Jones, Sambrook, & Irvine, 2008). Though the concept of power may be interpreted in many ways (Christopher, 1994), empowerment is essentially about changing the nature and distribution of power (Kuokkanen & Leino-Kilpi, 2001). The individual has power originating from self-esteem and freedom to make choices and to accept responsibility for actions should they wish to do so. Therefore, a redefinition of empowerment could be a process of recognizing, promoting and enhancing people’s abilities to meet their own needs, solve their own problems and mobilize the necessary resources in order to feel in control of their own lives (Bradbury-Jones, et al., 2008; Johnson, 2011; Tims, King, & Bennett, 2011).

Considering empowerment as an intrinsic quality of the individual, it may be valid to question how an external intervention can impart inner empowerment. Here, it may be useful to consider that empowerment is a process as well as an outcome (Toofany, 2006; Zimmerman, 1995). Engagement in an empowering process can definitely be described as a facilitation or provision of a conducive framework that facilitates a matching outcome (Aujoulat, d'Hoore, & Deccache, 2007). On the other hand, Kapp (1989) reminds us that empowerment, though a noble and desirable process, cannot be imposed on people who are not willing or capable of
taking it on; rather, they should have the power to make a choice of delegating decision-making authority to others, which often happens in the case of the elderly.

In the context of healthcare, healthcare professionals assume a position of power over the patients by virtue of their knowledge, social influence and mannerisms (Goodyear-Smith & Buetow, 2001). This phenomenon gets exaggerated while dealing with a particularly disempowered group like dependent elders (White-Chu, Graves, Godfrey, Bonner, & Sloane, 2009). Care of the elderly is not only seen as a liability and financial burden on the healthcare system but an assumption of dependence tends towards ageism, conveying a subtle sense of discrimination and stigmatization (Bousfield & Hutchison, 2010). Declining capacity (cognitive and physical) and declining autonomy in decision-making – with a progression of frailty and dependence – makes them vulnerable to such stereotyping (Williamson & Harrison, 2010). Decision-making is automatically delegated to or even taken over by healthcare providers who have the power to make decisions and influence choices. An increasing alienation, external surveillance and intrusion into privacy leads to loss of rights in the context of citizenship (Clarke & Agyeman, 2011; Tu, Wang, & Yeh, 2006).

7.2.2 Designing technology for empowerment

Healthcare providers often desire to enable patients to achieve better health outcomes and increasingly look to information technology to achieve their objectives. It could be argued that from their point of view empowerment is about getting a patient to come round to a way of behaving that the provider or agent (as expert) knows is good for the patient, and trying to implement it whilst encouraging the patient to think that it was their idea in the first place (Skelton, 1994). It is the provider who assumes the responsibility of persuasion, but it leaves comparatively less onus for the patients to assume self-care responsibility. The goal here is not so much to develop the patient’s capacity to think as it is to reinforce, in their mind, the nursing and medical vision of what is normal and what constitutes pathology. The patient’s participation is often limited to the daily production of information on their health condition and whether they are following directives. This paradox of empowerment indirectly represents a subjugation of the patient’s expertise (Fox & Ward, 2006; Wilson, Kendall, & Brooks, 2007). The empowerment paradox fosters reinforcement of the medical model’s normative messages and uses technology to intrude itself all the way into a patient’s home. Lemire (2010) examines how information technology could foster control objectives that reflect the technocratic assumptions and exercise control over patient behaviour. There is even a sanction mechanism to ensure that the guidelines are respected, where the case manager may intervene to remind
the user of the guidelines, or even decide to end the relationship if the desired level of collaboration is not attained. Developing such a system involves goals that go well beyond clinical objectives into organizational and management objectives, including solutions to staff shortages and improved performance and efficiency in practices and services (M. Lemire, 2010). In summary, these objectives could foster reinforcement of the control and command processes inherent within the power relationships typically found within healthcare services. These observations could be seen from a sociological lens, where the use of tele-care or home monitoring technology, in many instances, appears to be another instrument to extend professional power.

The designers of monitoring, assistive or persuasive technologies may either acknowledge the power equations or disregard them completely. Technology, if carefully designed, can give the capacity to think critically and make autonomous, informed decisions (Anderson & Funnell, 2010), develop new forms of knowledge or knowledge acquisition, and pave new ways forward to empower patients (Chu, Huber, Mastel-Smith, & Cesario, 2009; Marc Lemire, Sicotte, & Paré, 2008; Samoocha, Bruinvels, Elbers, Anema, & Van Der Beek, 2010). However, ignoring power equations in healthcare of the elderly and designing technologies based on medicalised views would probably further entrench and deepen the power gaps, with resulting inconsistencies in achieving significant outcome advantages (Marc Lemire, et al., 2008).

The power imbalance may be potentially amplified multi-fold when a powerful engaging tool like a robot representing a healthcare provider attempts to interact with an elderly person who may be in a relatively dependent position (Kruijff & Jancek, 2011). Some may argue that using an expression of authority may elicit higher compliance, while others may consider it as a form of coercion (Brodwin, 2010). Technology designed on coercive and non-empowering considerations may end up being rejected after a short period of successful use (Söderström & Ytterhus, 2010). However, empowerment as a primary design strategy (not to the exclusion of, but as complimentary to other design principles) could increase the likelihood of better outcomes.
7.3 Objectives

1. To test the safety, efficacy, functionality and acceptance of a smaller Static Robot for Medication Management Services (StRoMMS) within residents’ apartments, without the physical presence of the researcher
2. To collect user feedback on the overall experience, appropriateness and satisfaction with the intervention
3. To test technical feasibility, connectivity, data transfer and errors to inform the engineering research streams
4. To collect feedback from other actors namely, physicians, pharmacists, caregivers and managers of Selwyn Village about the usefulness of the intervention, especially the Robogen dashboard.

7.4 Apparatus: Shift to a different robot and revised dialogue system

One of the major changes introduced in AR Cycle 4 was a shift from the idea of one mobile robot reminding many people to one smaller, static robot dedicated to one person. The need was revealed in AR Cycle 3 (Chapter 6) while assessing fit to the environment; there was a logistical difficulty in moving the robot from room to room. Also, users indicated difficulty in living with a large mobile robot in their apartments. The robot’s value was somewhat shifted from being a mobile agent to its value as companion, leveraging on its anthropomorphic presence and expressive social gestures.

Secondly, the face recognition system was not found to be as effective as we had expected. Variable light conditions, the variable sitting height and posture of users and perhaps the image processing ability of the robot over a wireless network made it difficult to rely on this method. The backup method of entering names using a soft keypad was challenging. Considering the idea of a personalised robot could easily get around these issues as it would be dedicated to a single user. Since there was only one person (or maximum two) in an apartment, simply displaying the intended user’s name (and picture), followed by an identity confirmation question could safely establish identity.

Thirdly, in the previous trial, we discovered less than satisfactory reliability and stability of the system, especially while depending on festival speech generation to provide a flawless user experience. Software features demanded a smooth user experience using a Rich Internet Presentation and a fluid audio-visual user interface that lent itself to a variety of dialogues impregnated with support, choice and information around their medication. Concurrently,
handling of asynchronous events from the Robot platform and web services, using the Representational State Transfer (REST) protocol was essential. The existing Software Development Kit (SDK) of a robot offered seamless connectivity between displayed dialogues, a built-in speech generation and gesture generation programs, which were highly desirable to meet design objectives.

Fourthly, making an attempt to accommodate user requirements led to an explosion of dialogue states. The handling of complex state transitions and a large number of exception cases necessitated safety measures to safeguard against potential error situations. Seamless, socially situated, temporal interactions leveraging compatibility with the Yujin robot platform were some more issues that required resolution. These issues were handled by redefining the dialogues, dynamic interaction between data fields in Robogen and the robot program over web services using more robust REST protocols.

7.4.1 The robot hardware
Cafero’s faceless large mobile frame carrying a touch screen was replaced with iRobiQ: a smaller robot with a childlike voice and a humanoid face with a smaller screen attached to its torso (Figure 7.1). Recently, it has been deployed in paediatric wards of hospitals and to guide patients. iRobiQ is powered by a Celeron processor based on Windows XP (embedded). iRobiQ runs Window XP as Operating System, and the services common to most computing devices could be installed. The development environment of iRobiQ is Robot SDK, which is supplied with the robot. The SDK provides tools necessary to develop the services by freely utilizing the functionalities of the robot. It allows a developer to test the service easily and quickly by interlinking the robot screen, motion, navigation, HRI (Human Robot Interaction). The tool provides the API (Application Program Interface) for the programmer and the script editor for the flash developer. Specification of standard versions of iRobiQ are listed below (Yujin-robotics, 2004).
1. Obstacle detection (Ultrasound sensor). The robot adjusts the moving speed when a person approaches as an obstacle.

2. Audio playback (Speaker). The robot can talk through the speaker or play the music.

3. Video recognition (Camera).
   The robot can recognize the external images through the camera and respond to the faces or actions.

   The robot can listen to and recognize the external sound through the microphone.

5. Emotion expression (Face LED and eyes LCD).
   The robot can express 5 different cute emotions through the LED on the eyes, mouth and cheeks.

6. Display & touch screen. One can control the robot by directly touching the contents on the screen of the robot with fingers.

7. Close obstacle detection (IR sensor). When a person or an obstacle approaches the robot, it can avoid by itself.

8. Fall prevention (Floor detection sensor). The robot can stop at the stairs or cliff without falling.

9. Collision detection (Bumper sensor). When an obstacle collides with a bumper, the robot can detect the collision and stop.

10. Not shown here at the back of robot is a USB port for connecting input devices.

Figure 7.1: iRobiQ from Yujin Robotics South Korea
The computing power of the regularly available version of iRobiQ was deemed insufficient to effectively run the software that the research team had been working on, so a request was submitted to Korean counterparts (ETRI and Yujin Robotics) through the NZ-Korean Centre for Healthcare Robotics, to upgrade the hardware and software platforms. Thankfully, the request was considered and funding was made available in Korea to build two upgraded versions called ‘super iRobiQ’. ‘Super iRobiQ’ had faster (dual core) processors and a more stable version of the native software. Many of the features described earlier were more useful if the robot was mobile. However, all the mobility-related features (1, 7-9) were disabled and the wheels were frozen so that it can sit on the coffee table or at the corner of the dining table in a patient’s apartment (Figure 7.2). A blood pressure measuring device was added which is being manufactured in New Zealand by a company called Pulsecor (Mookerjee, Al-Jumaily, & Lowe, 2010). Pulsecor is part of a vendor consortium affiliated with the wider NZ-Korean healthcare robotics project. Additionally, a USB mass storage was added to log brief videos taken during the interaction (for which participants had given consent). The new apparatus was taken for field testing that allowed four users to interact with the robot in their apartments continuously for one week with the researcher supervising remotely. To summarise:

1. The power cables were connected fulltime, given the robot and other apparatus connected to the robot were static, avoiding the need to charge the batteries or the risk of power failure coinciding with reminder time.
2. The blood pressure device could be connected safely and securely.
3. Since there was only one USB port on the back of super iRobiQ, the USB devices needed to be pooled through a USB hub.

Figure 7.2 demonstrates the set-up. Two sets were prepared by the researchers for taking two robots to the field that would be working with two participants simultaneously at any given time. The multiple cables and wires connected to the robot were neatly organised into a cardboard box for the sake of keeping the apparatus minimally obtrusive when placed in the participants’ apartments.

The only implication for usability was the reduction in size of the touch screen from 11 inches (on Cafero) to seven inches (on iRobiQ). However, it seemed to make little difference as the text string length, font size and button size were adjusted to a smaller screen with minimal impact on readability. Usability testing described in the next section was to affirm these assumptions.
Figure 7.3 details the circuit diagram of the apparatus inside the box where a power distribution hub supports the power supply to the robot (using standard laptop power cable), USB hub and the blood pressure device. The USB hub connects the robot to a mass storage device, internet connectivity device (using wireless 3G network) and the BP apparatus.
7.4.2 Medication management module: Additional features

There were many requirements elicited earlier (for additional features/modules) that needed to be addressed but could not be designed earlier, namely:

1. Refill reminders – to go to the pharmacy for a refill
2. Appointment reminders – to go to the doctor and get a new prescription
3. Customise preferences – user should be able to change
   a. His/her preferred name (by which the robot addresses him/her)
   b. Preferred clock time for ringing reminder alarm that could be different on different days of the week (e.g. wanting to wake up later on a weekend)
   c. Customise reminder dates
4. Call for assistance – using a text messaging system
5. Recording medication intake video logs – as an objective verification of medication intake
6. Ability of the user to start the module even without waiting for the alarm
7. Easy user identification method
8. Medication education built into the dialogue process
9. Ability for side effect monitoring/subjective symptom reporting
10. Two additional but indirectly related modules to improve engagement (i.e. blood pressure measurement and entertainment).

Many of these requirements/features were successfully addressed by redesigning Robogen (Robogen II) and refining the dialogue system.

7.4.3 Robogen II

The purpose of designing Robogen was to handle the prescription on the one hand and prompt a highly tailored and personalised dialogue on the other. The purpose was difficult to achieve because consideration and resolution of most, if not all, possible scenarios and error conditions was imperative. Instead of 20 odd states in the first phase, there were now over 200 possible states of dialogue system informed by Robogen in real time tested in the last cycle, but still as sense of incompleteness remained. Moving forward, it was essential for Robogen to have a capacity to further handle complex state transitions customised to each user, where multiple thin clients (or robots/ touch screens) are being served. The robot had no patient information stored on it, but the flash action script driven states were dynamically received from and relayed back to Robogen. Therefore, unbroken internet connectivity became absolutely essential to the running of the reminder dialogue on the robot. These programming decisions
were partially established earlier but were now consolidated. The backdrop of literature, participatory feedback of users, results of previous trials and field observations provided mock-up sketches and functional requirements that were then actualised into a working prototype. It is also important to mention that it was not possible to accommodate the entire list of requirements at this stage. Only the essential core elements were coded, leaving other cosmetic and fine grained requirements for future versions, in the face of time and resource constraints, recognising the research scenario being antecedent to a commercial application development scenario.

7.4.3.1 Last check-in time on Robogen home page

The screenshot of the revised home screen shows the last check-in time (Figure 7.4). The arrow points to a new column that was added, which shows the patient’s name and when the robot allocated to that user last polled the Robogen server. The Robogen server was polled by the robot computer every 15 seconds for update. The last poll from the robot is displayed to show if the robot is booted, connected and working. This informs the researcher about the robot status in addition to the medication interaction log. The researcher could check if all was going well as many times in a day as desired during the trial, especially if the log of interaction was not received at the expected time or there was a troubleshooting call from the user. Moreover, even without the user calling up, the researcher could know if and when a robot had become disconnected or switched off and take appropriate action. This was one of the safety measures to ensure an unsupervised deployment, as well as a tracking tool for researchers to time the bugs that could crash the application.
7.4.3.2 before breakfast medications

In the earlier trial, it was noted that we had omitted to include ‘before breakfast’ medications. On opening the window to edit patient details, an extra tick box and a drop-down menu can be seen in Figure 7.5. One could specify if the patient was taking any medications on an empty stomach before breakfast and a specific time could be chosen for the same.

![Figure 7.5: Selecting before breakfast timing](image)

The concept of before breakfast gets added to all the screens wherever the timing of interaction or dosage needs to be indicated. For example, the screenshot (Figure 7.6) shows the side effect monitoring set screen. There also one can see that the [Before breakfast] button has appeared.

![Figure 7.6: Selecting before monitoring parameter](image)
7.4.3.3 Refill date and physician appointment date

Also, at the bottom of the page shown in Figure 7.5, two more additional features are visible:

1. Next refill date
2. Next appointment date.

Usually in a prescription the prescriber mentions for each long-term medication how many refills could be dispensed by the pharmacy before the patient needs to revisit for an appointment and assessment. This was a good example of participatory design where the designers were informed of user needs to include features into the system. In addition to reminding to take medications on a daily basis, it could now be specified when a patient’s medications were due for refill and when a long-term medication needed a prescription. This informs the reminder dialogue to include additional reminders two days in advance before medications finish. At this stage, the choice of reminder date was keyed manually by the user, instead of being automatically calculated from the number of dispensed pills and their usage.

7.4.3.4 Handling ‘as needed’ (PRN) medications

In earlier trials, we discovered the need for addressing ‘as needed’ (PRN) medications in a scenario without a fixed reminding time. In situations where a human caregiver manages medications for residential care patients, the most common cause of suboptimal management is not asking for PRN medications. The patients are reluctant to ask and nursing staff members fail to actively seek if the patient has any symptoms. As a result they end up not receiving adequate symptom control (Jones et al., 2006).

This observation has implications for designing a PRN reminder dialogue. On the one hand, it is desirable that such a question is asked about the presence of symptoms requiring PRN medication; on the other hand, a simple clock-driven reminder system would face several difficulties in handling such a situation. For example, if the doctor prescribed ‘Tab. Paracetamol 500 mg. 2 tablets when having pain’, then an automated system should:

1. Note that Paracetamol is not a regular medication but an ‘as needed’ one
2. Collect additional information to ascertain a symptom (pain) is present
3. Associate the symptom (pain) with the medication (Paracetamol)
4. Prompt to take only if the preconditions are met.

These issues were addressed by adding another field in Robogen and giving an option to enter if this is a PRN medication (Figure 7.7). If the prescriber chooses that option, then a prompt to
enter the question dialogue (e.g. *Do you have pain now?*) and specify how frequently this question is asked during the day. This in turn would inform the dialogue system to ask a question – *Do you have pain?* at the end of the reminding for regular medications. If the user answers [Yes], then prompt – *Please look for Paracetamol 500 mg* (that was marked as PRN in Robogen). Once the patient reads the label and confirms he/she has the right medication, then prompt – *Please take 2 pills with a glass of water preferably with something to eat.* Once the user indicates [Done], move to the next dialogue. If the user says [No] then go straight to the next dialogue.

![Image](image.png)

**Figure 7.7:** Choosing ‘as needed’ (PRN) medication

The arrow in the figure indicates the insertion of the radio button ‘as needed’ (PRN) medications which was not there before. In the above example, PRN is not chosen. The options *pillbox* and *loose* appear next to PRN only when one indicates in the patient’s home page that this person is using pillbox. If one chooses sachets there, then the option *sachet* will appear here. Any medication for this patient could be put in the sachet, marked as loose or marked as PRN. The advantage of this loop was to enable Robogen to handle packaged, loose and PRN medications all at once. We had noted in an earlier trial that we had failed to cover a scenario where the patient was on sachet as well as on loose and/or PRN medications outside the sachet. It is by building on the logic explained above that it became possible to handle this complex scenario.

Coming back to PRN medications, on clicking the radio button [As needed (PRN)], the screen brings up an additional PRN question prompt text box and an ending date (Figure 7.8).
The ending date is essential, especially for pain medications or medications that need to be closely controlled or revised frequently by the prescriber. The ability to enter the PRN question creates a customised prompt that will be used by the robot in its dialogue flow. The reason for prescribing is visible only to the healthcare providers in multidisciplinary or palliative care environments to inform who prescribed and why. The robot also has a choice of entering start and stop date as well as editing or deleting it from the prescription.

Once this choice is completed and saved, then the PRN medication appears on a separate region on the patient prescription screen. The screenshot of the new version of Robogen (Figure 7.9) shows the patient’s home page with a list of medications. The arrow indicates the new file, as needed (PRN) medications (compare with Figure 6.4 in Chapter 6).
7.4.3.5 Modified medication education module

As noted in Chapter 6, the results showed participants do not acknowledge the passive availability of information. In response, the design was modified with two strategies. Firstly, the system design attempted to insert educational information within an ‘active dialogue’ rather than leaving it as a passive ‘on demand’ button. After reminding about a medication, the dialogue state on the robot screen displayed a direct question: *Would you like to know little bit more about the medication you just took?* If the user indicate an affirmative choice, then the detailed information appears on the next screen: *Did you know …*(insert information). The information was not shared before taking medication as it might interfere with the goals that the user was attempting to pursue (i.e. take the medication) and be seen as another step before reaching the goals, or might induce displeasure. However, this remains to be validated.

Secondly, more details about the medication were included. In earlier versions, the user was informed why this medication was prescribed for him/her as deemed fit by the clinician. An informed patient is deemed essential to the safe and quality use of medication. The medication education module was designed according to World Health Organisation (WHO) guidelines (Buck, 1998). The Food and Drug Administration (FDA) recommended guidelines for Consumer Medication Information (CMI) (NCPIE, 2004) and the Australian government initiative on Quality Use of Medicines (Department of Health & Ageing 2000). The information was further simplified to improve ease of understanding. In this version of Robogen, more elements were added to this as seen in Figure 7.10.

![Figure 7.10: Medication information and educational elements](image-url)
Another example of educational material on a medication dispensed as eye drops for Glaucoma could look something like this:

1. **Purpose:** This medication has been prescribed to lower the pressure inside your eyes.
2. **How to use:** Instil one drop into both eyes every night regularly. Discuss with your ophthalmologist or pharmacist in case you are using other drops simultaneously. This is a long-term medication.
3. **Side effects** (word not seen by the patient): Over time you may experience change in the colour of your eyes and eyelids which is harmless. Report any blurring of vision to your doctor immediately.
4. **Storage:** Keep the bottle in a cool, shady place. Not compulsory to refrigerate.
5. **Refill instructions:** You have been prescribed 2 repeats. Please collect another one from your pharmacy as soon as this bottle is about to finish. Please contact your doctor after two repeats, for a new prescription.
6. **Additional Information:** Please do not stop unless instructed specifically by your doctor. Stopping it may cause increase in the pressure inside your eyes which can lead to worsening of your eyesight.

It may be argued that detail might be overwhelming for an elderly person to handle at one time. It could be more useful to provide detailed information in smaller amounts, spread over a period of time, rather than all the information in one go. To avoid cognitive overload (and cluttering the robot screen), the above information was presented section by section as dialogues over a few sessions. The dialogue system was programmed to pick up one section at a time out of the six sections mentioned above (i.e. during each session), and share it with the patient if he/she so desired. At this stage, only those patients capable enough to self-manage loose medications were given this information and those on packaged medications were shown only the names of medication in their package.

Moreover, the researcher deliberately refrained from picking this information directly from leaflets or online resources in light of the data where the study participants pointed out how impersonal, misleading or confusing general information could sometimes be, especially when involving medical jargon.
7.4.3.6 Adding dialogue preview

In the previous trial, we worked with a simple rule definition between Robogen and the robot dialogue system. The rule associated the medication dosage and informs the dialogue *Please take out ‘2’ (dosage) pills* (form). However, there was no ability to add qualifying words, e.g. *swallow whole, do not crush or chew* for sustained release forms or *Take it with food* for gastric irritants or *Instil into both eyes* for some eye drops or *Apply in the area where it feels itchy* for some creams. Hence, it was agreed to construct and display the dialogue within Robogen as it would appear on the robot screen, so that any inaccurate expressions could be manually corrected. The bottom of the page shown in the screenshot (Figure 7.11) now displays the resulting dialogue as the medication name; dose and forms were entered in Robogen.

![Figure 7.11: Showing dialogue preview in Robogen](image)
Figure 7.12 demonstrates how the customisation works.

a) The dialogue preview shows *Please take out one pill*

b) Clicking on the *edit* hyperlink opens the next window, showing a free text entry box. In that box was typed ‘*and swallow whole do not crush or chew*’ and saved.

c) The resulting preview now shows the changed dialogue as it would appear on the robot screen.

![Figure 7.12: Editing a dialogue in Robogen](image)

### 7.4.3.7 Icons on summary screen to reflect more meaning:

The user taking different routes and exit points while navigating through the dialogue system was noted in the earlier trial. The summary screen then had only three possible icons: a tick (medication taken), a cross (medication not taken), and a question mark (not known or no logs available). In this phase, there were five possible icons that could be seen on the summary screen. The screenshot in Figure 7.13 shows some of the examples.

1. Question mark (Unknown) – default state. Means the robot has no information as to whether the user has taken the medication or not.

2. A question mark with a box around it (Negative PRN) – user went through the dialogue and indicated *No* to the PRN question prompt (i.e. responded *No* when asked *Do you have pain?*) hence did not receive the prompt to take medication.
3. Tick inside a box (Taken With Robot) – means the user had gone through the dialogue with the robot and indicated that they have taken the medication.

4. Tick without a box (Taken By Self) – means the user had indicated up front that they have taken their meds without the robot’s assistance.

5. Cross (Not Taken) – means the user indicated that they prefer not to take their medication.

Figure 7.13: Compliance summary

The provider viewing this screen would get a snapshot of interactions and what went on over the week at a glance. If the provider was interested to know more, he/she could click on any of the icons and actually see the dialogue sequence and path that the user took during that session. The screenshot in Figure 7.14 shows the list of dialogues delivered and the user responses to them.

Figure 7.14: Log record of user activity on the robot
This feature enabling an interaction view was not available in the earlier version. It was deemed important in this study considering the researcher’s absence from the scene of action, and the possibility of darting in the dark to guess issues if something went wrong.

**7.4.3.8 Working towards standardization and interoperability**

Working on a collaborative model of care and shared decision-making (Charles, Gafni, & Whelan, 1997), one of the desirable situations would be the automatic reading of a prescription from the healthcare provider’s computers and electronic population of a compliance summary back into the provider’s computer. The availability of fine grained patient-generated data is envisaged to enable effective decision-making as has been the idea behind most home monitoring systems in modern times. To enable this interoperability with the providers system, the onus would be with Robogen to read and write information in standard terminology. Striving to achieve that objective over the longer term in this phase, an attempt was made to achieve semantic interoperability using SNOMED CT terminology for log records wrapped in an XML file following CDA (Clinical Document Architecture) convention. At this stage, further demonstration of interoperability with proprietary systems in real world clinical practice was not possible, given its financial implications and meeting the vendor’s interest. Instead, it was considered sufficient to demonstrate a manual export process where a standard compliant summary report could be generated.

Carefully looking at the summary screen (Figure 7.13), one can notice ‘Export CDA’ hyperlink on the top of the page. Clicking on that link, another screen would query the export file boundaries.

![RoboGen Portal](image)

*Figure 7.15: Listing PRN medication on home page*
On clicking OK after choosing start and finish dates, an XML file would be generated as shown below in Figure 7.16.

This export file would contain:

- Medication compliance summary
- Side effects monitoring/subjective symptom reporting summary
- Vital signs summary (blood pressure, augmentation index and pulse rate) – this new addition is explained below.

7.4.3.9 Vital signs monitoring to complement subjective symptom reporting

The screenshot in Figure 7.13 showed part of Robogen’s summary screen; medication logs are recorded along with side effect symptoms. As compared to previous versions, one can see the vital signs data coming from the robot. It shows the date when the reading was made, time/s of the day when the reading was taken, along with values of those parameters.

It was essential to ensure the safety of patients self-managing their medications who would agree to test an unproven technology to assist them. The potential risk of introducing errors and compromising health was at the front of our minds while seeking ethics approval to field test this application. A simple measure of blood pressure and pulse rate was considered sufficient as a reflection of the patient’s baseline health. Moreover, it could add some objective validity to the subjective reporting of symptoms/side effects if a proper combination of query dialogues
and vital signs measure was used (e.g. dizziness and low blood pressure in heart failure patients could signal diuretic overdose).

7.4.3.10. Integration with SMS gateway (future Skype services to initiate a call)

Another safety feature that was required was the ability of Robogen to record a difficult situation and alert a caregiver/family member instantly by sending a text message on a designated mobile phone number (Figure 7.17). The dialogues path that ended in a situation where the user indicated she/he was having some difficulty with medications or the system recorded missing a dose or getting stuck (time out), the robot system informed Robogen to send a text message via the internet-based SMS gateway (Intellisoft, 2012) that could enable this service.

![Figure 7.17: Pathway for text messaging](image-url)
7.4.3.11 Decoupling the robot clock from Robogen clock for testing purpose

As the dialogue system was tightly coupled to the clock with safety mechanisms designed to prevent double dosing, it became difficult for the researcher to perform lab testing. Every time the medication or parameter was changed on Robogen and its impact on the dialogue system needed to be checked, it was impossible to repeat it unless the robot was reset. For example, the researcher was unable to test any dialogue in the afternoon because most test patients had only morning medication. Whenever an attempt to test was made after 11am, the robot would acknowledge it was not medication time. Thus, an ability to turn off the mechanism was requested. The way it was enabled is as follows.

By clicking on the Other tab on the top menu ribbon a new page opened (Figure 7.18). The page had Account control and Change password features from before, but in this version of Robogen, a choice was enabled to bypass the scheduled time and run the dialogue for test purposes, i.e. the researcher could override the clock.

These features were clearly articulated in advance by the researcher in light of the data and submitted to engineering colleagues for converting into functional elements. Therefore they remain the original contribution of the researcher barring the actual coding and debugging of applications which were external to his domain knowledge.
7.4.4 The dialogue system – presenting on iRobiQ

7.4.4.1 Overview of refined dialogue system
This phase of AR determined the attributes of an independent semi-autonomous robot assisting an elder user in his/her apartment over a longer period of time. When the robot is not dedicated to any user, it will be in an unauthenticated state and will need to be set up for a dedicated user by choosing from a list of known profiles on Robogen and entering the appropriate ID code into the robot XML dialogue schema. Here, it is assumed that the Robogen already has the profiles stored for all expected users prior to the study and can exclusively link the user’s profile to one iRobiQ for a period of time and that the preferences and prescriptions are updated. Once the system is set up a typical medication session will proceed as follows.

Medication time reached → Alarm rings → User responds → positive ID is established → user prompted to locate correct medication/s → support self-administration of routine medications → probe need for PRN medication (and prompt if needed) → share educational information → query for side effects/subjective reporting of symptoms → Offer other features (blood pressure measurement and entertainment) → finish session. (Upload activity logs into Robogen at each step).

There could be a large number of variations to this typical flow of events and multiple error conditions might crop up. The following sections describe an attempt to deliver the desired features and cover for error conditions.

7.4.4.2 Concept of time
There are four concepts of time used in this system:

1. Clock time – displayed on the top right corner of the home screen in am/pm convention
2. Medication administration time slot – refers to a discrete time window during the day during which medications are usually taken. Arbitrarily chosen, it can be one of:
   a) Before breakfast [00:00 – 06:59]
   b) Breakfast [07:00 – 10:59]
   c) Lunch [11:00 – 13:59]
   d) Tea [14:00 – 16:59]
   e) Bed [17:00 – 23:59]

Naturally, any given time of the day must correspond to only one time slot. The boundaries between adjacent time slots were fixed in this iteration but can be optionally extended to be customisable by the user in future iterations.
3. **Preferred medication time** – the preferred time either entered in Robogen or customised by the user to ring the reminder alarm. It is the concept of ‘now’ described in Chapter 4, where the user is prompted to take medications belonging to one of the time slots mentioned above. For example, the user can take breakfast medication anytime in between 07:00 and 10:59. Let’s say he/she prefers 8.30am, so the alarm for breakfast-time medication will ring exactly at the 08.30 clock time in the robot computer clock (see (b) in Figure 7.19). It is important to mention that ‘breakfast time’ cannot go beyond 07:00-10:59 time slot, meaning the user cannot take breakfast medications at 11.15 because it is lunchtime as per the definition. The scenarios and consequences of actions/events are described later.

4. **A greeting time** – refers to the time of the day when greetings change. This is more guided by general convention and informs the dialogue accordingly.
   
   a) Good morning – [00:00 – 12:00]
   
   b) Good afternoon [12:01 - 17:00]
   
   c) Good evening [17:01 – 24:00]

7.4.4.3 **Home screen**

Once a robot is dedicated and the robot is installed in the apartment, a *home screen* would be displayed as long as the robot was switched on and sitting on the table in an idle state. Some of the ideas to keep the home screen useful between interactions were displaying weather conditions, upcoming Selwyn Village social activities, health tips and family pictures, to name a few. In this iteration – given the resource constraints – the home screen presentation was limited to one of the three states (Figure 7.19). As seen in the three screenshots, the home screen displays:

1. Current time (top right corner)
2. A message panel with appropriate message depending on the user’s medication status (see below)
3. Buttons: [Take my meds] and [Other features]

The home screen and the content of the message are determined by the current time in relation to the current medication time slot. The robot should periodically consult Robogen to check these two parameters and act accordingly. When the time to remind is reached, e.g. the user set up the system that the lunchtime medication reminding alarm should ring at 12.30pm, then as soon as the 12.30 clock time (hypothetical ‘now’) is reached (Figure 7.19 (b)) an alarm rings.
The three possible states of home screen can be described as:

a) Before the scheduled reminding time is reached – a display of greeting text. The text changed according to the time of the day (good morning, afternoon or evening) and anticipated expression (Morning - had a good sleep, afternoon - having a good day, evening - had a good day).

b) On the scheduled reminding time – the screen colour changed from green to red, and an attempt to seek user attention is made using audio and visual cues. The text on the screen matched the spoken words using preferred name of the user. This made it clear whose attention is needed in case there are more than one person in the room.

c) After the scheduled time is passed and the user did not respond to the alarm and the next medication time slot is not reached – the home screen displays the pending action from the previous missed timing. This remains on screen until the time for the next medication (a) is reached. The concept of these timings is further explained later in this section.

This display was silent most of the time (without any speech generation associated with it) other than while sounding the alarm. In instance (a), the current time reaches the scheduled medication time, and the robot enters the alert mode. During alert mode, the robot performs attention-seeking gestures including ringing an alarm sound and (optionally) flashing LED lights and moving its head and/or arms. The robot performs the gestures for a one-minute period at five-minute intervals three times, after which the alert mode ends. The robot must adhere to the correct medication timing and never initiate the medication dialogue for the same time slot more than once, in order to prevent double-dosing.
The user has a choice of responding to the robot or initiating the medication dialogue at any given time. This can be done by pressing the [Take my meds] button. Also the user has a choice of invoking other modules at any time by pressing the [Other features] button.

As soon as the user chooses to initiate the module (by pressing the [Take my meds] button) the next step is identification.

### 7.4.4.4 Identification

Figure 7.20 shows the same three possible states (a, b and c) as explained earlier but goes on to explain that from any of these states the user can progress to state (d) by pressing the [Take my meds] or [Other features] button. The solid lines show the pathway taken if the [Take my meds] button was pressed and dotted lines show the pathway taken when the [Other features] button was pressed.

For both of these buttons, [Take my meds] and [Other features] the robot presents a confirmation dialogue (d) to check the user’s identify: *(Before we go on, could I please confirm...)*

![Figure 7.20: Robot screens during face recognition](image)
that you are (Mr/Mrs) <name>, and the photograph of the user is shown to self-identify). If the user selects [No], then the robot displays (g): I’m sorry, I can only allow <name> to use these features and returns to the home screen. If the user confirms their identity positively by selecting [Yes], then the next screen for the option chosen is displayed. [Take my meds] leads to the medication intake confirmation screen (e) (solid line arrows), but if [Other features] was chosen, then it leads to the menu screen (f) (dashed line arrows). The [Take my meds] button initiates the medication dialogue, while the [Other features] button presents the user with the choice of four features, namely: Entertainment, Blood pressure measurement, Customisation and Home (Returns to the home screen described earlier).

7.4.4.5 The Entertainment module
The entertainment module was considered useful to present the robot as a friendly companion rather than as solely a representative of the healthcare system. The module complemented medication management in many ways. By avoiding a complete mediatised image and adding the fun factor we hoped to maintain a long-term user engagement with medications and healthcare activities. This module upheld the participatory feedback and catered to user preferences by offering a choice of music channels, quotes and photos.

7.4.4.6 Blood pressure measurement module
This module was also not originally designed or conceptualised by the researcher, but he gave some suggestions for tailoring the dialogues to address error conditions while incorporating them into the current version of the independently interacting robot.

7.4.4.7 User customisation/confirmation module
The user could press the customisation button icon on the menu screen, which presents the user with a set of dialogues to edit his/her preferences (Figure 7.21). Once the user has customized the preferences then the Robogen schedule is appropriately updated. Users could:

1. Check and edit their preferred name (the name by which the robot addresses the person)
2. Check and set the refill reminder date
3. Check and set the physician appointment date
4. Check and confirm the before breakfast, after breakfast, lunch, tea and bedtime medication list in sequence (only those that apply to the user are displayed – for example if user has no teatime medication in the prescription then it will not be displayed)
5. Check and set each occasion of applicable reminder time (i.e. before breakfast, after breakfast, lunch, tea and bedtime).
Figure 7.21: Customisation module
The flow of screens in Figure 7.21 shows the options presented to the user to enable him/her to change the preferred name that the robot uses to address the person or change the preferred timings of reminders for different time slots. The option appears to the user only if the medications are scheduled at that time. For example, if the user takes no lunchtime medication, then there is no point in presenting an option to customise a lunchtime reminder. At each of the timings, the user can check which medication he/she is on and can request assistance in case any error is noted. At each instance, there is a change to the corresponding fields in Robogen which needs to be updated. This was made possible by synchronising the respective fields between the robot and Robogen.

7.4.4.8 Medication dialogue activation from other features

It is possible that the scheduled medication time is reached while the user is interacting with other features. In this case, the robot should ideally signal an alarm which overrides the current interaction and guides the user to the medication dialogue (Figure 7.22). If the user has left the music on and the interaction times out, then a window appears to check if the user is still around.

![Figure 7.22: Bringing back to medication management module](image)

7.4.4.9 Handling potential error scenarios

There is a hard 10-minute limit from the beginning of the dialogue to the end. Considering this scenario, what if the user went to take medications and got distracted, or fell over and for whatever reason failed to complete the session? The dialogue would ‘time out’ after 10 minutes of waiting and initiate caregiver notification.

At the end of a successful medication session, the system would attempt to reschedule the next drug so that the interval between the current and next session is maintained as originally planned, e.g. if the scheduled breakfast and lunch sessions were 9am and 12pm respectively, and the user woke up late to start the session, let’s say the breakfast session started at 9:30am, then the next lunch session would also be pushed by half an hour to be at 12:30pm instead of
12pm. However, the system should obviously not push the scheduled time beyond the time slot boundary, e.g. if the actual breakfast session started at 11:30am (off by 2.5 hours), then the scheduled lunch session should not be pushed beyond the boundary of 2pm, even though the interval between the two sessions would shrink as a result.

Tables 7.1 to 7.3 illustrate parts of the requirement table for dialogue states as prepared by the researcher and Figure 7.23 illustrates the actual design as it looked on the robot screen to handle error scenarios.

It is important to point out that the alarm should ring only when there are medications scheduled. In case there are no medications in the given time slot, then there is no alarm or reminder issued. Let’s take the example that the patient went out for community service in the morning and took his medications with him. Obviously, he would have missed the breakfast and lunch reminders (where Robogen log status remains unknown). He comes back at teatime and responds to a teatime medication reminder in person. The dialogue would in this case try to ascertain whether the user took the lunchtime medications or not. Upon starting the medication dialogue, the robot would consult Robogen as to whether the user had missed the previous sessions (i.e. medication status/es is/are unknown). If this is true, then the robot would prompt to check whether the user had taken the medication themselves. If the user indicates ‘Yes I have taken my medications already’, then the same should be reported back to Robogen and the status updated.

Table 7.1: Missed medication dialogue

<table>
<thead>
<tr>
<th>Screen No.</th>
<th>Display</th>
<th>Buttons and Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>By the way &lt;name&gt;, I don't recall whether you took your &lt;missed time slot&gt; medication. Did you manage to take them by yourself?</td>
<td>• Yes → Screen A3 (record ‘taken by self’ in Robogen)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No → Screen A2 (record ‘not taken’ in Robogen)</td>
</tr>
<tr>
<td>A2</td>
<td>I see. That's alright. Please don't take those medications just mentioned. I'll just make a note of it and we can move on.</td>
<td>• Next → Proceed with ‘current medication’ dialogue.</td>
</tr>
<tr>
<td>A3</td>
<td>I'm pleased to hear that!</td>
<td>• Next → Return to Home screen</td>
</tr>
</tbody>
</table>

In another scenario, let’s assume the patient had taken medications by himself without waiting for the alarm to go off (by pressing [Take my meds] on the home screen) and forgotten about
it. Thinking he/she has not taken the medications, Robogen initiates the module once again within the same time slot with or without the alarm ringing. For example, if the user has already taken the lunchtime medications and attempts to take them again, then the system would attempt to prevent double dosing (Table 7.2).

Table 7.2: Already taken medications dialogues

<table>
<thead>
<tr>
<th>Screen No.</th>
<th>Display</th>
<th>Buttons and Actions</th>
</tr>
</thead>
</table>
| B1         | <Name> my data says that you already took your <current time slot> medications earlier. If you think this isn't right, I can call someone to help you | • No thanks → Return to Home screen  
• Call → Screen B2 + Send text message |
| B2         | I've just notified your caregiver. Hopefully the issue will be resolved soon | • Next → Return to Home screen |

In another scenario, there are no medications prescribed to be taken during teatime, but the user thinks he/she has to take medications and initiates the module on the robot (by pressing [Take my meds] on the home screen). In that case, the system tries to prevent wrong dosing and informs the user as shown in Table 7.3.

Table 7.3: No medication now dialogue

<table>
<thead>
<tr>
<th>Screen No.</th>
<th>Display</th>
<th>Buttons and Actions</th>
</tr>
</thead>
</table>
| C1         | <Name > my data says you do not have any medication scheduled for this time today. If you think this isn't right, I can call for help. | • No thanks → Return to Home screen  
• Call → Screen B2 + Send text message |

However, there may be circumstances (e.g. PRN medications) that the machine could not predict and wrongly obstructs the patient, causing frustration. In order to cover for such situations, the system attempts to call another human (in this case the designated caregiver or researcher) to get the issue resolved.

The concepts presented in Tables 7.1 to 7.3 are demonstrated again with the help of actual screenshots taken from the robot (Figure 7.23). The arrows attempt to indicate the logic of screen flow, illustrating the consequence of pressing a soft button to indicate choice.
Figure 7.23: Screenshots of robot handling error scenarios
7.4.4.10 Ideal medication prompting scenario

In an ideal scenario, the patient would press the [Take my meds] button within the correct time slot before/after the alarm goes off, and actually have some medications scheduled in this time slot that have not yet been taken. Even in this case, one cannot rule out the possibility of the user having taken the medications earlier without interacting with the robot. Therefore, the system must first establish the prior intake and compliment the user for accomplishing the task unassisted. Only if the user affirms negatively to medication intake earlier during this time slot would the remaining dialogues follow. Table 7.4 summarises the chain of dialogues, many of which are similar to the ones presented in earlier chapters, and Figure 7.24 illustrates the same with the help of screenshots.

The new additions from the previous version of dialogues described in AR Cycle 3 (Chapter 6) are:

1. PRN medication dialogues (M5 – M6)
2. Time out dialogue (M7) which would be triggered when the overall medication module session time overshoots a total of 10 minutes
3. When patient indicates difficulty (in M4 & M5) and attempts to call for help.

The description of scenarios that could possibly follow when a patient goes to find his or her medications and brings them to the robot before continuing further is explained with the help of screenshots (Figures 7.25 and 7.26). The possible states could be that:

1. The user may have organised medications or loose medications. The organised medications could be in pill boxes, sachets or blisters. Loose medications could be in various forms (e.g. tablets, syrups, drops).
2. The user may only have PRN medications for this time slot.
3. The user may have a mix of situations where some medications are organised, some loose and/or some PRN. For example in an earlier trial we encountered a participant on packaged medication (sachets), who also had a sublingual spray for her chest pain on as needed basis, an eye drop for dry eyes and loose Paracetamol tablets for her arthritic pain, also on PRN.

Once Robogen is equipped with this information, the dialogue system first picks up the organised medications dialogue, then moves on to any loose medication and finally to PRN medications.
<table>
<thead>
<tr>
<th>#</th>
<th>Display</th>
<th>Available actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>&lt;Name&gt;, have you taken your &lt;time slot&gt; medication already?</td>
<td>• “Yes” screen # A3, update med. Status (taken by self)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If user prefers shorter reminder:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “No” screen # M12, Otherwise:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “No” screen # M2</td>
</tr>
<tr>
<td>M2</td>
<td>Shall we do it together?”</td>
<td>• “Yes” – screen # M3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “No” – screen # M8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “I’ll do it myself” – screen # M12</td>
</tr>
<tr>
<td>M3</td>
<td>“Great! Please bring your medication and a glass of water and let me know when you are ready to take them”</td>
<td>• “I’m ready – screen # M4</td>
</tr>
<tr>
<td>M4</td>
<td>“Please find the &lt;medication&gt;”</td>
<td>• “Next” – screen # M5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “Can’t find” – screen # M7</td>
</tr>
<tr>
<td>M5</td>
<td>“Please take them now &lt;instructions&gt;”</td>
<td>• If more meds:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “Done” – screen # M4 for next med</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Otherwise if there are PRN meds:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “Done” – screen # M6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Otherwise:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “Done” – screen # A3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “I couldn’t take” – screen # M7</td>
</tr>
<tr>
<td>M6</td>
<td>“&lt;PRN question&gt;?”</td>
<td>• “Yes” – screen # M4 for next PRN med</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “No” – try next PRN question</td>
</tr>
<tr>
<td>M7</td>
<td>“It seems like you need help with your medication. Let me call someone to help you.”</td>
<td>• “OK” – send notification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “Take me back” – back</td>
</tr>
<tr>
<td>M8</td>
<td>“May I ask why?”</td>
<td>• “I’m not feeling well”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Problem with my meds” – screen M9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t want to specify”</td>
</tr>
<tr>
<td>M9</td>
<td>“I have just notified your caregiver. Hopefully the issue will be resolved soon”</td>
<td>• “OK” – send notification (text message)</td>
</tr>
<tr>
<td>M12</td>
<td>“Alright. Please go ahead and take your medication now. If you need my help at any time, I’ll be happy to assist you”</td>
<td>• “I’m finished” – screen # M13, Update med status (taken by self)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• “I need help” – screen # M4</td>
</tr>
<tr>
<td>M13</td>
<td>“Excellent! Well done.”</td>
<td>• “Next” – end section</td>
</tr>
</tbody>
</table>
The screenshots in Figure 7.24 illustrate the teatime medication reminding scenario. The system first checks earlier compliance if the user confirms medications have not yet been taken; then it prepares the patient and reminds them to take meds as per their personal choice.

The screen M4 is explained in the next section (Figure 7.25) by showing two of many possible scenarios.
The scenario illustrated in Figure 7.25 shows two examples out of many possible dialogue constructions. If the pills were organised then the dialogue would tailor itself to the method of organisation (pill box in this case (M4a)), but it could be sachets or blisters, where the dialogue would say pouch or pack. If the medications were loose then it would go medication by medication till the list was exhausted. Such loose medications may be pills, drops, syrups, puffs or patches. Screenshot (M4b) shows eye drops but it could be a variety of forms and names (brand or generic) and doses. The dialogue in screenshots (M5a) and M5b would also follow a variety of compositions. Here (M5a) shows ‘container’ because it was referring to one
of the containers in the pill box and (M5b) says ‘instil drops’, but it could be ‘inhale puffs’, for example.

7.4.4.11 Handling PRN medications

The screenshots in Figure 7.26 demonstrate the dialogues for PRN medications. It shows the prompt question that is asked once all the regular medications are taken (by running through tailored M4 as many times as required for each loose medication and others). Only when the user says yes to the presence of a symptom does the system prompt him/her to take the respective medication. There could be more than one PRN medication. PRN medications are always considered loose (considering only regular medications are organised). The idea has been challenged in the last trial where we saw users mixing PRN medications with regular medications in their pill boxes. However, we could not work around that, other than educating patients to take them separately.

![Figure 7.26: Prompting for PRN medication](image)

Go to next medication in the current list till the list is finished. After the user says [I’m done] to the last medication, go to: ME1.

Go to M7

Dialogue construction error: repetition of word spray – prompting the researcher to check dialogue preview in Robogen
The screenshot (M5c) shows an inappropriate utterance due to error in automatically constructing dialogue, justifying with an example of the design process where researcher requested the engineering colleagues to provide a dialogue preview in Robogen so that the errors could be manually fixed.

7.4.4.12 Education

When the dialogue reaches this point, the robot randomly selects a maximum of two drugs from the current session and displays Table 7.5.

<table>
<thead>
<tr>
<th>ME1</th>
<th>“Would you like to know a little bit about the medication you just took?”</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME2</td>
<td>If loose medication – “&lt;education dialogue of drug 1&gt;, &lt;Did you know &gt;?”</td>
</tr>
<tr>
<td>ME3</td>
<td>If packaged medications – (display the list of medications in package)</td>
</tr>
<tr>
<td>ME 4</td>
<td>“Well done! Now we shall move on”</td>
</tr>
</tbody>
</table>

| | “OK” – Go to screen ME2 (if loose) |
| | Screen M3 (if packaged) |
| | “Not now” – Go to MS1 (if any side effect question scheduled - as explained in next section) or end session |
| | “Yes”/”No”– display text from next information box (till all 6 slots from Robogen are covered) |
| | “Next” – Go to MS1 (if any side effect question) or end session |
| | Once information related to one drug is done then go for next drug: |
| | “Next” – ME1 with next drug |
| | Otherwise go to MS1 (if any question) or end session |

The information is picked up from the medication education information in Robogen (see Figure 7.10). There are at least six pieces of information related to each medication. Once the user has displayed one piece of information (e.g. purpose), then the next piece is displayed. If the user is on organised medications (sachet, pill box, blister), then the system only displays the list of medications in that package, the assumption being that people on organised medication have reached a stage where they may not be ready to handle the cognitive load of detailed information about each medication. However, in order not to undermine their capacity, such a feature could be incorporated in the next phase of design. The screenshots in Figure 7.27 show example screens from these two scenarios. ME3 shows the list of medications in the pillbox, whereas ME2 shows the details associated with a loose medication.
Figure 7.27: Medication education dialogues
7.4.4.13 Medication safety (side effects monitoring)

At the end of the education section, the robot performs a check on the user for any side effects to monitor for the current session. If there are any, then the dialogue goes to screen MS1 of the side-effects monitoring section; otherwise, it skips to the end of that section.

Table 7.6: Dialogues to assess medication safety

| MS1 | “<Name>, Before we finish the doctor would like to ask you a few questions about medication safety.” | “OK” – screen MS2  
“Ask me later: – MS3 |
| MS2 | <Monitoring question/s>? (a, b, c…) | If more questions:  
“Yes”/”No” – update status; MS2 for next monitoring parameter  
Otherwise:  
“Yes”/”No” – update status; MS4 |
| MS3 | No problem. I’ll ask you next time.” | “OK” – end section |
| MS4 | “Would you like to use me for anything else?” | “Yes” – Go to menu screen  
“No” - #MS5 |
| MS5 | “Thank you. Have a nice day!” | “Next” – end section |

A set of screenshots of some example screens and their flow is illustrated in Figure 7.28.

It may not be difficult to imagine situations involving drugs with narrow therapeutic index like Warfarin or Digoxin being closely monitored with daily questions about bleeding tendencies or palpitations. Timely detection of flagged events could trigger a lifesaving intervention.
Figure 7.28: Medication safety and side effects monitoring dialogues
Appointment Reminders
If there are any user-defined appointment or refill reminder dates, they are displayed to the user once a day starting two days in advance (Table 7.7).

Table 7.7: Refill reminders and appointment reminders

<table>
<thead>
<tr>
<th></th>
<th>“&lt;Name&gt;, Please remember that you have an appointment with &lt;doctor/pharmacist&gt; coming up &lt;in two days/tomorrow/today&gt;.”</th>
<th>• “OK” – screen AR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR1</td>
<td>“Thank you. Have a nice day!”</td>
<td>• “Next” – end section</td>
</tr>
</tbody>
</table>

Text notification to caregivers
If a caregiver notification screen is reached (e.g. M7 – Figure 7.25), the robot should instruct Robogen to send a text message. The content of the message is one of the following:

- `<Name>` is having problems with his/her medications. Please assist immediately.
- `<Name>` has not taken his/her `<time slot>` medications today because `<reason>`

For all notifications, there should be at least one additional default recipient (i.e. the researcher – during this phase of the trial).

Video log
The robot should be able to keep a video record of the user between the start and end of each medication session. If possible, it should process and send the video file over to Robogen without disrupting the user interaction performance. However, in this stage of research it was decided to keep the video logs in the local USB drive for various ethical concerns (e.g. risk of a private video being exposed to a larger research team) and technical limitations (i.e. uploading video over 3G network and incorporating within Robogen would need more resources than available).
Handling connectivity failure and robot failure

In case the mobile data network connection is lost, the robot still needs to continue operating and updating Robogen as and when connectivity returns. It was noted during lab testing that the medication management module becomes inoperable without connectivity to Robogen. Moreover, the robot may malfunction or fail for unspecified reasons, with implications on medication administration. The attempts to bridge this gap were technically elaborate and exceeded the scope of programming resources. At this stage, it was only possible to request the trial participants to call the researcher on his phone in case the robot becomes non-functional. Secondly, an activity log on Robogen was created to see when the robot was last connected in order to estimate a disconnection period and its implications on the medication log.
7.5 Methods

This AR cycle was informed by the results and observations of AR Cycle 3. Assessing the hardware needs to meet the objectives of AR cycle 4, a request was placed to the Korean robot manufacturers for a smaller robot. Robogen was updated to Robogen II as noted earlier. The dialogues were refined to empower the user, and an attempt was made to close the possibility of errors, making it safer to work with, and to promote collaboration while keeping it simple and usable for end users. Again, the contribution of the researcher in this phase of research was more medication process focussed and overall design oriented, while the supporting team members did the necessary coding and incorporated design requirements. This fourth and final cycle of AR followed a similar pattern to earlier ones. Having described the apparatus earlier, data collection and analysis are described in the next sections, followed by discussions about this AR cycle. Figure 7.29 illustrates the four steps followed in the AR cycle.

In addition to assessing and addressing hardware and software needs, the planning phase also involved seeking approval from the ethics committee for experimenting with human participants (University of Auckland Human Participants Ethics Committee protocol approval 2010/ 557). In this trial, other features and modules on the smaller robot were also tested simultaneously (namely entertainment and vital signs modules).

In many ways, the ‘acting’ phase presented in this chapter falls short of qualifying as a full study. Rather, it could be called a pilot study that would inform a fully formed trial that follows. However, the effort invested and learning gained in this pilot were significant enough (as the reader might appreciate after reading the sections below) to be called an AR cycle.
AR Cycle 4 involved installing the robot for participant interaction in Selwyn Village. Two robots working simultaneously in each instance – *Harry* and *Henrietta* (as the participants named the two iRobiQ) – shared the residential apartments of four participants in Bishop Selwyn for one week each. This was a different building to the previous trial to avoid participant bias and data contamination from previous experience. The web-based EMR application (called Robogen II in this version) was hosted on a *secure* server this time as it took a while to get the necessary approvals within the university’s IT environment. The server was accessed by robot computer through a USB port mobile device using 3G internet connection. The trial was conducted in the later part of September and early October 2011. It took a long time because the long list of issues that cropped up in first week needed some resolution before heading back for another week, which may perhaps be called another rapid AR cycle within the larger cycle.

During testing, the main data collection methods were video recordings of user interaction and field notes, and, post interaction, questionnaires and semi-structured interviews. The data was then analysed using GT to inform the categories as well as using feedback to refine the prototype design. Table 7.8 summarises the research methods and tools used during the testing and evaluation phase.

<table>
<thead>
<tr>
<th>Objectives of the study</th>
<th>Measurement tools used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To test safety, efficacy, functionality and acceptance of a smaller Static Robot for Medication Management Services (StRoMMMS) within residents’ apartments, without the physical presence of the researcher</td>
<td>Robogen logs, SMS messages, direct observations, field notes, semi-structured interviews</td>
</tr>
<tr>
<td>2. To collect user feedback on the overall experience, appropriateness and satisfaction with the intervention</td>
<td>MedMaIDE questionnaire. Semi-structured interviews</td>
</tr>
<tr>
<td>3. To test technical feasibility, connectivity, data transfer and errors to inform the engineering research streams</td>
<td>Reliability &amp; technical feasibility, e.g. connectivity issues, error rate, type of errors, resolution etc.</td>
</tr>
<tr>
<td>4. To collect feedback from other actors, namely physicians, pharmacists, caregivers and managers of Selwyn Village about the usefulness of the intervention, especially the Robogen dashboard</td>
<td>Semi-structured interviews</td>
</tr>
</tbody>
</table>

Table 7.8: Data collection methods used in AR Cycle 4

The criteria for excluding the patient from the trial (or stopping their participation) were:

- Robot having technical errors and becoming unusable
- Robot reporting inaccurate vital signs
- People falling over the robot or pulling it over
• Significant psychomotor challenges that would make even the supervised interaction challenging or stressful e.g. forgetful patients taking medication twice to oblige researchers
• The robot running into people/things
• People feeling ‘watched’ by the robot or similar paranoid ideation about robots
• Inconvenience caused by a visiting team of researchers and a large robot every morning
• Participants becoming incapable to use the robot during the course of research

The interviews were transcribed and coded to confirm the elements and themes underpinning the theory that emerged in the previous AR cycle (Chapter 6). The reflection phase compared, contrasted and drew conclusions about a well-formed theory of automated medication assistant for older people. Figure 7.29 summarized the important steps during this iteration.

7.5.1 Preparing for the trial
The high sensitivity and potential risk involved in leaving an unproven piece of technology with vulnerable users performing potentially high-risk tasks for the first time, required detailed attention. Risk management strategies were implemented systematically in steps.

Step 1: Thorough lab testing
Lab testing was done by running test case scenarios and going through various dialogue pathways after entering participant information and real prescriptions.

Figure 7.30: Researcher (right), Dr HongYul Yang (left) and Chandan Datta (middle) during lab testing

Thereafter the researcher tested the robot at his personal residence for one week, continuously running the robot 24x7 and interacting using a dummy prescription to detect any hardware failure issues or bugs that may show up on continuous use.

Step 2: On-site dummy testing at Bishop Selwyn:
1. One day of testing at Bishop Selwyn, where two dummy patients were set up, interacting with the robot in different locations, getting both robots running two ‘dummy-patients’ simultaneously, testing all dialogue branches, Robogen connectivity and associated peripheral functions.

2. The researcher to practice patient registration, adding photo and profile customization, setting up a robot independently and practising minor troubleshooting protocols, in case engineering support is not available in a real life emergency call situation.

3. Verifying the data on the server; workaround procedures including recovery from connection error and overriding normal bounds of medication administration times. Running the scenarios, then giving demonstrations and reviewing patient safety protocols with the GP and the nursing manager at the Selwyn medical centre.

4. Researcher to explain the PIS (participant information sheet) and the participant to sign the consent form.

5. Take a picture of the participant and load it on to the robot linked to his/her profile.

6. Access medication record from pharmacy, reconciling medications/nutritional supplements with the GP and participant.

7. Enter reconciled data into Robogen and set up a patient profile.

8. Perform a quick test to check linkage between Robogen and iRobiQ to ensure the right patient is linked to the right prescription.

**Step 3: Installation and testing of apparatus**

1. The robot (iRobiQ) unpacking, connecting to the peripherals as shown in Figure 7.30, powering up the robot computers and testing connection for internet signal adequacy.

2. Quickly run through the dialogue system, its sync with Robogen and text alert mechanism.

3. BP apparatus cuff and connecting leads – researcher to check integrity and take BP on self once to confirm working condition.

4. Check USB drives and USB hubs connectivity to robot port and with other devices.

**Step 4: Participant preparation** (Figure 7.31)

1. Call up to schedule appointment.

2. On appointed day and time take the apparatus to his/her apartment.

3. Set up a test of the apparatus (as explained above).
4. Explain user manual, and observe the participant reading it while becoming familiar with the robot. A fifteen-page manual detailing every step of apparatus use in simple to understand terms was prepared by the researcher specifically for this phase.

5. Lead the user to become familiar with the apparatus and peripherals, with dialogue scenarios and pressing of buttons and with taking blood pressure and using entertainment modules.

6. User to set up preferred name, check medication list and set up preferred medication timings in ‘customisation’ module, under supervision.

7. Explain the process for text alert. The alert text message or missed dose message would come to the researcher’s mobile first, the researcher would call back on the user’s landline to confirm validity of this alert, and then he would inform the Selwyn Village nurse if necessary.

8. Share emergency contact details of the researcher (who would be available on call 24x7 during the trial) and explain video logging and request for being appropriately dressed while using the robot.

Figure 7.31: Explaining and training the user for independent handling of robot

**Step 5: Concluding the initial session**

1. Hand over the robot and user manual and explain how to note observations and issues on the error reporting sheet.


3. Perform pill counts to check objective usage.

4. Be available on site for the first day and if possible visit the user within 24 hours to check if everything was going well.
7.6 Results of field testing in AR Cycle 4

7.6.1 Patient profile
Table 7.9 summarises the profile of four participants who were living in Bishop Selwyn apartments on two different floors. Their ages ranged from 74 to 84 years with a mean age of 80.5 years, with one male and three female participants.

Being a feasibility pilot study preceding a larger clinical trial, it was conceived that a small sample size should provide the insights to test the applicability and guide further refinements for the trial planned later. A qualitative approach was more appropriate which could lead to a summative study involving a larger number of participants. The participant profiles might contribute a selection bias because a tendency for risk avoidance prompted convenience sampling and voluntary expression of interest by participants encouraged interested and capable people. In fact, half the participants had already been exposed to earlier trials conducted under the same project. However, this was a different study using independent robots, and none of the participants had earlier been exposed to medication management modules in unsupervised situations.

Table 7.9: Participant profiles

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Gender</th>
<th>Medication Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74</td>
<td>Male</td>
<td>Pill box</td>
</tr>
<tr>
<td>2</td>
<td>78</td>
<td>Female</td>
<td>Sachet</td>
</tr>
<tr>
<td>3</td>
<td>82</td>
<td>Female</td>
<td>Loose</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>Female</td>
<td>Loose</td>
</tr>
</tbody>
</table>

7.6.2 MedMaIDE questionnaire
Multiple tools have been developed to assess cognitive and psychomotor abilities of patients (especially older patients) while using medications (Elliott & Marriott, 2009). Most tools use a simulated scenario except MedMaIDE, MedTake and DRUGS. MedMaIDE questionnaire (Appendix A) gives a comprehensive and standardised way of measuring people’s capability of managing medications (Aspinall, Sevick, Donohue, Maher, & Hanlon, 2007; Elliott & Marriott, 2009; Orwig, Brandt, & Gruber-Baldini, 2006). The tool was preferred over other tools because:
i. Brief: took only 5-15 minutes to administer depending upon the number of medications the patient was on

ii. Both subjective and objective – it tests memory and psychomotor abilities

iii. Assesses patient’s own medication

iv. Comprehensive: DRUGS only assesses capability to identify (read label), access (open bottle), count and demonstrate right timing. Whereas MedMaIDE questionnaire asks names and times of medications (memory) why the person takes this medication (education) and probes post medication issues (side effects), how they are stored (organisation), how to get them (refills) and whether the labels are read each time. It also requires physically observing respondents using different forms of medication.

These components of assessment closely resemble the dialogue components of the medication management module on the robot. An assessment of these components ensures that the user has competence for three domains important for ensuring medication compliance (knowledge of medications, how to take medications, and procurement) and yields a total deficiency score. The results give insights into the cognitive capacity of an older person in specific relation to medication management. From the maximum possible deficiency score of 13, three out of four participants had 0 (zero) scores, indicating no deficiency. Only one participant recorded a score of two (as she was unable to remember or locate the expiry date of her medication).

7.6.3 Pill counts
The pills of all four participants were counted and matched with the prescription. Pill counting on the third day and the last day of the trial revealed no deviation from that expected, meaning they were regularly taking their medications as advised and the intervention did not affect the overall pill consumption.

7.6.4 Error reporting sheets
Despite reaching very close to aspirational design, the system continued to fall short on many fronts. As logs on the error reporting sheet show, each participant faced three to five serious system crashes (almost every alternate day, if not daily). Most of these errors were related to losing connections and a simple system reboot fixed the problems.

The second set of participants faced more problems than the first set especially when the robot was left switched on for two to three days continuously. Screen freezing errors had never been detected earlier under lab testing conditions. Table 7.10 shows the compiled error records from the four participants (P1 – P4). As seen there have been a range of technical errors and failures
requiring the researcher to visit the apartment of participants multiple times during the trial and even terminate the trial for one participant before seven days.
<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Error Noted</th>
<th>Action taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Day 1</td>
<td>6.30 am</td>
<td>Reminded wrong medication</td>
</tr>
<tr>
<td></td>
<td>Day 3</td>
<td>2.15 pm</td>
<td>Network connection lost</td>
</tr>
<tr>
<td></td>
<td>Day 5</td>
<td>3.25 pm</td>
<td>Screen gone blank. The robot is on but the touch screen has crashed</td>
</tr>
<tr>
<td>P2</td>
<td>Day 2</td>
<td>4.00 pm</td>
<td>Screen crashed</td>
</tr>
</tbody>
</table>
|      | Day 3  | 10.00 am  
BP apparatus was not detected by the computer  
The network connection was lost | Rebooting the robot  
The wireless data device was loose  
Had to disconnect and reconnect                        | Rebooting the robot  
The wireless data device was loose  
Had to disconnect and reconnect                        |
|      | Day 4  | 5.40 pm                                                                                                                                         | Network problem                                                                                       | Rebooting the robot worked                                                                            |
|      | Day 5  | 9.45 am  
The BP device not sending the readings  | Rebooting the robot worked                                                                             | Rebooting the robot worked                                                                            |
| P3   | Day 8  | 11.15 am  
Screen gone blank. The robot is on but the touch screen has crashed                  | Rebooting the robot restarted the screen                                                              | Rebooting the robot restarted the screen                                                              |
|      | Day 10 | 9.00 am  
Screen gone blank. The robot is on but the touch screen has crashed                  | Rebooting the robot restarted the screen                                                              | Rebooting the robot restarted the screen                                                              |
|      | Day 11 | 5.00 pm  
Screen gone blank. The robot is on but the touch screen has crashed                  | Rebooting the robot restarted the screen                                                              | Rebooting the robot restarted the screen                                                              |
|      | 6.00 pm  
The home screen is frozen, not responding to touch                      | Rebooting the robot did not fix the problem  
Took the robot back to the lab                          | Rebooting the robot did not fix the problem  
Took the robot back to the lab                          |
| P4   | Day 9  | 6.24 pm  
Loose connection of 3 G stick                      | Auto recovery                                                                                         |                                                                                                       |
|      | Day 12 | 9.00 am  
Screen gone blank. The robot is on, the touch screen frozen                          | Rebooting the robot restarted the screen                                                              |                                                                                                       |
|      | Day 13 | 6.00 pm  
The home screen is frozen, not responding to touch  
Did not send any text message  
Did not update Robogen despite medication dialogue not completed in time slot | Rebooting the robot restarted the screen                                                              |                                                                                                       |
|      | Day 14 | 7.45 pm  
Screen gone blank. The robot is on but the touch screen has frozen                | Rebooting the robot restarted the screen                                                              |                                                                                                       |
7.6.5 Robogen logs
The activity log on Robogen correctly displayed the robot status and allowed estimation of the time when the robot failed. In instances of interaction where the robot worked, Robogen accurately logged medication-related acts and assigned symbols. It also correctly logged and displayed responses to monitoring questions and blood pressure readings. The log of dialogue paths revealed participants were following appropriate routes, both for routine as well as PRN medications. Two interesting observations were made while analysing Robogen logs:

1. The participants were spending more time on entertainment and blood pressure monitoring activities than on medication tasks, often interacting/recording those more than once during the day. The observation could reflect the participant’s curiosity in exploring a new gadget and/or them demonstrating the features to neighbours or family members.

2. When the robot failed, there was no recording of medication, nor did a text message originate to alert the researcher. The text messaging was dependent upon a functional robot. The feature may need to be reconsidered in the next phase of design; it might be better to allow Robogen log records to trigger a text message instead of the robot.

Field notes captured the instances when the researcher was present with the participants during the initial introduction or after making a visit to troubleshoot and reboot a frozen robot. They indicate useful observations that could inform refining the design or validate the value proposition.

7.6.6 Video logs
Video logs were the small clips of video recorded by the robot’s camera. The recording started every time the user reached the dialogue state indicating readiness for taking medication (M3) and stopped when the user finished taking medications (M5). Four participants interacting over a week each generated 22 video logs. Some of the interactions did not generate video logs given the many instances of robot failure (Table 7.10) and users indicating having taken the medications already, without entering into detailed interaction.

Checking the video logs revealed very little useful information. Most of the times the camera was pointing away from the users and it could not be established with certainty whether the user took his/her medications or not. Figure 7.32 shows a sample screenshot.
### 7.6.7 Field notes recorded by the researcher

The following table shows the notes recorded in the researcher’s diary:

<table>
<thead>
<tr>
<th>Day</th>
<th>Notes</th>
</tr>
</thead>
</table>
| 1   | Setting up the robot for a new participant is not easy for a person without software engineering background  
Setting up the user photo required going into XML  
Setting up USB drive to record videos through an error and required deeper diving into the code |
| 2   | The flash media server required set-up because there was an action script error  
BP apparatus was very difficult to synchronize, needed to reinstall the drivers  
Connectivity is patchy at its best within the apartments |
| 3   | Participant 1 went out in the afternoon to watch a movie, hence no one responded to the reminder alarm at lunchtime. The Robogen correctly relayed a text message (to researcher’s mobile phone) that participant has missed to take his medication. The researcher called the participant later in the afternoon as per ethics protocol and confirmed the situation. Interestingly at bedtime the robot asked the participant if he had taken the lunchtime medication by himself, the response was affirmative and thereafter correctly logged into Robogen |
| 4   | The touch screen crashing problem is a serious issue and may lead to technical failure of the trial |
| 9   | The BP apparatus failed to take readings because the patient’s pulse was irregular  
BP apparatus failed to complete the reading as the cuff was leaking (we had to bring the robot back to the lab to detect this fault and then replace the cuff) |
| 10  | I made a mistake in entering date for a medication that is taken once a week (entering Thursday instead of Wednesday). Participant 3 was alert enough to detect the error |
when the robot reminded her. A wrong reminder provoked anxiety. She said: “Harry was turning red and blue and singing its song telling me to take the wrong pill.”

However, she did respond to touch screen buttons and told the robot that she has taken the pill!! Possible implications: There is a great possibility that someone else might make the same mistake in real life when medications change or a nurse not familiar with person’s routines enters information. The chances of error dosing cannot be ruled out even if a professional enters the information, therefore cross verification of entered information is essential. Despite having the choice of saying “NO! I did not take this medication”, the participant said “YES I have taken the medication” to the robot, before calling me to report the error. Interesting observations about people not giving appropriate answer or may not want to ‘displease a robot’.

Day 13 Participant 3 recorded positive response to side effect monitoring questions (dizziness and nausea) on three consecutive interactions. The results were conveyed to the village medical centre and triggered a nurse response where she visited the participant’s room to execute necessary action.
7.6.8 Questionnaire analysis

Table 7.12 shows the open-ended questions asked and the responses of four participants to those questions.

Table 7.12: Open-ended question responses

<table>
<thead>
<tr>
<th>Questions</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
<th>Participant 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>How did you like being reminded about medications by a robot compared to a person?</td>
<td>Much better. Liked robot, freedom you could go out and not having to inform anybody</td>
<td>It was great as I sometimes forget</td>
<td>I liked the robot reminders. Less intrusive than a person coming in</td>
<td>Not a problem. At least no one tells me what to do</td>
</tr>
<tr>
<td>What did you like and not like about this robot staying with you for the last few days?</td>
<td>Company, music entertainment. Nothing in particular. Technical failure was irritating, good talking point to a visitor</td>
<td>That it sometimes did not do all I required like taking my BP</td>
<td>I enjoyed the experience of taking my own BP but I found some aspects of the robot overwhelming</td>
<td>The flashing mouth was a distraction otherwise ok</td>
</tr>
<tr>
<td>Are you satisfied, overall, with the way of reminding of medications and services around it?</td>
<td>Satisfied, BP taking and data goes back to doctor make good sense. Correct prompts and questions</td>
<td>I was satisfied with the reminders</td>
<td>I liked the services it offers, I thought the music was outdated and quotes were superfluous. The reminding sound could be more gentle</td>
<td>It was OK to be reminded</td>
</tr>
<tr>
<td>Do you feel that your knowledge and/or understanding of your medications and their effects have improved after these interactions?</td>
<td>Yes, it did make you think about how you feel about it</td>
<td>Yes</td>
<td>Not really</td>
<td>No change</td>
</tr>
<tr>
<td>Can you make any suggestions for an improvement of the service that the robot provides?</td>
<td>Tailored to my needs</td>
<td>Better connections are needed to improve the technology</td>
<td>As above, the reminder sound should at least begin more softly. The reminders should be consistent</td>
<td>Gentle, not angry looking or sounding, please use better quality speakers</td>
</tr>
</tbody>
</table>
7.6.9 Semi-structured interviews
The following actors were interviewed:

<table>
<thead>
<tr>
<th>Role</th>
<th>Numbers</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial participants</td>
<td>4</td>
<td>Selwyn Village</td>
</tr>
<tr>
<td>General Physician</td>
<td>1</td>
<td>Selwyn Village Medical Centre</td>
</tr>
<tr>
<td>Manager</td>
<td>1</td>
<td>Selwyn Village</td>
</tr>
<tr>
<td>Caregivers</td>
<td>2</td>
<td>Selwyn Village</td>
</tr>
<tr>
<td>Pharmacist</td>
<td>1</td>
<td>Pharmacy serving Selwyn Village</td>
</tr>
</tbody>
</table>

Analysing the interview transcripts revealed saturation of categories and validation of the themes that had emerged earlier. Interestingly, all participants preferred to be reminded by a robot instead of a human caregiver. The participants said:

“*It does not make me feel dependent and I don’t have to pay anyone*” (P2)

“I *can choose how I want to interact with it*” (P1)

“I *don’t have to inform anyone that I am going out*” (P4)

Some of the participants enjoyed the robot’s companionship, while others treated it just like a machine, without assigning much value to its anthropomorphism. For example, one of the participants expressed:

“*Leave it with me even if it is a little inconvenience, at least it takes my mind away from my problems*” (P2).

One may infer that people will vary in their relationships to a robot. Not everyone would be able to form a relationship and respond to it. There would be people who would like a robot, while there may be others who just need a system that works and is practical to use.
“For me machine is a machine, perhaps because I have been an engineer all my life. I don’t think I can relate to it like children relate to their dolls. But I do know a lady in this building who treated her dolls like real people” (P1).

“It is unfortunate that it crashed after building its credibility” (P3). “I don’t want something that doesn’t work” (P4 responding to the robot malfunction).

All participants expressed that they would prefer a smaller robot compared to the big one walking in each day and some even considered iRobiQ was bigger than they needed.

“I want something small that I can carry with me, and does not occupy my entire coffee table… but I like the way it talks and tells me about my medicines and tells my doc about me… I am not a fan of blinking eyes and smiling face, but its kind’a cute”(P3).

In previous trials, the results questioned the value of the mobility of a robot and the results of this trial further questioned the value of the current form factor of the robot. Willingness to own/buy is considered a useful way of eliciting real appreciation of value. Some very interesting responses were received to the question, “Will you buy this robot?” Two expressed concern with the state of technology. They would buy only if it was more robust and did not crash as often. One of them saying:

“… but only if it was smaller, cheap and more robust” (P3).

One participant did not see any value in spending money for something he did not need, while another said, obviously concerned about the value for money:

“…only if my doctor recommends and my family agrees to pay” (P2).

That shows that if such a system is to become a reality, it has to prove its worth. People are not going to own it just because it is a novel, cute-looking robot. The novelty factor would wear off soon, so there must be value in it being portable, useful, consistent, stable, reliable and integrated with the larger healthcare system. It is for the future researchers to test and discover the best form factor and build a business case for presentation of information; however, this research points in the direction of fundamental principles on which it should be based.
On the other hand, Robogen was seen to be highly valuable by the healthcare providers and caregivers. The GP went on to say:

“The way I see, it has been successful for relatively healthy and capable people, now we should try it with some of my frail and challenged patients… Frailty and clinical conditions overlap, creating confusion as to what to treat and what not to treat … it would be useful to see the summary/pattern of what happened during the period between visits as it could help to make better informed decision… I must congratulate your team for it has been a fruitful journey to be able to record such fine grained data. It remains to be seen how it actually influences the quality of care” (GP).

The pharmacist and the GP agreed on the importance of temporarily eliciting a subjective responses to side effect questions and vital signs measures.

“Compliance is not always helpful for older people; it is safety that is equally important” (Pharmacist).

The GP, pharmacist and the managers agreed that the real value of such an intervention could be realised for both the patient and the healthcare system if the patients are able to keep themselves out of hospital by allowing early detection and intervention.

“I just thought in relation to …even if we can delay shifting to a rest home by a few months it could mean huge savings for the patient and the family… also maintaining autonomy for even a few extra months is extremely valuable to residents and family in addition to any cost-savings” (GP).

“Be great to be able to monitor adherence to the care plan and each of us could see what is going on. For example, the village nurse could be monitoring them regularly and flag cases for closer follow-up or call them up or even ask the pharmacist or the GP to log in and have a look” (Manager).

“Now that you have successfully tested this application with good patients of mine, I guess we could test it with more challenged patients whom I know are struggling with medications but don’t want to take caregiver assistance” (GP).
Robogen was appreciated in its potential to help smaller number of nurses/caregivers to care for a larger number of people on complex medication regimens.

“If we offered a medication robot as a service, I don’t have to run around and check how everyone was doing with their medication. I can just go to those who are having problems that day” (village nurse).

Table 7.13 captures the results of open coding of interview transcripts.
<table>
<thead>
<tr>
<th>Categories</th>
<th>Codes/concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Freedom</td>
</tr>
<tr>
<td>F2</td>
<td>Support memory</td>
</tr>
<tr>
<td>F3</td>
<td>Readiness</td>
</tr>
<tr>
<td>F4</td>
<td>Companionship</td>
</tr>
<tr>
<td>F5</td>
<td>Entertainment</td>
</tr>
<tr>
<td>F6</td>
<td>Intrusiveness</td>
</tr>
<tr>
<td>F7</td>
<td>Family involvement</td>
</tr>
<tr>
<td>F8</td>
<td>Politeness</td>
</tr>
<tr>
<td>F9</td>
<td>Disappointment with failure</td>
</tr>
<tr>
<td>F10</td>
<td>Utility</td>
</tr>
<tr>
<td>F11</td>
<td>Feedback</td>
</tr>
<tr>
<td>F12</td>
<td>Safety</td>
</tr>
<tr>
<td>F13</td>
<td>Nutrition</td>
</tr>
<tr>
<td>F14</td>
<td>Knowledge</td>
</tr>
<tr>
<td>F15</td>
<td>Communication</td>
</tr>
<tr>
<td>F16</td>
<td>Portability</td>
</tr>
<tr>
<td>F17</td>
<td>Value</td>
</tr>
<tr>
<td>F18</td>
<td>Variety</td>
</tr>
<tr>
<td>F19</td>
<td>Mobility</td>
</tr>
<tr>
<td>F20</td>
<td>Flexibility</td>
</tr>
<tr>
<td>F21</td>
<td>Collaboration</td>
</tr>
<tr>
<td>F22</td>
<td>Empowerment</td>
</tr>
<tr>
<td>F23</td>
<td>Integration</td>
</tr>
</tbody>
</table>
These categories were then aligned to the themes that emerged earlier and once again a similar pattern was observed. Saturation of themes further validated the theoretical elements that had emerged in the earlier iteration. However, the categories generated in this cycle allowed some more themes to emerge that were not exactly relating to usability, but were adding a layer deeper than the tool just being usable (Table 7.14). Reflecting on themes of enjoyment, emotional response, desire to make it multi-functional and personal in light of the data, it emerged that ‘Engagement’ would be a more apt theme than just usability. Being usable is a technical measure or meeting basic design needs, but the concept of engagement adds another layer of emotional interactivity and likeability, that builds upon usability. If a system is not usable it cannot be engaging, but an engaging system must be usable.

Table 7.15: Category-theme alignment and emerging theory

<table>
<thead>
<tr>
<th>Categories</th>
<th>Themes</th>
<th>Emerging theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Companionship, Utility disappointment, Nutrition, Portability, Value, Variety, Mobility, Flexibility, Entertainment</td>
<td>Evokes emotion, Multifunctional, Enjoyable Usable</td>
<td>ENGAGEMENT</td>
</tr>
<tr>
<td>Family involvement, Feedback, Collaboration, Communication, Integration</td>
<td>Share information</td>
<td>COLLABORATION</td>
</tr>
<tr>
<td>Safety</td>
<td>Privacy and security, Medication safety</td>
<td>SAFETY</td>
</tr>
<tr>
<td>Freedom, Politeness, Support memory, Readiness, Intrusiveness, Knowledge, Empowerment</td>
<td>Respect sensitivities, Support performance, Not disempowering, Build capacity</td>
<td>EMPOWERMENT</td>
</tr>
</tbody>
</table>

It may be interesting to note that many of the themes directly emerged from the data in this phase of research: safety, collaboration and empowerment. But new themes that emerged this time, reflecting saturation of data and modification of the theory that had emerged earlier. Testing of theory in this cycle and its refinement added its richness and perhaps generalizability.

The above observations and analysis presents a snapshot of the challenges and learning involved. The result validated many assumptions but also indicated the need for further refinement. Though we did not get everything right in this phase of research, a method and a pathway to keep moving forward was identified.
7.7 Discussion

The current cycle of action research allowed many features to be incorporated that were learned over previous iterations. Robot’s utility was tested in a very small cohort of four participants who tried the robot in their apartments over a two-week trial period. Two participants tried two robots simultaneously for one week. Most of them completed the sessions, except in the situation where the robot malfunction made it difficult to continue. Participants picked up quickly what was expected of them and learned to use the system in one or two sessions. The intention of this trial was more to seek participatory feedback than to test efficacy. Since concerns about exposing high-risk patients to untested intervention were raised by the ethics committee, fully capable participants, who could detect flaws with the design, were preferred to those who could be exposed to risks posed by possible and unknown design flaws. The participant’s cognitive capacity was established using a MedMaIDE questionnaire, where most of them had no or minimal deficiency. The safety concerns were further addressed by repeated pill counts, and no discrepancy was found throughout the trial period.

Objective measurements of vital signs to complement subjective reporting of symptoms could add to medication safety as well as indicate adequacy of medication dosing. For example, if a doctor could see subjective reporting of dizziness after a particular medication was started and lower blood pressure readings displayed on the same page it would be easier to correlate and make a prescribing decision. Therefore, in this iteration Blood Pressure monitoring was added as a component of side effect monitoring.

The entertainment module was added in AR cycle 4, taking cues from AR cycle 3, where it was observed that rating for the medication management module improved after playing interactive cognitive training games and watching videos on the robot. It aligned with the theme of engagement where coded data indicated fun factor and entertainment as parts of the emerging theme. The association that humans tend to develop with technology could be enriched if the perceived symbolism could connote pleasure and give users a sense of control at the same time minimising connotations of chore, dependency or being instructed. In future the entertainment module could include interactive media, family members sharing photos, infotainment, rehab exercise or wellness applications or education, but for now it was limited to music videos, jokes and inspirational quotes. Reducing user anxiety while dealing with complex healthcare tasks could contribute to continued acceptance of technology over the long term, an observation that remains to be affirmed.
Reflecting on the findings in light of the literature presented earlier around user empowerment, several observations could be made. The users appreciated being given a sense of control and confidence when they found themselves programming the robot reminders and handling it independently. Improving their knowledge and understanding of medications (reported by two of four participants) furthered the empowerment agenda. The observations about self-measurements of vital signs and not having to depend upon the village nurse or go to the clinic and the comments about not depending on anyone to come and help them were very important. Not having to tell anyone before going out, no one telling them what to do, and a preference for being reminded by a machine which they programme and control themselves rather than by a human, clearly show the desire for and value of user empowerment, and how the proposed intervention could contribute to it.

In recent times the value of engagement has been realised and tools have been designed that measure engagement in addition to standard ‘usability testing’ (O’Brien & Toms, 2010). However, the small size of the study, limitation of resources and time constraints limit the scope of this thesis to generating theory and leave it to future researchers to test and quantify value of engagement and empowerment on medication related outcomes.

In the earlier studies the private spaces of elder apartments were found to be not conducive to the safe and effective navigation of the mobile robot. In the meantime, a static robot that maintained key look-and-feel/interaction characteristics could sit near the kitchen or dining area where residents usually keep their medication, with water within reach. In the context of the larger project, which is concerned with a mobile robot, the use of a static robot was somewhat incongruous. It was affirmed that a timely detection of side effects and report to the clinical staff for appropriate clinical decision-making was valuable. An enhanced sense of control and safety by residents around medications was validated. Doubts about older people’s ability to handle a robot independently, concern about accuracy of information, accuracy of subjective reporting, anxiety caused by false alarms and asking about side effects were proved to be unfounded. The potential of its impact on clinical decision-making and collaboration around medication use was appreciated. Subjective reports about improved medication knowledge and a sense of self-efficacy in medication management and associating positive entertaining engagement with healthcare tasks was a valuable learning.

Since this was the first iteration of the customisation module it is unsurprising that some users had minor difficulty using it requiring the researcher to assist. There is room for improvement
in further iterations of this module, however, the observation that older people (even those with limited computer experience) can set up their own device after one or two guided sessions is significant. It supports the theme of empowerment where user felt ‘in control’ and in ownership of what the technology represents. The ability to change robot behaviour shifts the perceptions from control to collaboration. However, there is much more to the theme that can be developed and tested further.

There were issues with system stability and problems with Adobe flash player which crashed the user interface. Data transfer and connectivity over 3G was inconsistent and some minor issues with system design came up that could be easily fixed. Despite the promise, the currently available technology is still evolving and is far from being stable, and unobtrusive.

7.8 Chapter summary

This final phase of AR aimed to test safety, efficacy, functionality and acceptance of a smaller Static Robot for Medication Management Services (StRoMMS) within the residents’ apartments, without the physical presence of the researcher. The robots were successfully deployed in the apartments of four residents of the ACF, two at a time. All four residents successfully set up the robot and were able to comprehend/follow instructions. They also successfully navigated through medication tasks and other features. User feedback on the overall experience, appropriateness and satisfaction with the intervention was collected and helped to generate valuable qualitative data. Other actors – namely the physician, pharmacist, caregivers and managers of Selwyn Village – found the Robogen dashboard to be highly useful. This cycle of AR successfully completed the design of the medication management module to meet most of the user requirements noted in earlier cycles. The cycle also tested as well as refined the theory. The theme of usability was changed to engagement as a higher level abstraction, themes of safety, collaboration and empowerment were also tested that held valid against the data. The design of the module and the development of the theory mutually supported each other arriving synergistically at the answer of the two research questions with which this research journey started.
Chapter 8: Summary and conclusion

Those responsible for healthcare delivery systems in many developed countries, including New Zealand, are concerned about the ageing of populations and implications of increasing dependency ratios on healthcare delivery. Simultaneously, the momentum of self-motivated, capable, relatively healthy, engaged, and technically savvy, self-determined older adults, desirous of living independently, is also building up (Jacobzone, 1998). Promoting self-care and community-based care is gaining strategic focus to contain costs, improve quality of life and prevent avoidable hospitalisations (Bodenheimer et.al, 2002, Chodosh et.al, 2005). Medication management is a significant component of self-care, which improves health status and clinical outcomes if performed well (Orwig et al., 2006, Lumme-Sandt & Virtanen, 2002). Information technology plays an important role in enabling self-care. By helping older people compensate for physical and cognitive limitations through appropriate design, technology can lessen their sense of vulnerability and dependence on the healthcare system (Borne, 1998). Tools that enable older adults to gain enough cognitive and emotive capability to engage effectively in self-care and especially in medication management are continuously evolving. However, despite rapid progress, significant limitations continue to exist not only in the design of technology but also in addressing implicit psycho-social implications that underpin its adoption in daily life. Social robotics is being explored as an option to support self-care for the elderly, but not much is known about how to best harness its potential.

8.1 Research assumptions

The following assumptions formed the basis of, and added significance to, this journey:

1. Quality use of medication is important for older people and, if managed well, it improves quality of life.
2. The current state of medication management for older people living in an ACF is inadequate and poses high risk for hospitalisation and medication-related mortality.
3. Automating medication management is a complex task; hence has not yet been significantly addressed.
4. There could be a high demand for such a solution that reduces cost of care and improves quality of life.
5. Getting the design right is not feasible through a standard software requirement gathering and coding approach.
6. Information and Communications Technology (ICT) tools to address complex and sensitive healthcare issues can be developed along a flexible design framework that allows uncovering of implicit and explicit elements embedded within ground reality.

8.2 Research environment
This study was conducted within the sponsorship and resources made available within the Healthbots project and its collaboration with Selwyn Village. It is the real life exposure of research that makes its results more relevant and of practical importance. On the one hand, being bound to a larger project plan with finite resources had its limitations, but on the other, it provided opportunities for multidisciplinary teams to come together and share expertise. The researcher’s mediation allowed healthcare providers, specialists, managers, caregivers, family members, older patients and pharmacists to interact with system architects, software programmers, robot manufacturers, vendors and business managers. It is this rich interaction that allows translational research to effectively solve real world problems.

8.3 Research overview
The principle goal was to investigate issues concerning the development of information technology-driven medication management support for the elderly. Of special interest was the use of a robotic platform to host and present such a system. This research was carried out to meet the growing need for quality use of medication by the elderly to address the inherent risk and inform the information technology-assisted self-care process at large. The research methodology employed a combination of action research, grounded theory and participatory design (AR-GT-PD) principles as core methodologies depending on a variety of qualitative and quantitative methods of data collection. The research process started with an ethnographic study to inform the context of the action research, which was then conducted over four iterative cycles. While carrying out design and development, the difficulties in creating a usable, collaborative and safe closed-loop medication management system were revealed. Attempts to perfect a design in a complex and sensitive scenario required four iterative cycles and yet much still remains to be achieved. However, this research has opened the door to a systematic enquiry and design process for a complex and clinically relevant problem.

8.4 Research themes explored
The journey explored and discovered the finer nuances in the context of medications and the elderly, particularly:

1. Relationships between the personal use of medications and a dynamic social environment involving multiple actors were explored. Implicit need for collaboration
and dynamic interaction was found to be an equally important component within a seemingly isolated process of self-management of medications.

2. It uncovered a dynamic and complex set of variables that personalise medication use, especially the need for knowledge and concerns about medication safety. These requirements far exceeded the scope of a simple reminder alarm.

3. The possible role of delivering a medication management module through a robot-mounted touch screen was explored. It was discovered that an ideal medication management module cannot be delivered independently on a robot or on a computing device. A standalone system does not fulfil the entire range of needs. There is a need for a closed-loop system, where the robot/device could work in synchronization with a web-based electronic medication record. The EMR in turn allows remote interaction with a range of healthcare providers, caregivers and family members.

4. The researcher was immersed in an environment reflecting the subjective reality of older people while using their medications and also while interacting with the proposed solution. Observations informed a process of matching the development of a prototype to the evolving theoretical framework, with some success. New components to the process of medication management were discovered, namely empowerment, engagement, collaboration and safety. However, the design remained short of meeting the entire range of needs, learned many new lessons and opened new avenues of research that could further inform development of a complete picture.

8.5 Finding answers to the research questions
The two research questions raised in this thesis were:

1. **What is the theory underpinning appropriate design of technology to enable older people to better manage their medications?**

2. **Can an automated medication management solution be developed successfully on a robot while being informed by the theory of automated medication assistance?** Which later got changed in Chapter 6 to: **Can an application be designed that empowers its users to engage in self-care that is usable, builds safety and facilitates collaboration?**

The answers to these questions were discovered in four iterative Action Research Cycles, blending Grounded Theory to uncover theoretical implications and Participatory Design principles to determine the functionalities and features desired of the system.
The initial set of data collection and its analysis pointed towards the need of theoretical sampling and further data collection. The emerging categories were further enriched by two more cycles of data collection, firstly to validate saturation of the categories and secondly to test the validity of emerging themes against a fresh set of data in a slightly different context. Embedded within the process of data collection and analysis was the perception, theoretical sensitivity and experience of the researcher. On saturation of categories, axial and selective coding allowed four salient themes to emerge, validate and refine. Empowerment emerged as the core-category along with engagement, safety and collaboration.

The theory derived can be stated as:

“A successful automated medication assistant for the elderly should effectively engage with and empower its users to self-manage their medications safely while collaborating effectively with others who care for them.”

Reflecting upon the interplay of four themes, empowerment emerged as the core theme around which the other three elements revolve. For example, engagement invites the user to interact effectively with the system; collaboration with providers not only empowers the user by allowing him to have his/her say in decision-making but also encourages confidence and trust. Balance between empowerment and safety is important too, because empowerment brings responsibility, and premature exercise of choice can also be risky especially if the process is not mastered or capabilities are limited. A safety net would be an essential backdrop while retaining a position of control and interacting with an assistive technology (Tiwari, Warren and Day, 2011).

Designing an application that lives true to this theory was more challenging than anticipated. Having started from the assumption of designing a simple reminder, the final outcome was far more feature rich and complex. The medication management module utilised dual output (written display and voice) delivery of interactive dialogues through a touch screen computer mounted on the robot, which communicated in real time with a back-end web-based application (Robogen). Iterative improvements to the design finally led to a smaller, static robot which enabled elders to programme their preferences and use it independently within their living quarters. On the one hand the dialogue system simplified the complex prescription information for lay users, and on the other hand, Robogen successfully dashboard displayed patterns of user performance in clinically relevant terms and formats.
Figure 8.1 shows a prescription in the language of a clinician on the left-hand table (note the jargon) and the ways in which dispensed medications could be organised (boxes in middle). On the right-hand table it displays dialogues in the language of the patient that converts a complex prescription into a simple set of instructions that were originally intended but not translated.

Separating the patient interface from the provider interface, yet keeping them linked, seemed to be a good way to reconcile user preferences with the prescribed regimen. Mutual understanding of terms of reference is the backbone of effective collaboration between patient and provider given their respective vantage points.

The dialogue system and Robogen were designed to be platform neutral, meaning they could run from any touch screen tablet or desktop computer, but delivering them through a robot offered some interesting advantages in terms of engagement. The value of anthropomorphic presence and embodiment of a computer into a human-like shape is an evolving topic of research, but personalisation of information, empathetic communication, building knowledge and skills and keeping the user in control at all times while supporting them is a delicate balance. The evaluation of application with test subjects affirmed that this balance was successfully achieved to a large extent. Handling of potential error situations, monitoring for side effects, measuring vital signs and informing caregivers and clinicians in real time add immensely to the safety of medication use.
The results validate capabilities and preference for self-determination in the use of medication. The older adults could complete the tasks successfully, felt confident while using the system and actually found it easy and simple. Although there were a large number of errors, most of them seemed possible to be addressed by making the application more robust. Ability to complete the interaction and reporting high user friendliness of the system supports the hypothesis that older people can successfully navigate through a touch screen-based system to assist them with a complex self-care task such as medication administration. It is also possible to unobtrusively query clinically relevant symptoms and side effects to gauge the adequacy of symptoms control or early identification of undesirable side effects. Just providing an option to access drug information may not be the best way to build medication knowledge and skills in older people, who may be interested in it but fail to select the option while their attention is focussed on other activities.

Currently available solutions rarely address the need for putting the user in control. Instead, implicit assumptions are to assist ‘a forgetful, passive and dependent’ user. The design presented here turns the other way and asserts that building knowledge and sharing complete information at the point of active use is a better way of supporting medication management. Reminding for refills and appointments is expected to support continuity of medication possession (Mabotuwana & Warren, 2009). Making healthcare tasks fun and associating them with entertainment takes away the feeling of chore and monotony, thus transforming the association between medication and health. Probing for side effects and objective measurements of vital signs also gathers equally important corroborative data to link medication usage with therapeutic efficacy. Though this research tested only blood pressure measurements, there is no reason to believe that other self-monitoring equipment cannot be combined with medication management applications synergistically. However, even more important than measuring is plotting this data temporally alongside the medication usage pattern. The two together would give clinicians powerful fine grain information, potentially influencing prescribing decisions and hopefully improving prescribing behaviour. Therefore the design not only empowers the patient but also the provider, with a vision to improve the overall quality of eldercare.
It can therefore be concluded from the results of four AR iterations that: The design of the application presented here was engaging and potentially empowering the users by giving them knowledge and confidence, enhancing safety and quality of medication use not only by preventing potential errors but also by promoting effective collaboration between users, prescribers, pharmacists, family members, caregivers and managers of the aged care facility.

In none of the cycles were mobility or the robotic aspect found to be critical to the achievement of the desired targets. Rather, the aspect of social robotics was found to be more useful in terms of promoting engagement and bringing a sense of novelty or fun. The use of a touch screen was definitely a useful function that enabled people to interact with the computer system. The reduction of screen size from an 11-inch to a 7-inch screen did not alter the usability of simple care dialogues coupled to ambiguous choices. The information handling capabilities of Robogen, the design of the dialogue system to reflect user preferences and address a wide variety of scenarios contributed to the success of the design.

8.6 Meeting research objectives
This section lists specific objectives of the research outlined at the beginning and reports on the fulfilment of those objectives.

**Objective 1:** To understand the context of an aged care facility in New Zealand and the healthcare setting within which a robotic medication management support system would function, and to determine the feasibility of implementing such a system.

An ethnographic study (Chapter 3) explored the processes around medications within Selwyn Village and identified the actors involved in those processes. The initial set of discussions with the actors and coding the data (Chapter 4) informed contextualization of the prototype design. A set of interactions with potential users (Chapters 5 and 6), informed the functionality and features that were desirable and feasible within the space of independent residential apartments.

**Objective 2:** To review the literature assessing the best practices in human computer interaction for older people, automated dialogues in healthcare, and issues around the quality use of medications.

The literature review sections in Chapters 3 to 7 covered the essential topics outlined and demanded further exploration at each stage.
Objective 3: To collaboratively design and develop an application that would integrate with the residential ACF environment as well as with the wider healthcare system.

Objective 4: To investigate the views, perceived values, and performance of older users while simultaneously using the designed application to explore the impact it could make on the clinical workflows, decision-making, and quality of care provided by healthcare providers.

Objectives 4 and 5 were addressed through the principles of participatory design that grounded the entire development process within the reality of elder residents of an ACF served by doctors and pharmacists working within the healthcare delivery system in New Zealand. Though the research stopped short of objectively testing the impact on clinical and system outcomes, the qualitative data did give a clear direction to designing efforts within the context of improving the quality use of medication. Indeed, while outside of the scope of the present thesis, the first such clinical trial extending from the work reported herein – with a larger number of robots and human subjects – has been running concurrent to the thesis write-up.

Objective 5: To inform the commercial development of the solution and justify funding for this research.

The work completed during this thesis is part of a multifunctional robot project and involved Uniservices, the commercialisation arm of the University of Auckland, which places the value of this research in light of its business strategy. The commercial partners – including the robot manufacturers (Yujin Robotics), a New Zealand-based personal health record vendor (Lifetime Health Diary), blood pressure monitoring device (PulseCor) and medication compliance monitoring device (Nexus 6) manufacturers – have already been taking an active interest in the outcomes of this research.

8.7 Refuting or validating research hypotheses

The hypothesis was affirmed that use of robotic technology by older people to self-manage their medications could be defined largely with the help of a theory. In particular, successful promotion of quality use of medications will constitute more than simply providing reminders.

The hypotheses that an application can successfully be designed to satisfy theoretical elements and practical usability for older adults who would see value in such a proposition were also affirmed, where most participants successfully completed the interaction and ranked it positively.
The hypothesis that hosting of interrelated modules on a social robot has a utility beyond reminders or passive pill boxes was also held valid. In AR Cycles 3 and 4, direct observations and analysis of field data clearly indicated the value of a social robot and related application (such as vital signs monitoring, entertainment, and cognitive training exercises) in enhancing the ‘engagement’ value of the medication assistant.

The Robogen log records of medication use data alongside blood pressure values also contributed to the clinician’s perception of utility.

8.8 Research limitations

Despite making significant advances, there were numerous limitations. Firstly, there were resource limitations. We could only test the applications on the robots that were available to us. The limited choice of hardware platforms, and often unstable software environments, curtailed the scope of our exploration. Significant bugs in the Adobe flash system which the parent company has not been able to fix were discovered and reported. Secondly, the programming resources were limited. Having access to professional designers and software engineers would have produced completely different results compared to having to share the programming skills of software engineering students and postdocs. Also, the funding constraints and multiple concurrent projects limited the time that the software engineers could spend on designing the module. Thirdly, this research was limited to the goals of the Healthbots project and deliverables within a larger project framework. Had this been an independently funded research, not limited by research constraints and partnerships with the University, the outcomes would have been different.

This research also faced the limitations of technology. Though using a robot with a touch screen and a dialogue system seemed to be a good idea, the science of human robotic interaction is still limited. The ability of software systems to handle multidimensional demands intelligently and apply them in the context of medications needs to be developed further. Though the users indicated a complex set of needs that could be framed in a theoretical framework, to translate that framework into a design remains an on-going learning process. During the research the system crashed on multiple occasions, limiting the perception of the users. The face recognition did not work as effectively as we had hoped. The wireless technology is still not widespread. Despite the ubiquitous use of mobile phones and wireless connectivity, it continuous to remain inconsistent and unreliable for medical-grade applications.
This research was also limited by the number of robots we used (one or two) and the number of subjects that were exposed (four to ten on each cycle). Moreover, data collection was limited to one facility; however, the site was considered to be a representative enough to yield significantly generalizable information. The results of exposing a larger number of people in multiple locations with multiple robots might have yielded different results.

This research was limited in its ability to fully demonstrate the development of a system aligned within a theoretical framework. We did establish the usability of the system but will need to run a long-term clinical trial to establish the value of safety and collaboration and its impact on clinical outcomes. Similarly, the aspect of empowerment needs to be objectively tested and understood in. Research has not been able to fully appreciate and explain implications of user empowerment on self-care, engagement with healthcare tasks, and the long-term use of technology. It has also not established the most desirable form factor or even the engagement principles that could determine long-term usability.

8.9 Contribution to knowledge, education and practice

This work contributed to a successful demonstration of three complementary methodologies that could be successfully blended to create software applications. For the first time, action research has been blended with participatory design and grounded theory to develop an information system. This methodological combination of AR-GT-PD could inform future researchers to develop technology solutions in difficult, complex and high-risk healthcare scenarios.

This research discovered a valid theoretical framework underpinning an ideal, automated medication management solution. The theory was not only grounded in the data but also was validated through the literature as well as against real life situations in the final iteration. The elements of the theory of automated medication assistance – namely engagement, empowerment, safety and collaboration – could be considered to be generalizable into situations beyond medication management (e.g. self-care, home monitoring) for relatively younger people, and beyond robotic applications. However, this hypothesis remains to be tested. The findings clearly showed that the social perceptions of automated assistants could very well encourage or prevent their use. If the design ignores user empowerment, people will fear the opposite (the residents & staff were all worried at first about being cared for/replaced by nursebots!), if the agent is monotonous, does not actively involve healthcare providers and assures everyone that it is safe to use, such a system is less likely to succeed in real world.
The research also demonstrated a number of facets of practical use for technology-enhanced healthcare delivery:

- It established that older people can gain mastery over a task as complex as medications using a dialogue system delivered over a touch screen. It also established that older people can independently handle such a system on a robot. We established that the system was simple and useful without posing any significant risks, at least within a short span of time in relatively independent and cognitively capable older individuals. Moreover, this research established an interactive development of the architecture of an information and technology tool using flexible design principles in a user-centric manner.

- This research also opened a window to the future of healthcare robotics, mainly in social and assisted roles, where robots can work as partners that empower and engage with humans at any age without discrimination or judgment. Earlier research on social robots to assist older people such as Pollack et al. (2005) suggested use of AI algorithms to prompt intelligent reminding, but this thesis adds that there is more to medication assistance than just reminding (e.g. user identification, engagement, collaboration, safety and empowerment). They also suggested that the robot holds necessary medication information because a caregiver manually programmed it, whereas we argue that a manual mechanism would have difficulty coping with frequent prescription variations, PRN medications and giving feedback to clinicians and may run the risk of becoming outdated or a source of iatrogenic error. This research addresses the bigger picture of closed-loop medication management and role of web based access and updating via Robogen. On the other hand the approach of Kidd and Breazeal (2008) with a weight loss coach robot had a primary focus on relationship management which could be refined on the basis of theoretical framework presented in this thesis. The role of safety features, real time collaboration and deeper understanding of empowerment and engagement may be useful extensions. Media driven negative perceptions of robots (e.g. invading or controlling entities of sci-fi movies) could very well prevent their use; if we don’t show empowerment, people will fear the opposite. An example was clearly evident during the trials where some of the residents and staff were worried at first about being cared for/ replaced by nursebots. Continuing comparison with Pollack and Kidd’s work, this thesis suggests that some additional ability be built within dialogue systems that enables handling of a variety of highly tailored and specific prompts (e.g.
medication names, forms, organisation, preferences, timings etc.) instead of assuming people to be passive consumers of medication. The system should also enable handling of dynamically changing goals determined by other actors (e.g. prescriptions by different prescribers and corresponding changes made by pharmacists) for this particular group of users. Moreover it may be worth considering a bigger role for human caregivers to be in the loop and be available for real time assistance and support while thinking about elders. This thesis also suggests that the value of a social robot may be better contextualised within an inter-personal social process rather than a robot (such as a coach) appearing to substitute human relationships.

- This thesis further suggests that adding of non-health-related features may minimise association of robot with ill health or personal limitations (e.g. obesity). Understanding and addressing metacognitive meanings assigned to human robot relationships may be important for building time extended relationships. A multi-functional robot with entertainment and engagement features makes it more engaging for healthcare tasks.

- This research also established that side effects could be assessed subjectively and objectively and linked to medication use records. Contrary to concerns, prompting the elderly about such side-effects was not found to raise unnecessary anxiety or adversely affect the medication use. This research also showed that education about medications becomes more meaningful when it is personalized, delivered in smaller sized chunks and delivered as a direct dialogue instead of, as is presently common practice, in a passive leaflet or a passive web page.

- A medication management robot should have additional hardware built into it, like vital signs apparatus, memory stick, 3G wireless communication stick or Wi-Fi sensors etc. Having too many separate and loose parts makes the system unstable.

- There have been some potentially important lessons learnt with respect to limitation of a robot or automated medication assistant and when it may not be a preferred choice. For example, situations involving:
  - Refusal or non-acceptance of the device by the user or his/her family members
  - Significant cognitive difficulty that may pose additional risk and necessitates human support
  - High risk medications (like warfarin) where technological errors could be life threatening (though this needs to be tested further)
  - Non-availability of stable and reliable mobile or Wi-Fi network in living quarters
• Malfunctioning devices/robot
• Moreover, in our project the research environment supplemented the ACF infrastructure and management; the importance of sound organisational and clinical support cannot be underplayed. In situations where backup support is missing there would be further situations where a robot could not be left in isolation. Before thinking about deploying robots:
  ▪ The developer of an ACF needs to put in place basic infrastructure that enables remotely supported self-care, such as Wi-Fi or mobile network, environmental sensors, trained caregivers with mobile phones and/or a medical centre equipped to respond in a timely fashion.
  ▪ Sufficient training and buy-in from doctors and Pharmacists to take ownership of creating and maintaining medication information up-to-date and personalising it for each individual.

• The research discovered limitations of data extracted from standard prescriptions or Personal Health Records (PHRs) and identified additional data elements that need to be populated if such an automated dialogue system is to work meaningfully. To bridge these data gaps a manual process was enabled into Robogen that allowed tailoring to suit the needs and preferences of a particular patient. However, moving forward, if such a system becomes a reality then the competence of the person entering data into Robogen will become important. There are chances that incorrect or incomplete data entry could influence dialogue content and could be a potential source of errors.

8.10 Implications and future of research directions
This research has implications for the development of a research methodology and a flexible framework to design automated assistance for older people.

• It opens a window to the implications of using robots in managing medications and highlights some important themes. This research only briefly touched upon the areas of user empowerment and engagement as behavioural strategies to impact health status; for example, defining closed-loop systems and supporting the social structure around medications. The theory of automated assistance could be tested in other scenarios and its impact on the long-term performance of self-care tasks ascertained. The small sample size limits scope to be able to do statistical analysis of responses. Once a theory and prototype has been created using qualitative methods (such as presented herein) one
could validate them further using a positivist approach (including clinical trials). The thesis presents more fundamental research that addresses important issues highlighted in the literature around medications. There are opportunities to study the impact on clinical outcomes and prescribing behaviour of physicians, (e.g. the reporting of side effects (dizziness) in light of a medication use pattern could contribute to a change of medication or reduction of dose). If fine grained feedback changes clinical behaviour, then this would be a significant step towards improving the quality use of medication and its downstream influence on morbidity and hospitalisation. Some possible mechanisms by which this application could help reduce medication related morbidity and/or hospitalisation not only through possibly improving adherence but also by detection of side effects and call for assistance

- There is an opportunity to build a clinical support system into Robogen that not only verifies the prescription for interactions between medications, but also matches them with concurrent use of supplements, clinical conditions and patient responses, and presents to the prescribing physician the most appropriate course of action.

- There are further opportunities in development for enriching the dialogues, enhanced presentation (e.g. with video), miniaturised robots with engaging features, and further refined behavioural strategies to improve the system’s performance.

- The research also indicates opportunities to refine technology. The hardware features that are required for a constantly ‘switched on’, accurate and stable apparatus have not been perfected. For delivering such interventions we need to have computers that can work over months or even years without developing hardware or software problems. There is also an opportunity to further refine network connectivity to make pervasive and ubiquitous computing a reality.

- There are opportunities to synchronize medication storage and dispensing devices with a system such as presented here.

- Some further research could be conducted to integrate a medication management module with existing tele-health and tele-care services.
  - Currently existing tele-monitoring solutions only look at vital signs and subjective responses. Medications are the most important part of the care plan and remain to be integrated with the tele-health solutions currently available on the market. For example, if a clinician was presented with home monitoring
blood pressure data, viewing it in the light of antihypertensive medication compliance data might lead to better informed clinical decisions.

- The theoretical elements presented in this thesis may also have implications on the design of home-monitoring technologies. The research in tele-health space is focused on ‘monitoring’ the patients at home, but a lesser emphasis seems to be placed on building an engaged, empowered user collaborating with healthcare professionals for self-care. Striking a balance between self-responsibility and shared responsibility with carers and providers remains to be resolved.

- A robot carrying a video camera and touch screen could easily enable telecare and provide visual access for care providers from a remote distance (e.g. in case the patient seems to be having problems and needing assistance)

- In future, the educational modules presented in this research could become interactive videos and e-therapy or problem-solving tools that continue to enhance the physical and mental health and overall well-being of users.

- Technology for robotic healthcare assistance could be further developed by:
  - Improving the methods of user recognition through more stable, secure and reliable devices for user identification.
  - Integrating context awareness. For example, the robot could learn from smart home technology that tracks preparation and cooking of a meal, which in turn could link medication reminding to meal timing, e.g. ‘after breakfast medication’ reminder could be issued exactly after breakfast whenever the user has it, instead of 8:15am every day. It has been shown that context-based reminders are more effective then clock-based reminders (Hristova et.al, 2008).
  - Integrating other methods to objectively confirm positive intake of medication. For example, the association between the hand, the medication bottle and the face could be interpreted as medication intake or other sensor-based solutions could be integrated to make it more robust (Huu Hung et. al, 2010).

- The possibility of delivering medication management support using alternative technologies such as tablets and touch pads could be explored. It is possible that as the hype and novelty factor of the robot wears out and task mastery is gained the user responsiveness would tend to even out across platforms as long they remains user friendly. It remains to be tested, however, how much a robot contributes towards long
term engagement. The researcher has favoured undertaking prototype development in a manner that is platform neutral

- There is the opportunity to avoid manual data entry into Robogen and directly extract data to prompt dialogues from a cloud-based medication record. To enable such a system would require developing detailed prescribing data sets as well as integrating with a drug knowledge base to engineer a knowledge management system where algorithms can be developed to automate more complex processes. But for the time being it seems a distant reality. For example, if the education module has to create a personalised dialogue to inform a patient the reason why a particular medication is prescribed - then the knowledge management system needs to understand and address complexities around medications that could be used to treat multiple disorders or multiple drugs can be used for a single or related condition. It may therefore be best left to the clinician to customise dialogues or to decide what information applies to a particular patient, The GP or other lead clinician would always need to verify if not tailor the information in the first instance; thereafter a visiting nurse or even community pharmacist, could have the option to monitor and/or modify selected elements.

- Further research could further define the boundaries and limitations of automated assistance. It would be useful to understand about situations where automation of support may not be the best intervention and when human caregiving would become indispensable. Further explorations in an open environment are likely to reveal such determinants and determine market forces that would shape practical application of similar technologies. Reflecting on these ideas it appears there should be a window, or niche, for most effective use of such automated assistants: relatively healthy and fit individuals may not need any assistance, and very sick or challenged patients may not be able to use it at all. There will be people somewhere in the middle who would need such assistance. Cases within this window may include patients: who are on multiple medications in complex regimen; with non-availability of medication packaging system in their community; living in rural/remote areas and desirous of maintaining independence in early stages of decline in cognitive faculties, or; in temporarily challenging situations such as post hospitalisation or travelling away from supported environments. One could ponder: in the face of progressive loss of cognitive faculties, where do we draw the line and how do we determine when the person should stop attempting self-support and accept dependence on human caregiving? Indeed it is a thin
line between accepting dependence and maintaining independence which is very personal, and technology such as explored herein could at best prolong the period of independence. As one of interviewed doctors pointed out (Page 256), if such technology could delay institutionalisation by even a year or two it will reflect substantial gains. An interesting observation about a participant (Page 152) who had significant memory deficits and was served medications by her husband was illustrative: watching her pick up skills and progressively improve identification of correct medication and self-administering them (with robots assistance) raises the thought - perhaps the patients that we assume to be cognitively deficient may actually be under challenged! Challenging an ageing brain to cope up with complex tasks (such as medication management) may actually support retention of cognitive faculties. An engaging application like the one presented in this thesis could prompt elder people to ‘use it’ whereas passive pill popping from a blister pack or sachet may encourage them to ‘lose it’. There is an opportunity for supporting limitations and building (both sensory and cognitive) capabilities, nonetheless system should be designed to detect its decay in timely fashion by others. There were a number of strategies used in this application, including:

- Prompting to confirm the date and time, find right medications and read labels. Inability to locate or identify correct medication would trigger an automatic text alert

- Prompting to prevent double dosing by letting user know if they have already taken their medications or the time gaps between two doses was not optimal. In the case where the user continues, the caregiver is alerted

- If the user misses scheduled doses, or fumbles with system e.g. multiple forward backward browsing of screens or total duration of interaction exceeding the set time limit, this would trigger an automatic text alert to the caregiver

- The users could themselves indicate difficulty and call for assistance, where an SMS message would be sent

- In addition to responding when alerted through SMS messages, the designated caregiver (or family member) would also be expected to regularly monitor
Robogen where compliance data, vital signs and side effect responses would be displayed.

Through these and similar mechanisms the caregiver would have a mechanism for possibly detecting emerging cognitive defects. In contrast, if one looks at current home monitoring systems the possibility of detecting and supporting emerging cognitive deficits remains sketchy at best.

Finally, the healthcare robots, at the time of writing of this thesis, seem to be on the upward slope of inflated expectations on Gartner’s hype curve (Fenn, J., Raskino, M., & Gammage, B. 2009). One can recognise in the thesis though, elements that may land a ‘less than mature’ technology into the trough of disillusionment, and readers may also identify possible drivers that might ramp healthcare robots on the slope of enlightenment.
8.11 Conclusion and closing remarks

The research presents an interesting journey starting from a fresh look at the reality of elders while they dealt with the incrementally complex task of medication management in the face of diminishing capacities. Starting from an assumption of medication assistance being a simple reminder alarm, the research process completely transformed the assumptions as well as the design. It discovered a theory of automating medication assistance for older people and showed that an interactive, touch screen-based, robot-mounted information tool can be developed not only to remind but to build their capacities, enrich communication and avoid possible errors. It found a hybrid GT-PD-AR approach to be particularly helpful for innovating and articulating design requirements in challenging situations. The research discovered new components to the medication management process in the context of self-care task automation and stimulates thoughtful consideration for designing the use of robots in the care of older people in the future. This does not only apply to robots: some of the lessons learned from this research could be generalised to other healthcare tasks, social robotics, self-care, other age groups, e-therapies and other computer-based support systems that could be delivered over a wide range of technological platforms including mobile phones, touch pads and intelligent dispensing devices.

The direction for further research remains open to exploring the immense possibilities that lie within the use of automated dialogues, semi-autonomous robots and other self-care support tools for the elderly – to make them intelligent, safe and empowering tools, harnessing their potential while at the same time, for the user, preserving the dignity of being human.
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Appendix A

Medication Management Instrument for Deficiencies in the Elderly (MedMalDE)

What a Person Knows About Their Medications
Have the individual . . .

**1. Name all the medications taken each day, including prescription and over-the-counter medications (including milk of magnesia, nutritional supplements, herbs, vitamins, Tylenol, etc.).
**2. State the time of day that each prescription medication is to be taken.
**3. Tell how the medications should be taken (by mouth, with water, on skin, etc.).
**4. State why he/she is taking each medication.
**5. State the amount of each medication to be taken at each time during the day.
6. Identify if there are problems after taking the medication (i.e., dizziness, upset stomach, constipation, loose stool, frequent urination, etc.).
7. Do you get medication help from anyone?
   If YES, from whom? Type of help?
8. What other medications do you have on hand or available (i.e., eye drops, creams, lotions, or nasal sprays that are outdated, unused or discontinued)?

If a Person Knows How to Take Their Medications
Ask the individual to . . .

**1. Demonstrate filling a glass with water.
**2. Remove top from medication container (vial, bubble pack, pill box, etc.).
**3. Demonstrate counting out required number of pills into hand or cup.
**4. Demonstrate administering the medication (e.g., put hand with medication in it to open mouth; put hand to eye for eye drops; hand to mouth for inhaler; draw up insulin; or place a topical patch).
**5. Sip enough water to swallow medication.
   Record how the medications are currently being stored.

If a Person Knows How to Get Their Medications
Have the individual . . .

**1. Identify if a refill exists on a prescription.
**2. Identify whom to contact to get a prescription refilled.
**3. Explain resources to obtain the medication (can arrange transportation to pharmacy, pharmacy delivers, family picks it up, etc.).
4. After getting a new refill, do you look at the medication before you take it to make sure it is the same as the one you finished?
5. Do you have a prescription card?
   Yes No
   If YES, specify type:
6. Are there medications that you need that you cannot obtain?
   Yes No
   If YES, ask person to explain.

** If NO, it is counted as a 1 in the Deficiency Score.

TOTAL DEFICIENCY SCORE: _________(sum of three deficiency scores: maximum total score = 13)

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Appendix B

Medication Inventory

<table>
<thead>
<tr>
<th>MEDICATION NAME</th>
<th>DOSAGE</th>
<th>TIME(S) OF DAY TAKEN</th>
<th>EXPIRATION DATE</th>
<th>PHYSICIAN’S NAME/PHONE</th>
<th>PHARMACY NAME/PHONE</th>
</tr>
</thead>
</table>


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