SMART WONDER: CUTE, HELPFUL, SECURE DOMESTIC SOCIAL ROBOTS

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Abstract

Sci-fi authors and start-ups alike claim that socially enabled technologies like companion robots will become widespread. However, current attempts to push companion robots to the market often end in failure, with consumers finding little value in the products offered. Technology acceptance frameworks describe factors that influence robot acceptance. It is unclear how to design a companion robot based on them, however, as they were derived from much more primitive, asocial technology.

Based on two frameworks of robot acceptance as a starting point, this thesis highlights the value socially enabled technologies could bring as conveyed by the views and experiences of three user groups: the potential users of companion robots being exposed to adverts; the people who lived with smart speakers – a successful socially enabled technology with a dedicated embodiment; and the people who lived with companion robots long-term. By discussing both the frameworks of acceptance, and how real people used and anticipated real socially enabled technologies, this thesis draws broad considerations for companion robot designers concerning form factor, (non-)acceptance over time, robot's personality, trust, and human-robot relationships. The implication is for the valuable traits to be replicated in the future iterations of companion robots.

Findings include the tension between familiarity and strangeness of robotic form factors and faces; the specifics of how socially enabled technologies fit and do not fit within existing frameworks of acceptance; the need for both authenticity and pro-activity in companion robot's personality; the differences between views and actions on security and trust towards autonomous devices in the domestic environment; and the construction of human-machine relationships between people and socially enabled technologies.

These findings highlight the need to extend existing frameworks of robot acceptance to include unique factors pertaining to socially enabled technologies. They also highlight the need to highlight the value of companion robots, dismissing the assumption of automatic robot acceptance by people.

Contents

List of Tables & Figures

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Author’s Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas, and contributions from the work of others.

Whenever there are papers stemming from this thesis, I acknowledge them both in a separate section (Published Work), and in each relevant chapter.

All ethical clearances for the research presented in this thesis have been approved. Approval has been sought and granted by the Ethics Committee of Newcastle University on 27/06/2016; by the Faculty Ethics Committee of Engineering and Environment on 01/12/2016; and by the Ethics Committee of Northumbria University on 09/10/2017.

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Published work

Some of the results in this PhD have been published or have been submitted for publication in the following journals & venues:

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- Dmitry Dereshev, David Kirk, Kohei Matsumura, and Toshiyuki Maeda. 2019. Long-Term Value of Social Robots through the Eyes of Expert Users. In CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3290605.3300896

Chapter 1 – Introduction

This chapter describes how companion robots have been portrayed in fiction. It then contrasts that view with what the Intelligent Personal Assistance (IPA) market has presented consumers to date. Based on the disparity between the fiction and the reality of socially enabled technologies, and the lack of understanding of how/if companion robots would diffuse into society, I argue a case for practical research into the matter, based on existing commercially available socially enabled technologies.

1.1 Companion Robots: From Fiction to Reality

1.1.1 Portrayals of Companion Robots in Human Homes

There seems to be a universal expectation in some countries that companion robots would inevitably end up living with people in their homes, be it for utility, pleasure or any other reason. Such robots would be on at least a human level if not above, in terms of intelligence, conversational abilities and physical capabilities, but at the same time be tame, subservient, and safe. In short – the best that humans could possibly be (if not beyond), and universally allied to their owner.

Whilst it may seem that companion robots are a modern idea, imbuing some form of automation with some human-level capabilities to serve human needs has been recorded in the pre-historic legends of Finland (Kalevala: "*Bride of molten gold and silver*" [67]), Greece (Iliad: *"… golden handmaids… were like real young women, with sense and reason, voice also and strength, and all the learning of the immortals*" [135]; Galatea: an ivory statue turned lover [227]; &c.), and later biblical legends, to name a few. The late middle ages (1250-1500 CE) saw the legends of Brazen Heads – human-like heads made of bronze that could supposedly answer any yes/no question [200:181]. The 16th century saw the Jewish legends about Golems made of clay or wood which "*grew in size, and could carry any message or obey mechanically any order of its master*" [33].

From the 19th century onwards, companion robots became popular and widely discussed in literature, introducing much of the thinking and reasoning about them that permeates popular culture to date. Humongous amounts of media were produced on the topic, therefore listing even just the most famous writers, illustrators, directors and their works would be impractical (non-companion-robot-specific lists can be found for literature [98], film [243], and video games [242]). It seems, however, that most of what the companion robots would look like, act like, and the purpose they would fulfil has stayed relatively stable across time and the different cultures that have produced numerous fictional works about robots.

Appearance-wise most portrayals of companion robots to date seem to be human or humanoid [139] (Figure 1). This is understandable for TV and cinema, given the cost or even the technical ability to produce a robot and make it do what the producer wants. However, books, comics, and video games portrayed humanoid robots just as well even without those limitations (Figure 2).

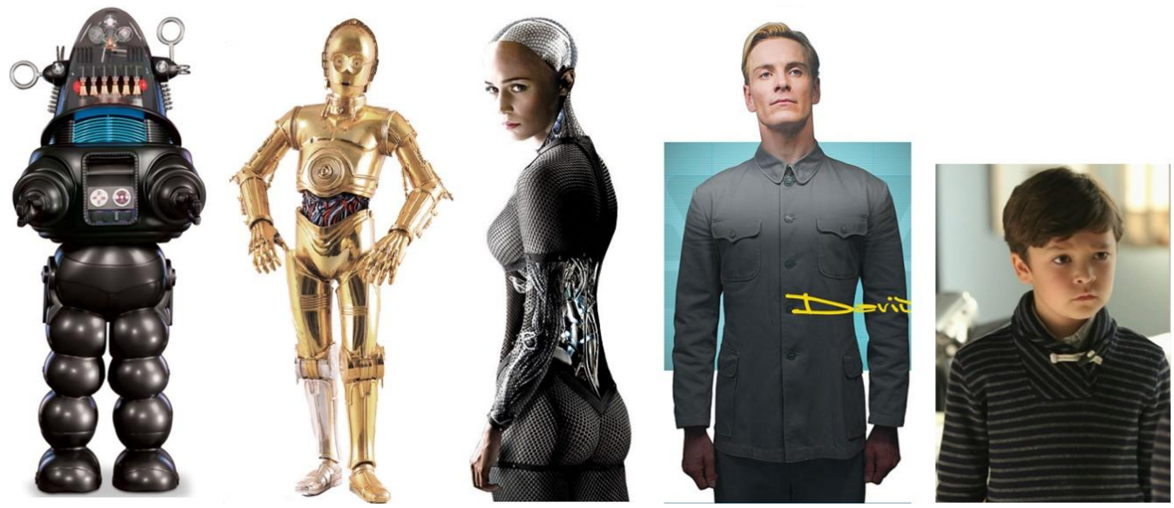

Figure 1. Portrayal of humanoid companion robots in film and TV (left to right): Robby the Robot from *Forbidden Planet* (1956) [315], C-3PO from *Star Wars* (1977) [196], Ava from *Ex Machina* (2014) [91], David 8 from *Prometheus* (2012) [266], Ethan Wood from *Extant* (2014) [87].

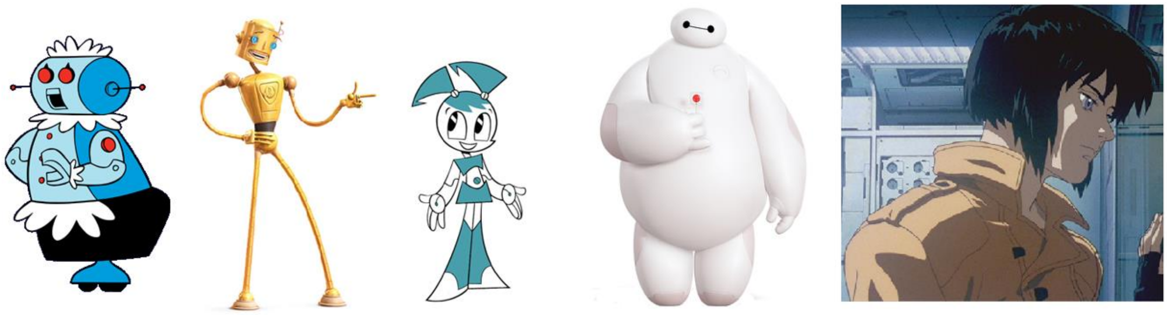

Figure 2. Portrayal of humanoid companion robots in animation (left to right): Rosie from *The Jetsons* (1962) [114], Carl from *Meet the Robinsons* (2007) [10], Jenny Wakeman/XJ-9 from *My Life as a Teenage Robot* (2003) [246], Baymax from *Big Hero 6* (2014) [112], Motoko Kusanagi from *Ghost in the Shell* (1995) [226].

There have been a number of non-humanoid portrayals of companion robots, but they appear much rarer than their humanoid counterparts do. Generally, those form zoomorphic and abstract groups, borrowing their appearance from either animals (Figure 3) or anything else (Figure 4)[1].

[1] A specific class of abstract companion robots would be spaceships with artificial intelligence on board, in which case the whole spaceship can be considered a body, with humans inhabiting it, rather than a robot inhabiting a human home. Such portrayals can be seen in various media about space exploration with examples of HAL from Arthur C. Clarke's *Space Odyssey* series [61], and EDI from the video game space opera *Mass Effect* [30]. This may seem farfetched, but if one considers a smart home with the Internet of Things (IoT) controlling many aspects of its functioning, from doors and windows, to heating and electricity, the comparison seems progressively more appropriate.

If one would want to create a companion robot, fiction producers suggest humanoid shape, although other shapes are generally acceptable.

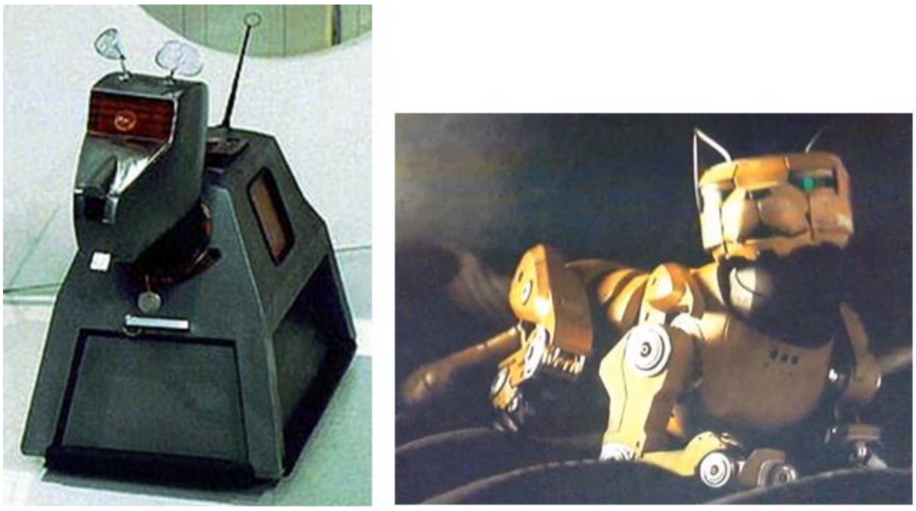

Figure 3. Portrayal of zoomorphic companion robots in film (left to right): K9 from *Doctor Who* (first appearance in 1977) [217], Gris from *Eva* (2011) [198].

Figure 4. Portrayal of abstract-shaped companion robots in film and animation (left to right): Drone from *Silent Running* (1972) [302], R2-D2 from *Star Wars* (1977) [196], AUTO from *WALL·E* (2008) [283], GERTY from *Moon* (2009) [159], TARS from *Interstellar* (2014) [219].

Functionally, a large proportion of subservient companion robots simply do domestic chores – portrayed from the early examples of *Helen O'Loy* (1938) [247] and *The Jetsons* (1962) [114], *I Sing the Body Electric!* (1969) [38] and *Mahoromatic* (2001) [317]. A broader common purpose is some kind of "general assistance" – portrayed for instance by TARS in *Interstellar* [219] or Baymax in *Big Hero 6* [112]. When the setting is a spaceship, companion robots often maintain it as well.

Most humanoid companion robots in fiction do human jobs – from being an investigator in *Almost Human* [316] to serving on a spaceship in *Star Trek* [252]. A significant proportion of companion robots also act human in a social sense – from something to simply talk to, to having extensive romantic and sexual relationships with (e.g. *Cherry 2000* [150]). Resurrecting or reincarnating a dead loved one as an (almost in all cases) android companion robot is a common theme as well [64,269,294].

Zoomorphic companion robots, especially cats and dogs simply emulate what real cats and dogs would do – from deviant behaviours of Gris in *Eva* [198], to a dog protector in *C.H.O.M.P.S.* [53].

In late 20th and early 21st centuries, the purpose of companion robots as portrayed by the media started to shift. It focused more on learning social norms: a companion robot would typically be portrayed as an android with high levels of physical strength and intelligence, but low understanding of social customs, norms and emotions (e.g. *I am Frankie* [60], *Small Wonder* [187], *My Living Doll* [170]). The general idea of this progressive humanisation of robots by learning human customs is that going through such a process and achieving human understanding (and often mortality) is a good thing (most directly presented by Asimov’s *The Bicentennial Man* [19] and *The Positronic Man* [20]).

Combining form and function, this brief overview suggests a preference for (or at least a predominant interest in) human-looking and human-acting companion robots, or animal-looking and animal-acting ones (in a few cases). The reviewed media portrays abstract-shaped robots as tools rather than companions with a social dimension.

There are a number of themes associated with robots in general and companion robots in particular worth mentioning as well, as they form just as much a part of companion robot portrayals and perceptions in an absence of real-life companion robots as their looks and behaviour does.

One of the most common themes pertaining to robots in general and companion robots in particular is conflict. Companion robots would disagree with humans enough to cause anything from a forced shutdown or having laws that would limit robots (Figure 5), to malicious actors taking over robots that were previously considered allies, to human extinction caused by robots (as early as R.U.R. (1921) [51]).

Figure 5. A companion robot from *Time of Eve* (2010) [321] featuring a halo above its head to clearly distinguish it as a robot which is otherwise visually indistinguishable from human.

Many works of fiction discuss prejudice against robots from aesthetics of how those look and behave (see E. T. A. Hoffmann's *Der Sandmann* (1816) [133] for one of the earliest examples, or even the pre-historic *Kalevala* [67]), to questioning whether robots should be considered on par with people (e.g. *A.I. Artificial Intelligence* [282], *Do Androids Dream of Electric Sheep?* [78], *Ex Machina* [91]), and whether romantic relationships with robots are "real" (e.g. *Helen O'Loy* [247], *Chobits* [17]). Some stories consider robots as being better than people whether physically, intellectually or emotionally (as early as *The Future Eve* (1886) [184]).

Child-robot interaction is often portrayed, with children being either the creators of robots [64], robots themselves [187], and/or primary users of robots [66] (which is in line with robotic toys/action figures which have been circulating since at least 1940s [295]).

These themes form a spectrum of acceptance, moving from rejection to complete acceptance, and even to a realization that robots might be better than humans (Figure 6). This quick review significantly deepens Bartneck's discussion of how robots are portrayed in fiction [24] which only highlights whether the body and/or the mind of the robots was similar or different to humans.

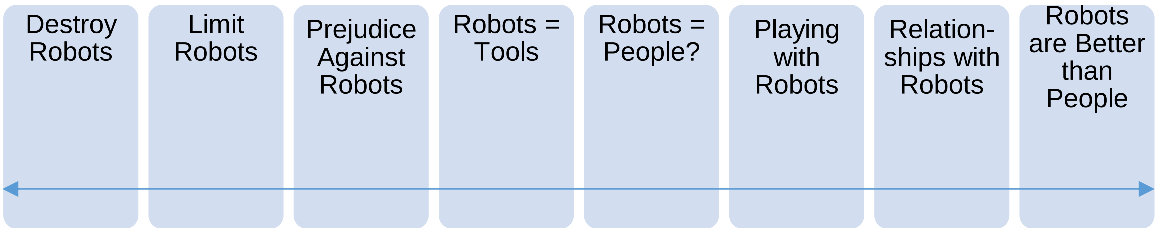

Figure 6. The Spectrum of Acceptance in companion robots portrayed in fiction.

All of these portrayals combined suggest that the most valuable companion robots would be human looking and human acting (or an animal simulation), and have at least human-level capabilities, if not above, in physical, intellectual, and social spheres, but at the same time be safe and universally allied to their owner. Or, in the words of Isaac Asimov: *"… you just can't differentiate between a robot and the very best of humans*" [18].

This raises a question: how far is the commercial market from these portrayals?

1.1.2 Existing Companion Robots

Even with the recent advances in robot mobility [15,36,193], visual design [26,27,239], and AI capabilities [274], companion robots as portrayed in fiction are yet to come. Current products in the forms of smart speakers and companion robots are slowly introduced to the market, but they are very different from what the media portrayals present.

Some of the first consumer-grade socially enabled technologies with dedicated embodiments appeared in 2014, when both Pepper by SoftBank and Aldebaran Robotics

[277], and Amazon Echo – a smart speaker [9], were first introduced [37,213]. Numerous challengers in the field have appeared since: Google [99], Apple [12], Microsoft [208], Baidu [157], and Yandex [325] (among others) compete on the intelligent personal assistant (IPA) market, which encompasses smart speakers and other devices that can incorporate IPAs – from remote controls to smart cars. More robotic companion robots have been demonstrated during exhibitions like Consumer Electronics Show (CES) [62], promising a wider variety of shapes and functions (Figure 7). Existing and promised companion robots come in various, not necessarily humanoid shapes, with many abstract shapes present. This deviates from fictional portrayals already.

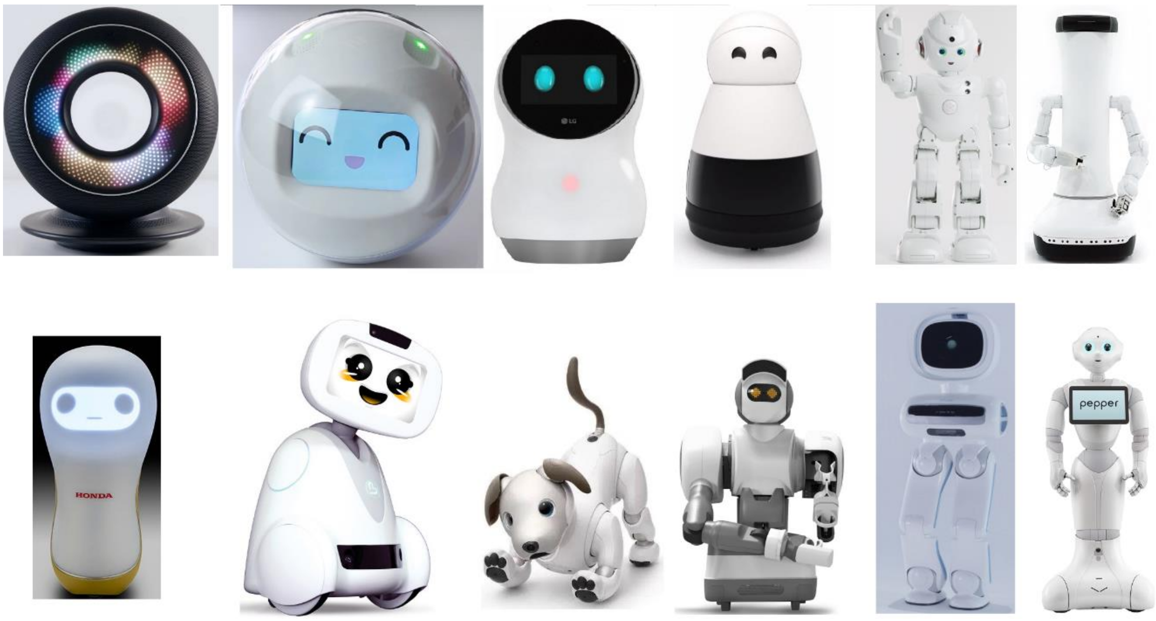

Figure 7. Examples of companion robots from Consumer Electronics Shows 2017 and 2018 (from top row, left to right): Olly by Emotech (UK), Leka by Leka (France), CLOi by LG (South Korea), Kuri by Mayfield Robotics (USA), Lynx by UBTECH (China), MoRo by Beijing Ewaybot Technology LLC (China); 2nd row: 3E-A18 by Honda (Japan), Buddy by Blue Frog Robotics (France), Aibo by Sony (Japan), Aeolus by Aeolus Robotics (USA), Walker by UBTECH (China), Pepper by SoftBank Robotics (France, Japan).

Concerning functionality, IPA-enabled devices from smartphones to robots seem to provide similar functionality regardless of shape, and those functions have not moved much beyond a smartphone or tablet capabilities to date. A number of companion robots demonstrated at CES actively promote the idea that the physical bodies of robots should host already existing IPAs like Amazon's Alexa. Companion robots often offer less functionality than a smartphone, however, e.g. being unable to use a cellular network, or having no screen. Some companion robots, like Leka, Aibo, and Pepper utilise their physical bodies specifically, as they react to touch or could perform physical tasks. Not all companion robots advertised to date make use of their physicality beyond projecting audio, however. This is, again, unlike fiction, where physicality plays an important role in perceiving companion robots.

Compared to the universality and humanness of companion robots in fiction, current commercial iterations of those robots are severely limited, offering some functionality in digital space, but very little in the physical environment. Even if only robotic "minds" are taken into consideration, the promises of general purpose artificial intelligence (AI) have been around since at least 1950s, but they have always been 15-25 years into the future if not more, and present predictions are not any different from the past [14]. Companion robots on offer are much more like smartphones, and much less like *"the very best of humans"* portrayed in fiction.

Even with these limitations, adoption rates suggest that both the smart speakers and companion robots are taking off given both the numbers sold (tens of millions for smart speakers [207], and over ten thousands for the Pepper companion robot [223,278]) and the variety of new products introduced into this commercial space [62]. The total number of service robots for entertainment and leisure – the closest category match for companion robots, is still surprisingly small, however. Only 2.1 million units were sold in 2016 worldwide, with the projected sales of 10.5 million units in 2018-2020 (compare these to strictly utilitarian domestic robots which sold over twice as much in 2016, and are projected to sale thrice as much in 2018-2020) [142]. This is fairly negligible still compared to smartphones, which have a subscription base over 4.4 billion as of 2017 [129], or personal computers which have been shipping above 200 million units a year since 2009 [284] (Figure 8).

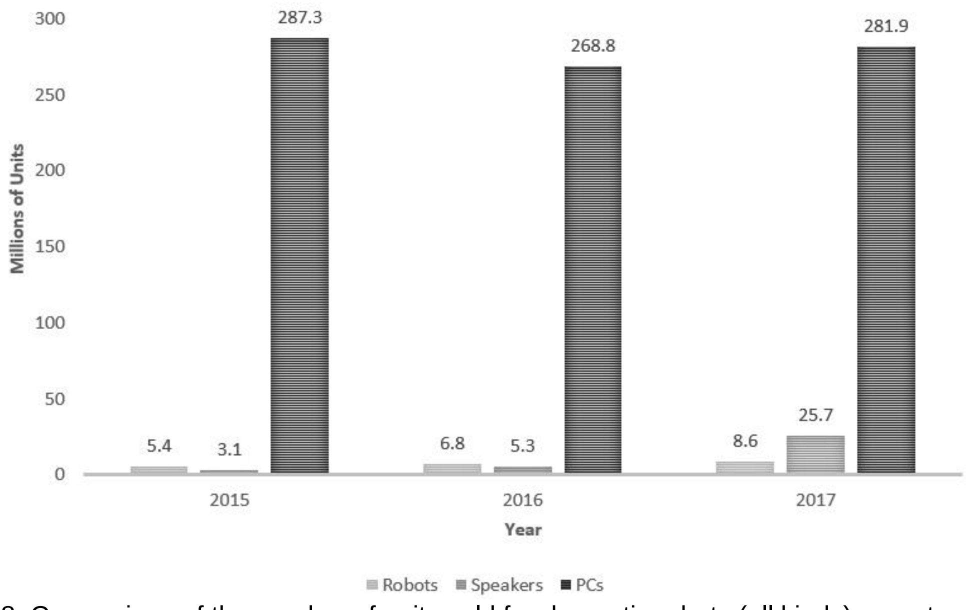

Figure 8. Comparison of the number of units sold for domestic robots (all kinds), smart speakers (Amazon Echo), and personal computers.

The reality of commercially available and advertised companion robots is thus in stark difference to fiction. Various media portray robots as being ubiquitous and universal. However, companion robots are almost non-existent, sold in limited markets, and possess a very narrow set of functionalities, which is neither universal nor unique to companion robots as platforms.

1.2 Qualitative Approach to Extracting Value of Companion Robots from Human Experiences

With both the expectations of having companion robots and the difficulty of creating them to satisfy those expectations, there are numerous challenges to overcome. While technological challenges may be somewhat understood, and the related fields from computer vision and object recognition, to speech-to-text and personalised interactions have made progress over the years, there is no established way to describe what *living* with a companion robot would feel like beyond fiction. It is even more challenging to suggest how to make such experience *better*.

Social presence of and extended living with robots in general and companion robots in particular is perhaps the most under-researched area when compared to either mobility or artificial intelligence. Designing robots in a responsible way, and in accordance with social desirability, and safety is considered paramount [259]. The effect a robot makes may not only be conveyed through how it interacts with its master, but also in how it looks and behaves towards others, and what the companion robot's looks and behaviours convey to others [259].

Qualitative inquiry into what value existing and potential users extract from smart speakers and companion robots provides one way to approach the challenge of creating a companion robot that would prove valuable, fit and fulfil purposes like general assistance, edutainment and companionship gleaned from fiction. These purposes lack a strict definition and may rest largely on individual preferences. Engaging users with existing technologies rather than speculative designs or prototypes allow incorporation of those technologies into existing ecologies of people's homes – the expected environment for the companion robots.

Providing an average experience for many kinds of users may prove much less desirable for companion robots given expectations, than providing superior experience for a specific kind of user. This sentiment is shared by some of the developers of companion robots already [318]. Investigating what individuals do, and what they express as they use smart speakers and companion robots may provide insight into such superior experience specifically for them, and potentially for a broader group of people.

Qualitative inquiry also supports the investigation of non-users – something that other methods like surveys rarely pick up. Non-use of companion robots as novel devices is important, as it provides information about which functions are under-utilized, and which ones cause frustration to the point of non-use. Individual stories allow tracing the entire path from acquiring a device, through experimenting with it, and on to the sustained use or non-use. A final point for studying non-users is to challenge the assumption that companion robots are going to be present everywhere, and be universally accepted – something that fiction often takes as a premise, while commercial markets tend to disagree.

1.3 Central Ideas and Contributions

Responding to the issues of disparity between the fiction and the reality of companion robots highlighted above, and the lack of lived experience with companion robots described in research, this thesis makes the following contributions to knowledge:

1. User-centric design advice with respect to form factor, functions, security, and social behaviour of companion robots.
2. Suggested extensions to existing frameworks of robot acceptance with respect to companion robots.
3. Promotion of value-centred design and human value engineering in robotic system design.

1.4 Thesis Overview

In this chapter (Introduction) I have highlighted the science fiction of companion robotics, which could have formed consumer expectations about how commercial companion robots ought to look and behave [139]. I then highlighted the current state of affairs concerning the existing and upcoming companion robots, and how those are different from science fiction. I have stated the need to investigate practically what existing and potential users of companion robots think of and do with *existing* technologies on the market. I have highlighted how qualitative inquiry into the matter could provide a better understanding of the issue, and how it could surpass quantitative inquiry into the same issue. Finally, I have summarized the contributions this thesis makes.

Chapter 2 (Literature Review) provides a literature review pertaining to how an ideal companion robot would look and act like based on scientific investigation, who would use such robots, and by summarizing design advice from frameworks of robot acceptance that explain how companion robots could diffuse into society. It points out the limitations of existing knowledge, and provides several directions for further research, one of which I explore in this thesis.

Chapter 3 (Methodology) showcases how instrumentalism accounts for interaction, process, and relationships needed to investigate the value that companion robots could bring, and contrasting that with the ideal static objects classical philosophies focus on. I build instrumental understanding from ontological level, through epistemology, methodology, and into the data collection & analysis techniques, as well as their limitations and applicability to this investigation.

Chapter 4 (Pre-Adoption – Adverts Study) provides original contribution to knowledge by showcasing how shape, functions, security, and social behaviour of companion robots are deemed dominant for the potential users' who watched advertisements of companion robots. I describe how twenty people viewed advertisements of three companion robots, how I collected their reactions via interviews, how those interviews were thematically analysed, and how the results of the thematic analysis answered the question of value at the pre-adoption stage of companion robot acceptance. I then outline the limitations of applicability of the results.

Chapters 5 (Smart Speaker Deployment) provides original contribution to knowledge by examining users' changing perceptions of living with a smart speaker for two months. I describe the deployment of three Amazon Echo Dots, the longitudal interviews and log collations, and the thematic analysis thereof, which resulted in three dominant themes: the expectation and the actual use of the devices; the non-use and the desired use; and the emotional attachment & character that living with the Dots highlighted. From that, I answer the question of value in the middle stages of companion robot acceptance. I then outline the limitations of applicability of the results.

Chapter 6 (Pepper Interviews) provides original contribution to knowledge by highlighting three kinds of value existing companion robot (Pepper) provides. By interviewing long-term users of Pepper, I highlight three different kinds of values: the utilitarian value of augmentation with software; the social value of Pepper forming a community around it; and the personal value of nurturing and comfort. I describe how thematic analysis of the interviews yielded the dominant themes, and how those themes answer the question of value post-acceptance. I then outline the limitations of applicability of the results.

Chapter 7 (Discussion) provides original contribution to knowledge by combining results across studies along the lines of appearance, (non-)acceptance over time, robot's persona, trust, and human-machine relationships with socially enabled technologies. It then outlines practical implications from this entire work summed up as design advice, and deployment advice.

Chapter 8 (Conclusion) returns to the motivations for undertaking this project, summarises study-specific results, highlights the overall value that companion robots could bring based on the results across studies, and outlines the overall limitations of those results. It then highlights the overall contribution to knowledge made, and secondary findings that this project produced that could be taken further.

Appendices provide the lists of the specific questions used in each of the interviews, the frequencies of codes, and the links between the derived themes across studies.

Chapter 2 – Literature Review

This chapter provides a state of the art literature review pertaining to how an ideal companion robot would look and act like based on scientific investigation, who would use such robots, and by summarizing design advice from frameworks of robot acceptance that explain how companion robots could diffuse into society. It points out the limitations of existing approaches, and provides directions for further research, one of which I explore further in this thesis.

Social and domestic robotic technologies have been separately studied and produced for several decades, with domestic utilitarian and edutainment machines seeing successful sales, while social robots from various labs keep wowing people across the world through press conferences, exhibitions and even some practical applications like reading news, or posing as fashion models. However, commercial companion robots seem to be less than what people expect, with sales confirming a strong preference for strictly utilitarian robots.

Although people seem to have an intuitive definition of a robot, it is hard to differentiate robots from other kinds of automations precisely (if any differences exist at all). One way to approach this is to delineate robots as physical machines that utilize sensors to adapt to the environment and carry out complex tasks [28:1], which is the approach used in this thesis.

Companion robots specifically can be classified as terrestrial, service, domestic/personal robots of various levels of autonomy and shape, intended for both utilitarian and hedonic uses, with human-like communication methods being part of their functionality [1:9.1.1].

2.1 Highlights of Social & Domestic Robot Technologies

In the following two subsections, I review the highlights of both commercially available robotic technologies for home, and social robots studied in research labs. I point out the need to combine the insights from the two strands to study companion robots, which need to both operate in the domestic environment, and have social capabilities.

2.1.1 Domestic Robots: Timeline, Purpose & Capabilities

Although home automation as a whole took off around 1900s with the introduction of consumer-grade domestic washing machines, fridges, &c., commercially available domestic robots for utilitarian purposes have only become widely available in the late 1990s (with the exception of robotic pool cleaners patented in 1960s [127,249]), while toy robots inhabited homes since at least 1940s [295].

Utilitarian domestic robots provide automated labour. Robomow introduced its classic robotic lawn mower in 1998 [250]. Year 2000 saw an automatic litter-robot for cat owners

[22]. Electrolux's Trilobite in 2001 [80] and iRobot's Roomba in 2002 [144] (among others) automated some of the cleaning tasks, and as a class, robotic hoovers are still successful [144]. 2005 saw iRobot launch Scooba – a floor washing robot [145]. In 2007 iRobot released several more robots for homes including Verro for pool cleaning, and Looj for gutter cleaning [145]. Massaging robots by Milagrow appeared in 2013 [209]. In 2016 iRobot launched Braava – a jet mopping robot [145].

The line between robots and home automation blurs with devices like Rotimatic – an automatic kitchen robot roti maker, which first shipped in 2016 [323]. While being very similar to a coffee maker, its ability to sense the ingredients, download recipes and updates from the internet, and prepare roti and other foods to a given preference positions it more as a robot, than a simple automaton.

A more universal robot for kitchen, Moley, was on pre-sale in 2018, and has been in development since 2014, when the first patent for it was filed [211]. It consists of a kitchen counter and two robotic hands encapsulated in an enclosed structure. The principle behind it is to record a person cooking a meal, and then reproduce the movements of that person with robotic hands, to yield a similarly cooked meal.

A possible future of dog-like robots was demonstrated in 2018 with SpotMini, a Boston Dynamics robot, *"that handles objects, climbs stairs, and will operate in offices, homes and outdoors"* [36,126]. The founder of Boston Dynamics has recently announced that the company plans to sell SpotMini commercially in 2019 [202].

CES 2018 showcased some of the latest upcoming and available utilitarian robots including Ecovacs' Winbot X (window cleaner), and Ubtech's Walker (security), among others [62].

Robotic toys have had a significant presence in homes since at least 1940s [295]. I refer to them as toys specifically, since, while they have inspired much of the classic representation of robots, they are much closer to dolls or action figures than robots, as many of them do not have any sensors, nor are they able to alter their activities based on external input.

One of the more famous robotic toys introduced in 1999 was AIBO by Sony – a toy robotic dog [162]. It was discontinued in 2006 [279] and re-introduced in 2018 with upgraded looks and intelligence [280]. Tekno released a robotic puppy in 2000, and later increased its range of toy robotic animals to include kittens and scorpions [293]. Pleo [140] was another toy robot shipped in 2007, with a reboot in 2009, and a second generation in 2011. Pleo was advertised to have development stages, character, and attributes like mood, emotion and health [140]. Borrowing from the tradition of action toy figures, Ubtech and Disney released Stormtrooper in 2017 – a robotic Star Wars character with playable missions, patrol routines and face recognition as features [306] – all of which bring it closer to the definition of a true robot, and away from just a toy.

Edutainment domestic robots primarily marketed as toys have also emerged relatively early. 2-XL was one of the early education robots for homes, running on 8-Track tapes, produced from 1978 to 1981 by Mego Corp [96]. The second version was released from 1992 to 1994 by Tiger Electronics: the robot was updated both in terms of design, and switched to using cassette tapes [96]. The Third generation of 2-XL, dubbed Kasey the Kinderbot, was produced by Fisher-Price from 2002 till 2004, and ran on cartridges [97]. Edutainment robots are popular to date with the more advanced examples like Alpha 1 Pro by UBTECH [307].

DIY robotic kits represent another kind of domestic robots, with the more recent versions like LEGO Mindstorm [188], Robotis [251], Abilix Robotic [2], Ubtech Jimmu [308], and others used to teach children (and adults) to code. Microcontroller kits that can in principle be used to create robots in a DIY fashion like Raspberry Pi [244] and Arduino [13] have also increased in popularity in recent years.

Qoobo – a robotic tail cushion [322] was designed primarily for comfort, and falls strictly into **hedonic** category. Its closest comparison is Paro – one of the social therapeutic robots discussed in more detail in the next section. Sex industry has also joined the race recently with companies like Realbotix providing software solutions before they could embody them [245].

All of these commercially available robots for homes suggest several successful avenues concerning the functions and purposes that they fulfil. Utilitarian robots automate certain tasks (thus freeing human time to do something else), similar to simpler automations for home, from washing machines to coffee makers. Robotic toys fulfil the purpose of entertainment for various ages and interests, like toys & action figures for children and fans of various TV shows and film, while sex robots and tail cushions fit companionship purposes. Edutainment and DIY categories fulfil primarily the purpose of education – be it education in a specific subject not connected to a particular robot, or education about robotics in terms of hardware and/or software. These robots primarily fall into the "Robots = Tools", and "Playing with Robots" categories in the Spectrum of Acceptance.

Several factors make available home robots different from the imagined companion robots. There is the specificity of commercial machines vs. the universality of companion robots as portrayed in fiction. Fictional companion robots fulfil or could fulfil all of the purposes that commercially available robots for home could do combined: utilitarian, educational, entertainment, and companionship. Moreover, fictional companion robots excel in what was (until very recently) non-existent in commercially available home robots: the social aspect of natural communication, and building extensive relationships with their owners. However, researchers have studied the social aspects of robots in laboratories.

2.1.2 Social Robots: Timeline, Purpose & Capabilities

Excluding purely bot solutions which were around since at least 1966 with ELIZA [313], one of the first social robots was a 1970-1973 WABOT-1 – a humanoid robot designed in Waseda University, Japan [168]. Listed as able to "*communicate with a person in Japanese and to measure distances and directions to objects using external receptors, artificial ears and eyes, and an artificial mouth*", it could grab and transport things with its hands, and walk with its legs [168]. This was a prime example of a generalist approach to social robotics – an attempt to embed speech, motion, and human-like looks all within a single platform, together with both physical and social functionality.

In 1980-1984 WABOT-2 was created [169]. It was a step away from a generalist approach of WABOT-1. Instead, WABOT-2 was designed as a robot musician, capable of reading a musical score, and playing a keyboard synthesizer [169]. It could converse with a person, and accompany singing. It was arguably the first humanoid companion robot [169].

MIT Artificial Intelligence Lab, and specifically Humanoid Robotics Group picked up social robotics as an area of research in 1990s, with Cog [44], TJ [301], and Frankie (a reimplementation of Polly robot [136,137]) projects starting from 1994, Kismet in 1998 [41], and Coco in 2000 [171]. MIT designed these projects to understand both how to teach robots social skills, and how people would react to those skills exhibited by robots. These projects, together with those on robotic toys in 2000s were discussed in depth in Turkle's *Alone Together* [305]. In short, the projects provided more evidence towards Nass' *Computers as Social Actors* paradigm [216] with both people acting socially in front of the robots, and ascribing social attributes to the robots, even if the mechanisms of how robots' actions were determined were explicitly described to them. This was especially prominent in children [305].

Paro, a robotic seal developed by the Japanese National Institute of Advanced Industrial Science and Technology (AIST) [270], has been used since 1996 for its therapeutic effects comparable to living animals like dogs and cats (although the size of the effect is disputed [48]). Dozens of papers were published on its use, especially with regards to the elderly residents of care homes [310], and with those suffering from neurological diseases like Alzheimer's dementia, and the like [311]. Unlike prior social robots that mimicked human speech, Paro is a good example of a social robot communicating via haptic feedback rather than voice or gesture.

MINERVA social robot for museum guides was unveiled in 1999 [299] with “emotional” interface being part of its programming (although its main purpose was navigation and learning in the semi-structured environment of the museum).

Figure 9 presents some of these 20th century social and companion robots.

Figure 9. Social robots 1970-1999 (left to right, from the top): WABOT-1, WABOT-2, Cog, TJ2, Frankie, Kismet, Paro, MINERVA.

Starting in 1986 with E0 – a bi-pedal robot prototype [256], Honda developed what became known as ASIMO – a robot which, by 2002, was capable of interpreting human gestures and moving in response [214]. Several generations later, ASIMO has improved capabilities in both human-robot interaction (HRI) and bipedal motion.

Intelligent Robotics Laboratory in Osaka University, Japan has researched humanoid robots with social features since at least 2004 with the development of ReplieeQ1expo version of Actroid – capable of both talking and replying to voice interactions with human participants [141,177].

MIT's Personal Robotics Group introduced Leonardo in 2004 [69] – a robot capable of learning through emotions expressed in voice and association of those with visuals, like toys [233]. Leonardo expressed its own social state via motion, e.g. extending its hands towards a toy associated with “good”, and covering its eyes against a toy associated with “bad” – all taught through a teacher’s voice and visual cues [233].

In 2005 MIT's Personal Robotics Group presented Huggable – a teddy-bear-looking robot designed with cameras, microphones and touch sensors hidden so as to make the technology “invisible” [285]. The primary purpose of Huggable was child education.

In 2005 Hanson Robotics introduced Albert HUBO, *“the world’s first android head mounted on a life-size walking robotic frame”* [117]. The purpose of the robot remains the study of how humans perceive emotions through facial expressions. The same year another creation by Hanson Robotics (and many supporting collaborators) - Philip K. Dick Android was built [123]. Lost in transit later that year, the company rebuilt it in 2010. It also focused on conversation abilities and HRI. Face perception and speech recognition were included [123].

Also in 2005, Maggie – a humanoid robot from Universidad Carlos III de Madrid, was presented [258]. Maggie was able to communicate through speech, gestures and touch [95]. The robot had research based on it published until at least 2017 [8].

Figure 10 presents these first social robots on the 21 century.

Figure 10. Social robots 2000-2005 (left to right, from the top): ASIMO, ReplieeQ1expo, Leonardo, Huggable, Albert HUBO, Maggie, Philip K. Dick.

2006 saw another Hanson Robotics’ creation – Jules, a *“complete package”* interactive humanoid, which used both statistical tools to simulate dialogue, internet tools like word.net, and efforts of writers who wrote some dialogue parts using *“chat-bot tools”* [115,118].

2006 also saw Hiroshi Ishiguro developing Geminoid HI-1 – a head and torso of Ishiguro's likeness was developed to study Sonzai-Kan – a feeling of presence and authority through such embodiment [146]. This was a telepresence robot, rather than an autonomous one, but Ishiguro designed it specifically to study embodied social presence produced by a robot.

In 2006, MIT's Personal Robotics Group presented Autom – a social robot to help people with weight management. Autom was an animated head and torso, capable of speech and presenting information on a tablet display [174].

2007 saw another Hanson Robotics' creation – Zeno, a "conversation" toy robot [124]. It could walk, talk, had cameras in the eyes, and microphones to pick up speech. Its face, much like with other Hanson Robots was expressive [231].

Actroid series robots were developed from 2005, producing numerous versions, notably Actroid-DER series available for rent from Kokoro Ltd. – the producers of the androids [177]. These robots looked like young women and were available to rent for hosting various shows as narrators, being chairmen (chairwomen? Chair-robots?), and acting as fashion models [177]. They were capable of hand and leg gesturing, talking, and facial expressions [236].

In 2010, Hanson Robotics released BINA48 – a robotic bust with compiled memories of Bina Aspen. BINA's purpose was to interact with people via speech and recite its own memories from the past [119].

Hiroshi Ishiguro lab also introduced Telenoid series in 2010 – a telepresence embodiment, with 7 versions spanning between 2010 and 2013 [21]. Telenoid supposed to represent the embodiment of the person communicating through it [220]. Some of the research with Telenoid showcased it as an *"autonomous cooperative agent for a shared environment by human beings"* [281].

Figure 11 presents some of the social robots described.

Figure 11. Social robots 2006-2010 (left to right, from the top): Jules, Geminoid HI-1, Autom, Zeno, Actroid-DER3, BINA48, Telenoid.

Between 2010 and 2015, MIT's Personal Robotics Group released a number of social robots focusing on interaction with children. These include Paediatric Companion (for socio-emotional support of children in hospitals) [153], Tega (an android-smartphone-based research platform in a robotic body) [314], and Social Robot Toolkit (teaching pre-school children through playful interactions) [100]. On a non-children front, MIT released MeBot – a semi-autonomous telepresence robot specifically designed to enrich audio/video conversations with non-verbal signals [3].

Hiroshi Ishiguro lab had also released a number of social robots between 2010 and 2015, including new versions of Geminoid, Telenoid (Elfoid, Hugvie) [221], Otoranoid, Kodomoroid, and ERICA [93], all focused on human-like presence and appearance, as well as natural speech and motion.

2015 also saw Sota and CommU developed and presented by Hiroshi Ishiguro [225]. The two pint-sized robots were able to communicate amongst themselves, and occasionally ask a question of a human interlocutor, thus providing a sense of engagement in the conversation. At the same time, neither could understand any language nor produce any communication based on the information in the human speech.

In 2014 Nanyang Technological University, Singapore released Edgar-1 for telepresence purposes, using an expressive body [56]. Nadine was also created in the same university, developed by (and in the image of) Nadia Thalmann. Nadine was another head and torso social robot capable of speech and gestures, and acting as a secretary for the lab [176].

2015 saw Sophia – a social robot developed by Hanson Robotics [120,125]. With the specific goal of learning socially from humans, its capabilities include (limited) facial expressions, life-like look, and the ability to converse on numerous topics [276,297]. Han – another project of Hanson Robotics, a humanoid head, also debuted in 2015, with the focus on "serving people", again through speech, British accent and humour [121].

Figure 12 presents some of these first social robots of the second decade of the 21st century.

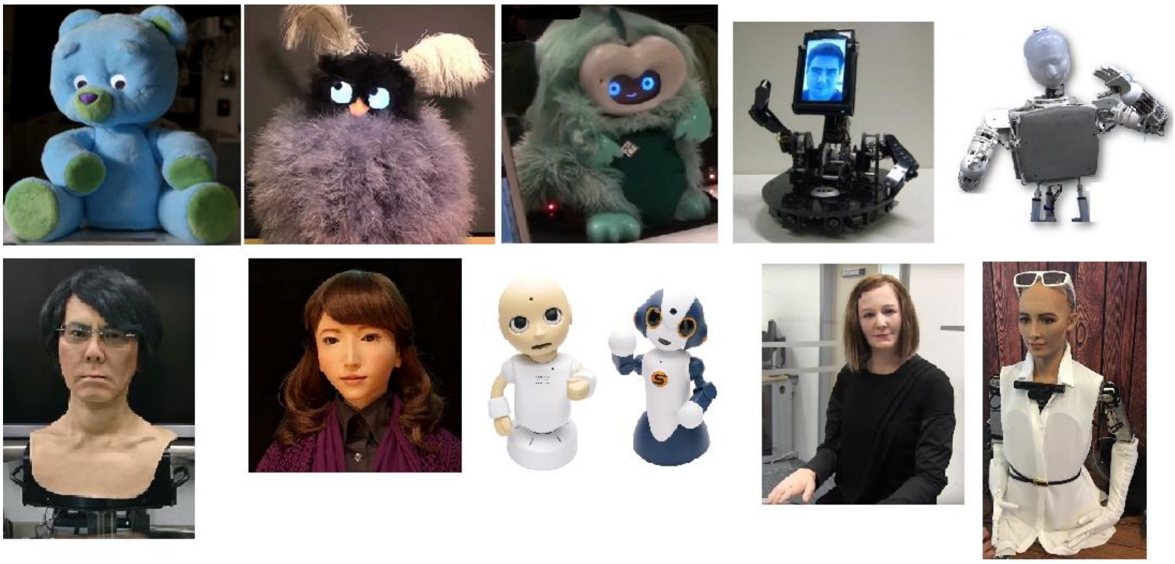

Figure 12. Social robots 2011-2015 (left to right, from the top): Paediatric Companion, Tega, Social Robot Toolkit, MeBot, Edgar-1, Geminoid HI-5, ERICA, CommU and Sato, Nadine, Sophia.

2016 saw Edgar-2 by Nanyang Technological University, a modification from the previous version being a slightly different look and a focus on autonomous behaviour [56]. 2016 also saw JiaJia, a robot from University of Science and Technology of China [218]. While not introducing any significant technological advances, the robot's character was the focus, making its speech and gestures submissive.

Hanson Robotics has developed a number of robots besides Sophia: ALICE was their latest iteration as of 2018, with the focus on facial expressions [122].

Figure 13 presents these latest developments in social robotics.

Figure 13. Social robots 2016-2018 (left to right): Edgar-2, JiaJia, ALICE.

Thus far, the overall trend in social robotics followed the fictional one – human-looking and human-acting robots with improvements in appearance and social interactions both verbal and non-verbal. However, these robots are not companion robots – most are not available to the public, as they only make pre-scripted appearances, and stay in the labs of the respective universities and developers. The consumer market for companion robots looks quite different, as I have described in the Introduction.

With first attempts to combine the success of domestic robots with the advanced communication capabilities of social robots, there are two questions to ask if companion robots are to be as widespread as science fiction suggests:

1. Do people actually need companion robots?
2. If people need companion robots – what are the specifics?

2.2 Frameworks of Acceptance

2.2.1 General Technology Acceptance Models

There have been a number of theories attempting to explain why and how people adopt and accept various technologies. These stem from many related fields, from HCI to psychology, as well as specifically theories of innovation and domestication. With each theory encapsulating some of the aspects of the overall phenomenon, a neat representation can be picked from de Graaf's recent work on the matter (Figure 14) [105].

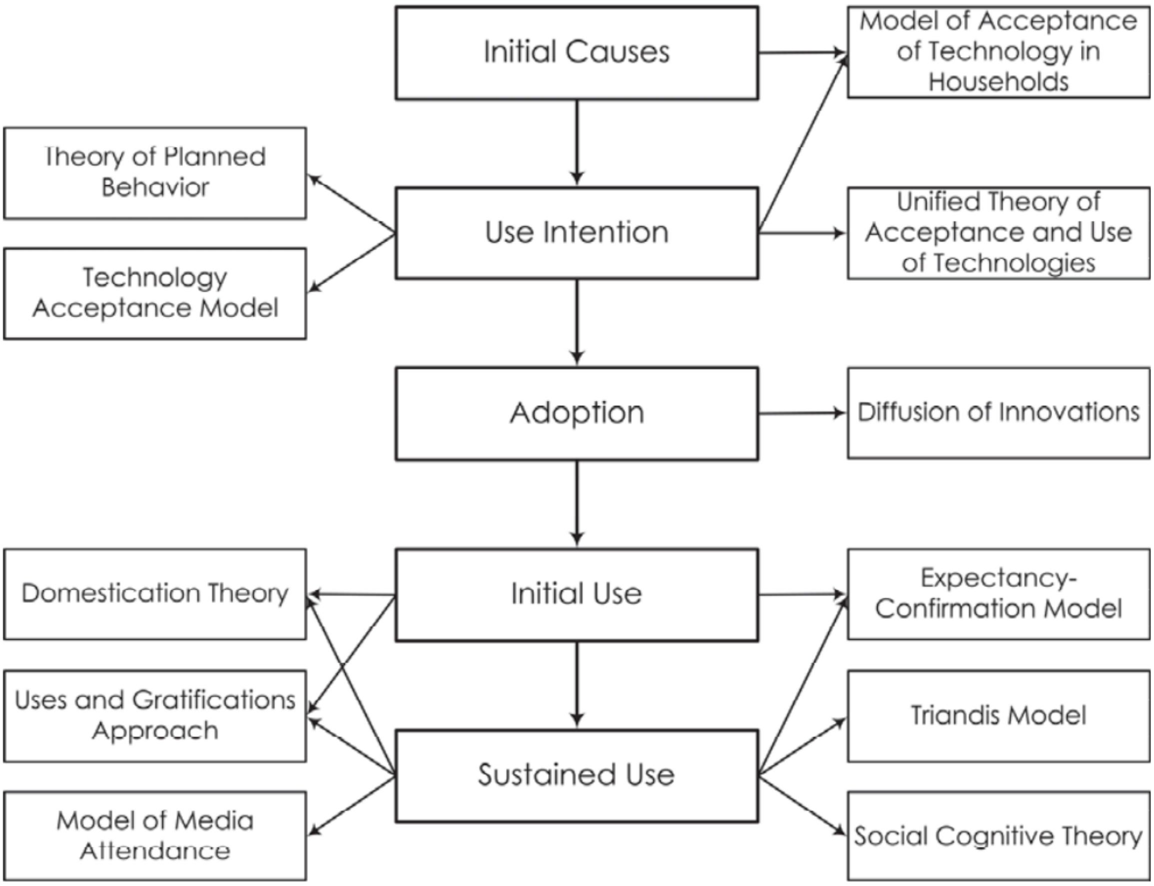

Figure 14. General trend of technology acceptance (middle column), and various theories that describe parts of it (left and right) [105].

Each theory expectedly has its limits, be it parsimony, consistency or extensive focus on either influence of social presence or usefulness, while ignoring hedonic factors like companionship [102]. Each theory used a different set of technologies to validate itself, and each had a specific goal in mind. As of 2017:

> *“No theory exists that offers an extensive phasing of the full acceptance process from anticipating the use of a technology and that goes beyond patterns of sustained use.”* [104]

There is a need to decide on a framework for companion robots that takes into account specifically the closest thing the market has to companion robots, and that was validated preferably in longitudal studies in a domestic setting. I have identified two such frameworks.

2.2.2 De Graaf’s Framework

Attempting to reconcile various theories and to come up with her own, de Graaf introduced *“a phased framework for long-term user acceptance of interactive technology in domestic environments”* (referred to here as “de Graaf’s framework”) [104], which both used the closest robots to the current smart speakers (Nabaztag/Karotz robots), and validated itself in the naturalistic setting of the home.

Exploring how elderly participants co-existed with robots over time, de Graaf noticed that:

> *"Although the acceptance of robots somewhat follows a similar acceptance process as other technologies, full incorporation of the robot in the participants daily lives seem to depend on their perception of the robot."* [103]

De Graaf based her model on domestication theory, theory of planned behaviour, and the diffusion of innovations theory. Nabaztag and its successor – Karotz were the test robots used. Nabaztag and Karotz represent the robots that are the closest to the ones investigated in this thesis: they have both social and utilitarian functions; are connected smart devices; are programmable; and use both verbal and non-verbal language to communicate (lights and ear motions in their case).

De Graaf introduced a six-phase framework of technology acceptance [104]. The phases proceed as follows:

Expectation phase – people learn about a new potential technology, form some expectations about it, and decide whether to introduce it to their home. They try to find out the purpose and use cases for the technology in question, as well as form a mental model about how it might work. Affection is also a part of this, as it forms an attitude towards technology. If people are still unsure about the technology, they may seek opinions of others. Specific factors deemed important at this stage include usefulness and enjoyment [109].

Encounter Phase – the first time people get their hands on the technology, which includes a trial at a store, or observing other people using it. Expectations can break at this point, and non-acceptance can start. The most significant factor at this stage is usefulness, with attitude to use having a significant influence on intention to use [109].

Adoption Phase – an initial decision to buy a given technology. As of itself, it does not mean that the technology is successfully accepted and integrated into the life of a given person, only that a person was curios enough to buy it. Adoption phase also includes initial trials of the technology in the ecologically valid (eco-valid) setting of home. This phase distinguishes early adopters from early majority by means of different expectations each group has of a given technology. Early adopters may be fine with significant changes in behaviour to accommodate the technology, while early majority may be more hesitant. At this stage there forms a cycle between the actual use and habit formation, with usefulness still playing a significant role, together again with attitude to use having a significant influence on intention to use [109]. Enjoyment is a significant factor [109].

Adaptation Phase – trying to adapt the technology to specific user preferences, while learning more about it, and sharing it with others. People attempt to adapt their lives to the technology. It is at this point that they either affirm their use of technology, or reject it. The cycle of habit and actual use continues in this phase, with usefulness and enjoyment again being significant factors [109]. Attitude to use affects the intention to use again in this phase, as well as having in influence on the actual use [109].

Integration Phase – functional dependency forms between the user and the technology, and the technology integrates into the daily life or the user fully. The user might modify the technology, use it differently from what the designers intended, and pay little attention to it, unless it is a primary focus. Usefulness plays a significant role again at this stage, with attitude to use still influencing both intention to use and actual use [109]. What is new at this stage is the growing social and media influence on both attitude to use, intention to use, and habit (which in turn has a small effect on actual use).

Identification Phase – people form a sentimental attachment to the technology, as it transcends being just a functional object. People use the technology in a social sense to differentiate from others, and/or to establish a sense of community with other people using the same technology. The technology becomes a part of self-expression, a status symbol. People seek reaffirmation of their decision to accept the technology, and may still reject it, given conflicting public perception. Given enough positive information, people at this stage may start advocating a given technology to others. At this final stage usefulness is a major influencing variable, with attitude to use still influencing the intention to use, which in turn has a smaller influence on the actual use [109]. Media influence continues to be strong, but adaptability comes as a strong factor on intention to use for the first time in this framework, and so does the cost [109].

While this framework builds analytically on previous work, and has some initial validation, its purpose is only to make the whole process of robot acceptance visible, not to be prescriptive about it. As the authors point out, the process, or even the phases, are not linear, and people in the process of acceptance or rejection of technology may move back and forth between them, skip certain stages, or drop out of the process entirely (Figure 15) [104].

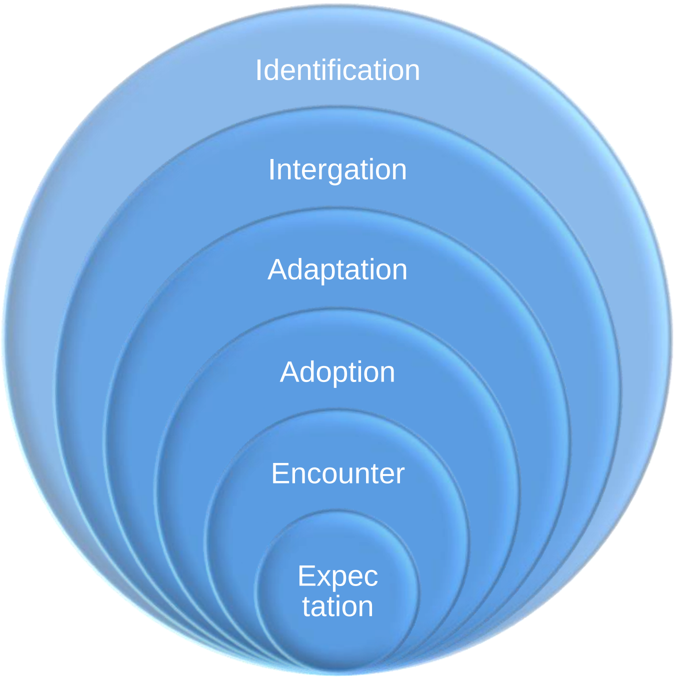

Figure 15. De Graaf's process of robots acceptance as emerging non-binding stages.

The environment of the home has changed significantly in recent years with the increasing popularity of the Internet of Things (IoT), and given that companion robots use IoT extensively, further exploration in search of new factors affecting acceptance of technologies that work in tandem is now necessary.

2.2.3 De Graaf's Design Advice

Compiling her framework into actionable items, de Graaf suggested the following design advice [110]:

1. The utility, usefulness or a relative advantage that the robot provides must be obvious to the user. It is evident that usefulness is a significant influencer at every stage of the acceptance framework.
2. Increased sociability influences robot acceptance in the long-term. The way to implement sociability is by applying results of human-human interaction techniques to human-robot interaction.
3. As people explore the technology, their preferences shift from familiarity and usefulness to attitudinal beliefs, to joy, to social presence, and to sociability. Thus, a given robot's design needs to accommodate all stages of acceptance.
4. Use context – what is in the person's home, what time of day it is, where the robot is, and other contextual factors may have a great effect on robot acceptance.
5. People's experiences with robots act as feedback on attitudes of future users. This feedback loop changes public perception of social robots, thus affecting long-term robot acceptance.

2.2.4 Domestic Robot Ecology (DRE) Framework

DRE is a framework developed by Sung, Grinter and Christensen [289], which was later simplified by Fink et al. [86] and is based off of Roomba robotic vacuum cleaner usage. The reason for including this framework in addition to de Graaf's is threefold:

1. First, it is developed out of the use patterns of a utilitarian robot with visible impact on physical environment (rather than an information provider with little physical influence that Karotz was) which generated a different kind of response both in people and in researchers trying to generalize the experience;
2. Second, it was a mobile robot, which led the researchers to pay attention to the compatibility of the robot with the household it was inhabiting, while Karotz, being a stationary device, received only a passing mention of the importance of the environment on the robot acceptance;
3. Third, the authors created not only a temporal human-centric framework of acceptance, but also a robot-centric model of the home (Figure 16).

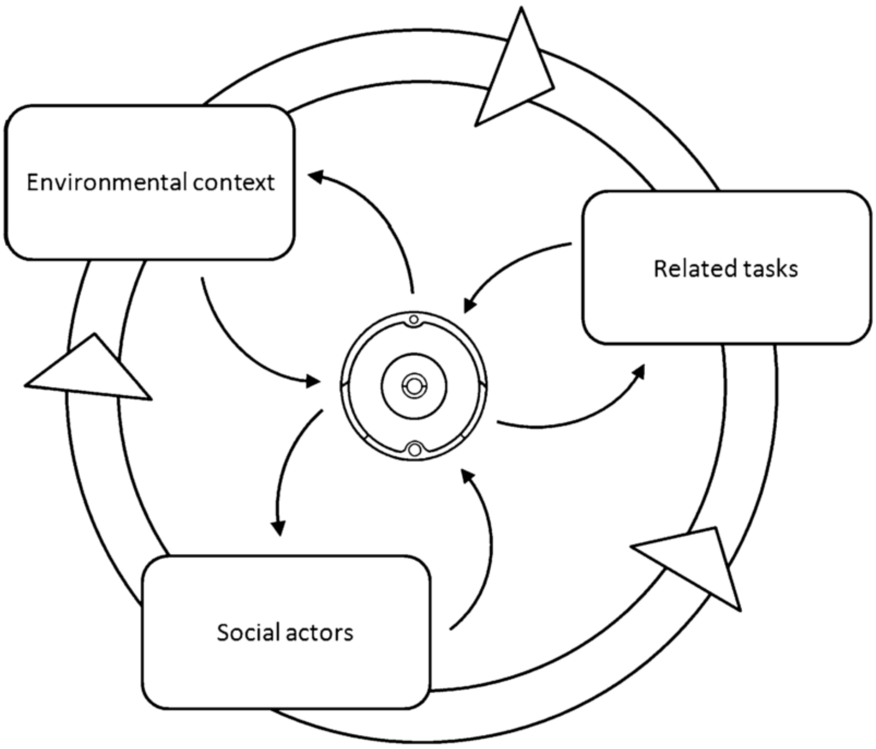

Figure 16. DRE framework – the robot-centric model of the home [86].

The DRE framework is comprised of three key attributes (environmental context, related tasks, and social actors) and four temporal dimensions. The temporal dimensions are:

Pre-adoption – people form expectations about robots, prior to actually having them. People of different profiles (e.g. pet owners, technical experts, older/younger families) form different expectations pertaining both to their knowledge of robotics and to their needs. People expect the robot to be able to navigate the domestic environment independently. Participants expected reliable performance, especially considering the price.

Adoption – people assess their expectations, in terms of both utility and compatibility with the domestic environment. That included attempting to obstruct the robot to see whether it was safe for children, should they bump into it, and running it in the presence of pets to see their reaction. Ascription of social features also takes place at this stage, from anthropomorphism to power dynamics, where e.g. parents used “playtime with Roomba” as a reward for good behaviour of their children.

Adaptation – people learn more about what a robot can do, and what its limits are. This results in an increased use as robots are tested under various conditions. Because the robot made physical changes in the environment (e.g. you could feel less hair/crumbs on the floor with your feet), its usefulness was reaffirmed. People were forgiving of its behaviour because it was “learning” new environments, and took action to prevent accidents. This led to both habitual changes (e.g. putting chairs up every time) and permanent alterations (e.g. cutting off rug tassel to prevent the robot being stuck). Participants both showed off their robot to others, and personalized it by giving it names, or dressing it up. Adapting the robot to other uses (e.g. as an entertainment tool or a conversation starter) was also common.

Use/Retention – robot’s maintenance and storage routines develop, and it is placed so that is neither too obscure so that one would forget about it, nor too obvious, so that it is not in obtrusive.

2.2.5 DRE Design Advice

Compiling practical advice, authors of the DRE framework mention the following [289]:

1. Designers can use the environmental context, user profiles, and tasks characteristics to design interaction scenarios.
2. Managing expectations – people expect seamless performance from a given robot, unless something or someone suggests otherwise.
3. Expressive motions can be used to increase emotional and entertainment value.
4. Robots should be able to inform participants through clear error feedback.
5. Even for a simple utilitarian robot, the ability to act according to social rules can become critical for long-term acceptance.
6. Robots should be able to recognize their given characteristics.
7. Robots need to identify household members and respond differently to offer personalized interactions, such as triggering companion-like relationships with children.
8. Robots should be able to activate self-initiated notifications to users for timely operation and maintenance.

9. Robot exterior design should be carefully crafted, and allow users to customize robots' look and feel to blend in or stand out in their domestic spaces.

2.2.6 Fragments of Acceptance

There have been a number of works that do not attempt to generate a complete picture of how technology in general, or robotics in particular is accepted, however they provide fragments or observations that could be used to compliment more comprehensive frameworks already discussed. I pick some of the most recent ones on the matter, as the overall thinking changes over time as new robots come to the market to challenge the previous notions of what a robot is, or how one interacts with it.

Smarr provided an alternative view on how technology is accepted via a framework that features task-technology fit, perceived ease of use, perceived usefulness, compatibility with physical environment, attitude and intention as the main factors, but without a longitudal component taken into account [275]. Smarr contended that personal robot adoption is not necessarily a rational process, as intentional acceptance in the validation studies was low, while attitude was a much better predictor of acceptance. Factors that participants expressed across two studies to validate the framework included a robot mediating the interaction between people, doing actions humans no longer can, cost, security of the robot from being stolen, speed, efficiency and intelligence (Figure 17).

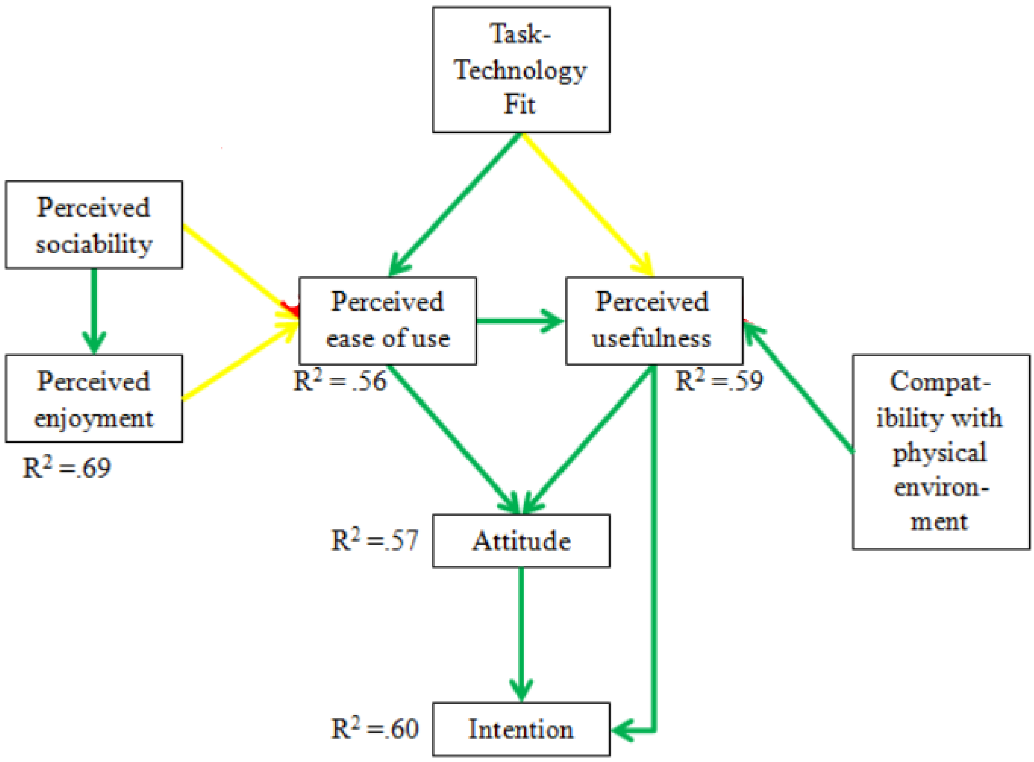

Figure 17. Positive relationships of Smarr's Qualitative Framework of Personal Robot Acceptance confirmed by one path analysis (light) and two paths analysis (dark). Adapted from [275] with unconfirmed factors removed.

Shum, He, and Li discussed chat bots without a dedicated embodiment with an example of XiaoIce and its Japanese version Rinna [273]. They pointed out that the chat bots in China and Japan have become celebrities and cultural icons, participating in many TV shows, delivering weather, news, being TV hosts, &c. [273]. This may contribute towards acceptance of artificial intelligence in general, and in homes as virtual agents in particular, as people are accustomed to their appearances on TV, writing news, and being celebrated.

In their 2018 study of AIBO users, Kertész and Turunen specifically proposed the following design advice for social robots in addition to de Graaf's framework and Leite's 2013 survey [173]:

1. Long-term ownership does not bias the tendencies of robot acceptance or degrade the appreciation towards a robot over several years; however, the owners expressed a desire to incorporate latest technologies into their existing robots.
2. Age and culture may play a role, although a sufficient sample size should be present to distinguish that from individual preferences.
3. The age distribution of the owners remained the same whether they discontinued the robot or not.
4. The robot should not replace the functions of a smart phone or a computer, especially with more hassle. The robot needs to differentiate itself from other machines with unique skills.
5. Do not sacrifice essential skills to reduce the hardware costs otherwise, consumers will not like the robot.
6. The robot must adapt its personality with subtle differences according to the human gender, age, and culture.
7. Older people tend to treat the robot as a toy and they are less positive about its social skills, but they are more enthusiastic to create new content for the robot.

This was based on a questionnaire of 78 long-term AIBO owners who were reached via Facebook, with the majority being Western (vs. Japanese) [173]. The authors concluded:

> *"… The emotional attachment is essential towards social robots. If this connection is missing, it is unlikely that the owner will use the robot for many years without treating it other than a soulless machine"* [173].

There has been very limited information about which factors designers should *avoid* in companion robots specifically or domestic robots in general. Irfan et al. highlighted HRI research field's over-reliance on the methods and results from psychology – a field in which 40%-70% of the results could not be reproduced according to some estimates [50,143].

Li et al. contended that interest in smart home automation (which in its 3rd phase includes companion robots) was correlated with the IT skills of the population [192]. The authors also pointed out that:

> *"Monetary expense remains one of the major motivations in moving towards smart living at home."* [192]

2.2.5 Summary of Advice from Frameworks of Acceptance

Advice from frameworks forms two general categories: temporal advice, pertaining to how factors change over time, and persistent advice – a general advice on how to build a companion robot or what characteristics it should have regardless of a specific period.

Three most stable factors across the reviewed frameworks include usefulness, enjoyment, and cost. Combining De Graaf's and DRE frameworks, robot acceptance temporally proceeds as follows:

1. *Pre-adoption*: potential users form expectations, influenced by prior attitudes, perceived usefulness and enjoyment, perceived reliability, and actual cost.
2. Next, a *trial* takes place where expectations break or are confirmed. User behaviour changes to adapt to the robot and in return users check whether a robot is compatible to their homes and use cases, they have envisioned for it. If the robot is compatible, habits start to form, with usefulness, enjoyment, attitudes and intentions play the key roles.
3. Next, *affirmation or rejection* of the robot takes place, and if the robot is accepted, personalization happens with users trying to make it their own – making personal outfits, displaying it as a status symbol, &c. Usefulness, enjoyment, attitudes and intentions still play the key roles.
4. Finally, if the robot is still accepted, *sustained use* develops, where the robot becomes mundane and maintenance routines develop to sustain the robot in the environment. Users may start advocating the robot to others. Usefulness, habit, adaptability, and cost are the key factors at this stage.

Combining design advice across frameworks and fragments of acceptance, the following general principles can apply:

1. Attitudes, expectations, and mental models have significant influence on both the initial decision to procure a robot, and its subsequent evaluation. Therefore, designers should prioritize setting realistic expectations through marketing materials, user manuals, and other means.
2. Usefulness, enjoyment, and adaptability to the context in which the robot operates are important factors throughout – users will continually evaluate the robot across those.

3. Users evaluate perceived usefulness and enjoyment with respect to the cost of the robot. The value of the robot at the initial stages lies in performance with respect to price (may sound super obvious, but a lot of social robotics research omits cost as a factor entirely).
4. Factors that people use to evaluate a robot change over time and the robot should accommodate that to provide value continuously. The shift is from perceived usefulness and enjoyment to sociability.
5. Ability to conform to social norms and exhibit social gestures like greeting or waving appendages is important, regardless of whether a robot is social or not. People will perceived a mobile autonomous platform as a social actor regardless.
6. Personalized responses to individual users are key at later stages of acceptance. Factors like culture, gender, and age may play a role. If it is possible to provide an individualized response with respect to those factors – it is worth considering.

Temporal advice provides a more realistic look at how robots could become widespread when compared to fiction: authors often write stories about a world where people already live with robots, thus skipping the expectation phase prominent in real robot acceptance, for example. Non-use, together with cost is some of the other aspects rarely portrayed in fiction.

The persistent advice seems to work well with existing successful robotic technologies. Many robotic devices automate manual procedures, which would form a sound basis for expectations of robot operation. Automatic hoovers, pool cleaners, and floor washers use similar materials and methods, and provide similar results to what manual cleaning and washing is like. Some companies advertise robotic automations as utilitarian, highlighting their usefulness, while others advertise their robots as toys or hedonic machines, highlighting the enjoyment one would receive from using them. Several kinds of robots also show adaptability to the context e.g. lawn mowers being able to work on uneven surfaces with multiple types of plants, to DIY robot kits having multiple configurations to suit various needs. Given successful sales over the years, the pricing point for many robots for homes seems right (and is getting cheaper).

However, some factors like changes over time, conformation to social norms, and personalized responses are only starting to emerge in commercially available robots for homes. These factors would be paramount for companion robots, which people expect to both act socially, and be companions with special responses to their owners compared to others. The following sections explore research from both studies of social robots in labs, and in homes, suggesting what a perfect companion robot would look and act like, according to research, not science fiction.

2.3 Companion Robots According to Research

Design considerations provided by de Graaf, DRE, and others are broad trying to cover a wide range of looks and functions domestic robots could take, which limits their appropriation by designers seeking concrete advice on how a given robot should look and act. What is more, the frameworks attempt to generalize from a specific kind of robot that researchers used to construct them, with features and behaviours being limited to the technological developments at the time. As novel devices become available, there is a need to test them against existing frameworks even if to point out that prior thoughts on robots and why people would want them become obsolete.

It is hard to visualize robots concretely from the abstract descriptions that frameworks present. The frameworks broadly illuminate a space of possibilities in which many kinds of robots could fit and manifest. When discussing or presenting, or asking about robots, often a specific representation (or a set thereof) is used. In that vein, I provide a summary of the latest research on some of the aspects of companion robots to try to address the question of a specific design advice. Most if not all of the topics discussed below are interrelated, and I make this separation only to provide some structure and focus, and to collate design advice accordingly.

2.3.1 Robot's Face

The need for a face on a robot may be doubtful for some applications, but companion robots specifically warrant a face for at least one reason: an expressive face is a tool for social signalling [68]. People recognize faces from infancy, and even non-human animals like monkeys can recognize specific faces early, even if reared without ever seeing a face [204]. Thus a companion robot with a face could utilize human brain machinery [83] and social cues derived from faces for better HRI.

Faces on robots could be mechanical, but many are computer-generated on a screen panel. A 2018 online survey with 157 images of robot faces boiled down to 12 representative examples showed that people prefer less realistic and less detailed robot faces for the domestic setting [164]. Most rendered faces in that survey were seen as most fitting to edutainment, and likeable faces were also rated highly on friendliness, trustworthiness, and intelligence [164]. Most robots designed by the developers for homes were perceived to be of other categories, from security to education [164], although the definition and mutual exclusivity of those categories is up for debate.

The overall conclusion seems to be that people like a robot's face for home to be somewhat realistic, while clearly maintaining the delineation that it is a robot. The authors noted the uncanny valley effect that was apparently present when participants rated highly realistic faces [164]. Participants chose Omate Yumi's face as the best-suited face for a domestic robot. The best face detail for a domestic robot was eyebrows (Figure 18).

Figure 18. The highest-rated face for a home robot which also features the highest-rated feature of a face for a home robot (eyebrows) [164].

One thing to note, however, is that the study used static images of faces, not animated ones, which may have a significant effect on perception. The participants rated images of faces, and not a full physical embodiment, which may have also affected the results. What is more, the images were of faces only, and not of bodies with faces, which may have had an effect on the overall evaluation.

A state-of-the-art summary on robotic gaze, reviewed by Admoni and Scassellati [4], discussed several approached to robotic gaze. Human-centric research on gaze suggests that humans have no problem identifying the target or robotic gaze, and having more socially-contingent gaze, as well as more animated behaviour overall improves gaze effectiveness [4].

Design-focused research uncovered a number of social inferences from gaze, like conveying emotions, regulating conversation pace, and establishing faster rapport with humans, as well as improved task cooperation and learning. Much like in the human-centric studies, if gaze is socially appropriate and task-oriented, it improves positive response towards the robot, have positive effect on task completion and recall [4].

When it comes to implementing gaze into a robotic system, three approaches were successful. Biological models produce good gaze, but that is an emergent behaviour, which a designer cannot fully specify. Empirical systems produce a good gaze, but they need pre-collected data to do that. Heuristic systems can be specified very precisely, but may not reflect how gaze actually works in humans [4].

Concluding their review Admoni and Scassellati [4] posited open questions some of which are pertinent to the companion robots:

1. What is the role of the detailed vs. not so detailed implementations of eyes, e.g. do pupils have to dilate to be considered realistic enough to elicit wanted behaviour, or is having just the overall shape enough?
2. How does embodiment of a robot affect the implementation of eyes and gaze? Do eyes have to be physical or digital? Does the robot have to be physical or digital? Is it sufficient for a physical robot to have digital eyes?
3. How can gaze be incorporated with other social behaviours, like mouth movement, speech, gestures?

Robotic mouth, was considered in a study by Castro-Gonzalez, et al. [52], where participants watched online videos of a specific robot with different kinds of animated faces, with a conclusion that if a robot has a mouth, it improves scores on life-likeness, and the shape of the mouth affects how people perceived the robot overall. This points towards a dynamic mouth simulating different impressions to e.g. make people stay away (wave-mouth condition in the experiment), or to come and cooperate (human-like mouth) [52] (Figure 19). The same study also points out that naturalistic observation of faces is always preferable to static or staged ones.

Figure 19. Different types of mouths for different reactions from the user: “stay away” (left), and approachable (right).

Comparing the perceptions of happy and angry human and robot faces, Raffard et al. found that the human faces were perceived differently from robot faces [240]. Positive emotions conveyed by a human face were perceived faster compared to a robot face by the participants, while negative emotions on a robot face were perceived faster than on a human face [240]. Researchers used images instead of real people or robots, however.

Overall, the literature suggests an animated, somewhat detailed face with animated eyes and mouth, and possibly being subtler when displaying negative emotions. For the purposes of testing, it suggests physical manifestations of faces over photos or animations on a screen. The evaluations were very limited, however, highlighting the need to construct real physical robots with the intended faces and expressions. Few if any evaluations were conducted in the domestic setting, and none was a long-term evaluation. All of these factors could have an effect on the results. How applicable these results are specifically to companion robots also remains an open question.

2.3.2 Robot's Form

In the Introduction, I have highlighted three broad categories for the robot shape: humanoid, zoomorphic and abstract. These three categories often surface in the literature. In the brief history of domestic and social robots, there have been many abstract robots for utilitarian purposes winning the market, while zoomorphic and humanoid robots were either toys or robots found in research labs. What does the literature suggest for the designers on the overall shape of companion robots, given this dichotomy between commercial and social?

Having arms and legs, looking anthropomorphic or not, all contribute to ascribing intelligence and character traits [1:149]. Anthropomorphic qualities also had strong influence on ratings of trust in the 2011 meta-analysis by Hancock et al. [113].

Barnes, et al. also suggested humanoid or animal-based shape over an abstract shape [23]. People in that experiment interacted with physical versions of robots for up to ten minutes. Robots were Robosapien, Pleo, Zoomer, Romo, and Lego Mindstorm.

De Graaf's and Ben Allouch's survey of 1162 people forming a similar demographic to the total Dutch population found humanoid robots to be preferred for domestic uses, including butler, companion and information source robot [108]. However, the authors noted that participants associated the choice of shape with what kind of function they imagined a robot to perform to some degree.

Hwang, Park and Hwang [139] tested 27 anthropomorphic shapes of robots based on either rectangular, circular or human-like shapes. The point of the experiment was to figure out which emotions participants would feel with different shapes. Researchers used both visual images and physical prototypes. Three emotions explained 71% of the variance in response: "concerned," "enjoyable" and "favourable." Participants perceived "enjoyable" and "favourable" stronger through real prototypes vs. images.

Złotowski et al. in their discussion on anthropomorphism in HRI proposed that *form of a robot should follow its function*: people would rather have a robot that does a good job, than looking pretty, but being useless [324]. They also pointed out that applying anthropomorphic features to a robot where it seems appropriate could help a robot elicit necessary social reactions from its users. Managing human expectations was still a major problem when creating anthropomorphic robots, however.

Walters et al. suggested that while people overall prefer human-like appearance, there is a significant individual variability which is not consistent with a universal effect [312]. Researchers used videos instead of real robots, although the authors claimed high agreement between videos and live trials for their experiment. Peoplebot was the robot in the video, with a head attached to it to represent the human-like aspect. Other findings include emphasis on expectations management, *form follows function* principle [183], and the need for longer interactions.

Anthropomorphism only works to a degree, however, and once the uncanny valley is reached, there is negative familiarity, with people perceiving robots as creepy [182,185,212]. There are, however, arguments for and against the uncanny valley idea, e.g. Beck, et al. noted [25] that individual differences affect perceived believability of the character, and that believability ≠ realism. Hanson et al. also call for the uncanny valley idea to be reconsidered [116].

Based on an online survey with pictures of robots, but no descriptions of functionality, Hosseini et al. [138] proposed that when novel devices like robots are evaluated, people use existing experiences and heuristics to categorise them, so animal-like, cute-looking and cartoonish robots may be perceived as non-aggressive, and human-shaped robots may be perceived as more familiar. They also agreed that designers should adopt the *form follows function* principle.

Bernotat and Eyssel point out that evaluating a robot overall is important and necessary for design, rather than evaluating it part-by-part [29]. Based on an online survey, participants evaluated the holistic images of robots equally, while evaluating heads-only images differently. Another suggestion was that design and usability ratings were similar regardless of the face, pointing that perhaps specifying a task might yield a different result. All robots shown were humanoid in shape.

A gendered approach to designing robots was also considered [163]. The authors used a physical robot and two types of gender cues: cues on screen, and cues on the physical robot itself. The visual design of the cues was the same in both cases (a men's hat vs. pink earmuffs). The authors concluded that simple on-screen cues can elicit the desired response, while a robot without gender cues was generally perceived as male. Participants interacted with an anthropomorphic robot for a few minutes in a lab condition in this experiment.

Tondu and Bardou suggested that physical appearance cannot be evaluated separately from social perception at least for humanoid robots [300] based on Gestalt theory perspective. They also suggested a high rejection rate if a robot is to perform progressively more affective roles in society, as it is in every way human, but devoid of "soul."

Based on questionnaire responses to printed adverts and videos, Kwak, Kim and Choi [182] proposed a connection between the shape of the robot, the expectations that potential consumers form based on that shape, and the consumer satisfaction about the performance of the robot supporting the *form follows function* principle [183]. They suggested that despite much of the research demonstrating human-looking robots supporting rich social interaction, when it comes to accepting a robot in one's home as a consumer, the abstract-shaped robots that fulfil a specific purpose created moderate user expectations that a given technology could fulfil, thus increasing user satisfaction and acceptance (Figure 20). Conversely, humanoid or animal-based shapes create user expectations that current technologies cannot fulfil, thus resulting in user dissatisfaction, and therefore a potential to reject a given technology.

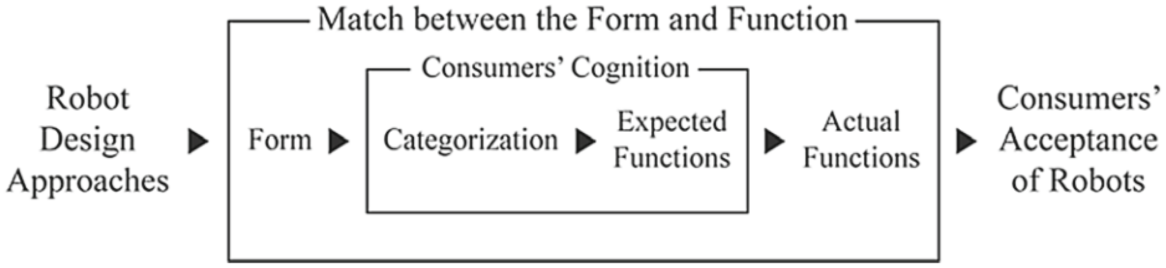

Figure 20. Model of how robot appearances affect consumer acceptance of domestic robots [182].

What is more, there was a significant relation between form and function of a robot, with categorization of abstract-shaped robots mostly into existing function-based product categories like "laundry and cleaning" or "babies and kids", while anthropomorphic robots were delegated to their own category of "robots" without a relation to function [182]. Researchers designed two alternative advertisements for two conditions (playing hide-and-seek and assistive robot for home). The same results occurred.

Paepcke and Takayama also confirmed setting user expectations as an important factor in influencing people's beliefs in robot capabilities and managing disappointment from the shortcomings or robots [228] based on their study with Pleo and AIBO. The manipulation was how the robots were described to the participants (since no participant actually interacted with either before), in that high-expectation group had robots described as having e.g. *"many people-sensing and interactive capabilities"* vs. *"This robot does not have many people-sensing and interactive capabilities."* Participants interacted with robots in a lab setting for a few minutes.

One of the abstract shapes for a robot is that of a drone, which was investigated using a questionnaire, a workshop, and a VR pilot [166]. The overall shape designed because of these activities was a quad-copter drone with a face, eyes, arms, and "machine-like features" (Figure 21).

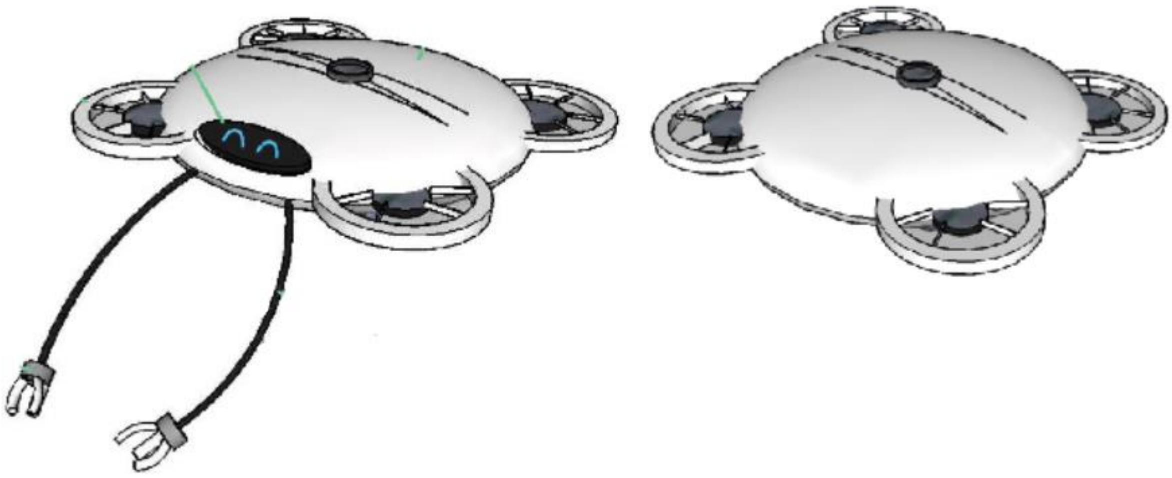

Figure 21. A drone design for home [166].

Design process for creating robots that love and can be loved instigated by Samani, et al. also generated an abstract half-spherical shape [5]. Researchers used a survey about human-to-human and human-to-robot love as a base for their design. Gender difference in design surfaced with males preferring straightedge forms and little expressionism, while females preferred the opposite. When considering the size of the robot, researchers focused on a “pet-sized” or “infant-sized” robot. To match the size, the researchers designed the robot to be lightweight, with the idea that people would carry it around. Researchers built personalization features and made the robot white. The robot reacted to touch and sound. Figure 22 presents the final robot design.

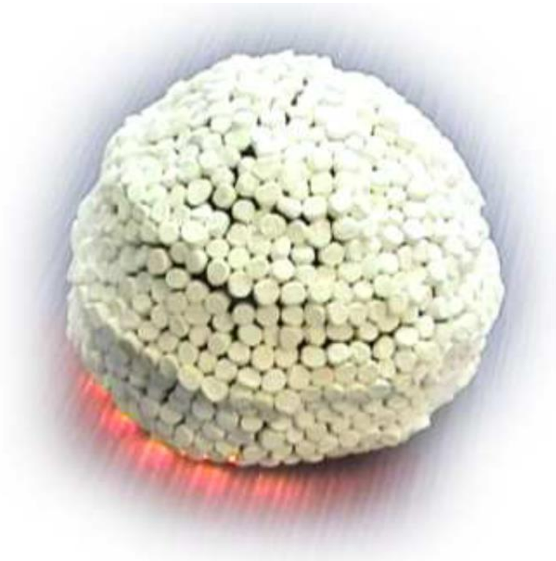

Figure 22. Lovotics robot [5].

Based on 12 images of faces tested in an online survey, Goetz, Kiesler, and Powers suggested that the *form follows function* principle applies to social tasks as well as purely utilitarian ones, in that human-like robots were more preferred for jobs requiring more social skills [94].

Robots with serious demeanour were more complied with when it came to doing exercise and the exercises were performed for longer according to a Wizard of Oz experiment by Sundar et al. [287]. The final test was to see whether participants complied more with the playful robots in playful tasks (creating recipes from jellybeans) vs. with the serious robots in serious tasks (exercising). Participants spent more time on a playful task with a playful robot and more on an exercise task with a serious robot.

Even with the idea that abstract-shaped robots might be better for homes, there is a significant difference as to the kind of shape. Acceptance/Rejection of abstract-shaped robots in children was investigated by Shiomi et al. [271], with the environment of a typical playroom. Sphero, Romo, and ChiCaRo were the choice of physical robots with two hours of free interaction. All robots were of abstract shapes, however the acceptance and rejection of differently looking robots within this group was different. Sphero – a ball-shaped robot was rejected the least (and thus accepted the most), while Romo – a "phone-on-wheels" robot was rejected the most (and thus accepted the least). The authors did not venture a guess as to why.

Categorization of robots into existing product categories [182], together with the idea of creating incrementally newer products that function largely similar to existing products [7] indicates that many currently proposed companion robots would fall flat in sales, while smart speakers – being a marginal improvement over wireless speakers overall would have comparatively more success.

Overall, the literature suggests an abstract shape to moderate expectations, with the overall shape and features directly relating to the robot's functionality (and a possible preference for utility vs. emotional benefit [182]). For the purposes of testing, it suggests longer tests with physical robots. This poses a counter-point to the sci-fi representation of companion robots, which authors often portray as humanoid. However, as the *form follows function* principle seems to be one of the key components for a successful companion robot, what kinds of functions would a companion robot perform? Sci-fi suggests universal functionality, while existing robots suggest automation of a very limited task set. What does research have to say about companion robots' functionality?

2.3.3 Functionality

As discussed in the Introduction, people's perceptions of robots could largely come from fiction [139], which forms unrealistic expectations about what people want from robots in reality. Abstract shape was the preferred approach to moderate such expectations in the discussion on robot's form. However, a robot's form could have a significant effect on its functionality. I discuss the desired functionality of companion robots below.

A systematic review of robots for the elderly identified three main problems that companion robots could address: dependent living (bathing, cooking, cleaning), social isolation (usually through telepresence), and lack of recreation (robots would suggest and/or assist in leisure activities) [272]. Between social isolation, compensation for a physical or a cognitive impairment, and suggestions for recreation, the authors cited *companion robot* as most desirable across the reviewed papers in all environments, not just homes.

In her keynote lecture, Dautenhahn emphasised robots as mediators for children with autism as well as the elderly, and pointed out that functionality of the companion robots should utilize the strengths that robots have, and compliment human strengths [70].

Bringing items, giving news updates, cleaning, cooking, and optionally following around were the activities assigned to a drone companion robot based on a multiple choice questionnaire that was distributed via personal social media networks [166].

A 1162 sample similar to the overall Dutch population was used [107] to evaluate acceptance of companion robots for a role of a butler, a companion and an information source. Participants evaluated companion robots most negatively, while there was a preference for specific forms to do specific roles, e.g. animal-looking robots as pets.

Malle and Thapa Magar conducted a survey about the kinds of capabilities people liked in potential robots [199]. Participants rated empathy with humans, having moral values, goals, logical and rational thinking, and ability to explain their own actions, as well as sensory capabilities (feeling heat, pressure, &c.) as desirable regardless of robot type (military, home or nursing). Having emotions, ability to blame for immoral behaviour, preferences for specific people vs. others, and feelings of pain or stress were highly undesirable. Those factors only explained 65% of variance, however.

John, Rigo and Barbosa pointed out that being multimodal, the robots could be built to adapt to the needs of populations with various impairments [158]. They introduced a humanoid robot prototype to the users with various degrees of visual or hearing impairment, and allowed them to interact for up to fifteen minutes. Authors used a questionnaire for data collection. The authors pointed out that apart from speech and text-based modality, sign language was a viable route, which some users may be prefer.

A focus group was conducted to explore what independently living elders would want a robot to do by Alves-Oliveira et al. [291:11]. Participants had to choose out of six pictures of robots towards the end of the discussion. The outcomes seem to point towards a companion robot with many functions, from medication regimen, to helping around the house, to maintaining personal hygiene of the participants, to going outside to get groceries, play games, and go to the cinema with the participants. *I, Robot* [18] in short.

Smart homes with social robots as the environments for the independently living elderly are a widely considered possibility in HRI research with multitude of trials taking place in multiple countries. A workshop by Kon, Lam, and Chan presented the overview of how smart homes may help the elderly, with implications for my consideration being personal hygiene, social engagement, safety, nutrition, and physical activity [178]. The authors also noted that researchers mostly focused on prevention of life-threatening conditions, and less on personal hygiene and care, social engagement, or leisure.

Companion robot as a centrepiece for home automation was also demonstrated in the design and research work by Luria et al. [197]. Their core design goal included engaging, unobtrusive, device-like, respectful, and reassuring kind of robots. The implementation of that goal included physical objects representing smart home devices, which participants used to control them. The robot used socially expressive and peripheral gestures together with subtle changes in idle movement to alert inhabitants (rather than traditional notifications). An abstract shape with a monocular dot simulated facial expressions. Rising when a user is nearby, and returning to a neutral pose when a user walks away was a typical behaviour. The robot utilised short acknowledgment movements and sounds. The researchers have set this in a lab setting.

All in all, the desires of various populations seem to align closely to the fictional portrayals of companion robots [324], while researchers mostly focus on assistive robots for the infirm, perhaps putting a stigma on using a robot as an assistant, instead of focusing on leisure, or social engagement that the population seem to want from companion robots. People want a companion robot, which would help them be the best they could be.

2.3.4 Trusting Robots

Overall, research on human trust towards autonomous system has been limited with respect to companion robots, and the general findings for other autonomous systems seeming contradictory [1:138]. While a universal definition of trust is not yet established, trusting an autonomous system (which a companion robot is) can affect the decision to continuously use it [1:8]. Trust is a dynamic relationship, which researchers must observe over time. There is no consensus about whether human-robot trust plays out the same ways as human-human trust [1:10.1.2].

Gaudiello et al. conducted an experiment in the lab with a humanoid robot which suggested that trust is part of the acceptance of social robots, although it is severely dependent on the nature of that task at hand, e.g. participants were more trusting when the task the robot performed was functional rather than social [92]. On the other hand, people who did trust the robot on social issues were less trusting of it in functional issues. The authors suggest that one cannot assimilate trust in social robots to either trust in computers or trust in humans. Desire for control was related to trust in robots, which points to user-specific profiles for robots (e.g. people who need more asserted control as part of their personality are more likely accept a highly controllable and customizable robot). Other factors were user intentions, and habits. The experiment lasted for several minutes, and researchers used questionnaires to collect data.

Trust seems to have both rational and irrational components, and is dependent on the consequences of trusting [1:9.7]. Typical examples of irrational fear are risks associated with nuclear power, nanotechnology, and climate change, with immediate disastrous consequences being of very low probability. On the other hand, people are likely to be overly complacent about risks that are familiar, voluntary, and visible. Examples of this kind of risks include driving a car, using a firearm, or using power tools [1:196].

Salem et al. suggested that faulty robots do not reduce trust, however that could largely be moderated by the irreversibility and severity of the effects of the task [257]. The experiment ran in a model of a home with an embodied robot. It lasted about 30 minutes per participant.

When the operator understands the system, it has a positive impact on trust, however. Experienced operators familiar with the faults, were not necessarily less trustworthy of the system when it did fault [1:140]. A system's ability to explain its reasoning also contributed towards human trust [1:140]. Indeed, it is proposed that designing systems that can explain their faults could contribute positively to repair of trust, once it has been breached [309].

This may only extend to some degree, however, as at least one small study suggests that conversational agents like Siri is opaque to a degree that not knowing how it works, but having experience with it improves global usability vs. having technical knowledge about AI, but not visceral experience [55].

Social robots specifically introduce additional dimensions to trust. For example, robot's appearance can play a role in how their intelligence and reliability are assessed prior to any actual interaction or even a statement about what the robot's purpose was [1:8.6.2].

Shaefer et al. too suggest that robot shape has an effect on trust, with the biggest factor being perceived intelligence of the robot [264]. For entertainment, service, and social robots perceived intelligence accounted for 34.9%, 37.4%, and 38.2% of trustworthiness respectively. Researchers connected trustworthiness with the intent to use. The experiment only used the images of robots, however. Participants filled in questionnaires.

Robot attributes like performance with moderate effect of the environment were deemed the most important in trusting the robot, with human factors having little effect in a meta-analysis by Hancock et al. [113].

Churamani et al. pointed out that while the interactive module on their NICO robot was perceived as more intelligent and likeable, it was also perceived as less safe, and thus having lower social influence [59]. Researchers used a questionnaire for data collection. The interaction lasted for 30 minutes. Participants taught a robot to recognize objects, and checked whether the recognition worked.

Measuring trust remains elusive. The Trust Perception Scale-HRI, for example, shows capability, behaviour, task, and appearance as major factors. Questionnaires may be the most direct ways to measure trust, but their numerous limitations including intrusiveness and the ability to measure trust only at one point, rather than moment to moment (which is more realistic, with trust being a dynamic relationship), using them remains of limited applicability.

> *"It seems unlikely that a single scale or battery of scales will be adequate for all types and contexts of HRI, and that as AI and related technologies advance, the measurement of trust in automatons will need revising."* [1:189]

2.3.5 Companion Robot Security

Having dealt with the human aspect of *trusting* a technology, there is a need to address the security and privacy of companion robots regardless of whether one *thinks* companion robots are safe or not.

As Miller, Williams and Perouli pointed out [210], there is very limited research on the topic. Robot Operating System (ROS) authenticating vulnerabilities were assessed and the counter-measures were developed by Jeong et al., demonstrating current vulnerabilities of this open source operating system [152]. IoT technologies in general suffer from security vulnerabilities [206], of which robots or devices that interact with robots can be considered part of. Denning et al. formulated a number of suggestion and demonstrated a number of attack scenarios for companion robots as far back as 2005 [71], citing both physical, intelligence, and social damage that could be done by adversaries via companion robots.

A 2018 case study/late-breaking report by Miller, Williams and Perouli of an undisclosed social robot [210] described ways social robots could be compromised by means of lack of authentication on the robot. This included a GUI-based programming interface that did not check who did the programming, could connect to any of the robots on the same network, and override any current task a robot performs. Remote code execution was also possible without authentication, provided an adversary knew IP address of the robot and the listening port (neither is hard to acquire). Finally, checking for robot status, list of running processes, logs and live camera did not require authentication either, so spying on residents through robots was at the time possible by any sufficiently educated party. SSH connection was left to the prudence of the user, with the same default login and password + root login and password for each robot. While changing a password for a default user is a reasonable action, and root user cannot be accessed via SSH, it was possible to execute a command remotely to add a user with root privileges accessible via SSH. It may also not occur to people to change login details on the robot from default for various reasons from being afraid to break the robot they know little about, to thinking that the default settings are secure.

Smart speakers have piqued interest of forensic scientists as well. Chung, Park and Lee devised a forensic tool that utilizes both client-based and cloud-based information from Alexa-enabled devices [58].

There have been a number of alternative system and add-ons proposed to alleviate some of the security issues. For smart speakers specifically, Alanwar et al. presented a sonar-based defence mechanism that would send a sound pulse to determine whether there is a person in the room (as opposed to a command via another device with a speaker e.g. a compromised TV) [6]. Another way to mitigate voice-based attacks was proposed by Feng, Fawaz, and Shin, who demonstrated a system that matched voice commands to the vibrations of a person's body with respect to what they were saying in an attempt to provide a continuous voice authentication [84]. To mitigate the overhearing of continuously listening devices like smart speakers, Islam, Islam and Nirjon proposed SoundSifter – a technology that filters incoming audio before it is processed by the smart speakers, thus reducing leakage of personal information when it is unwanted [147].

Some organisations take it in their hands to promote privacy of individuals with one example being The Big Brother Awards – a group of academics, rights groups and other concerned parties. In recent awards held in Germany (April 2018) Amazon Alexa was the winner of the *Consumer Protection* category, showing the growing privacy concern for the product [79].

Another example of an organisation supporting both trust in and security of digital market is the European Commission, which published a scientific opinion, emphasizing user choice and engagement, privacy and compliance, as well as further development of the European cybersecurity industry [47].

Overall:

> *"Given the novelty of robots for the majority of the population, along with the well-known fact […] that people seem to be influenced very easily and for trivial reasons, it would be useful to perform longer duration studies to investigate the transient nature of trust assessments."* [1:151]

2.3.6 Social Features

Interfacing is the key differentiator between social robots and other kinds of robots, as it should happen in a natural, human-like way. Such human-like way could include verbal and non-verbal interfacing, tactile, speech, gesture, behaviour, facial expression and gaze, and neural computer interfaces as modalities [167]. To date however, robots are nowhere near human-level communication capabilities.

2.3.6.1 Speech

Opinions on voice were surveyed with Taiwanese 50+ year olds, who watched a video of a social robot, and later a selection of 8 voices (2x2x2 on gender, age (50 or 20 year old voices), and introvert/extrovert) as experimental condition, with the conclusion that while on average, people preferred female, extroverted voices, variations on perceptions remained [54]. It is unclear whether different languages and cultures would feel the same with similar pitch, intonation, and speech rate. Furthermore, why participants rate specific kinds of voices consistently one way or other remains an unanswered question, with possible explanations ranging from brainwashing and ingrained expectations, to the *form follows function* principle. None the less, the study proposed an adaptable voice for an assistant robot – something not currently implemented [54]. This preference may not be suitable in all cases, given the previous observation where robots with serious demeanour were more effective in making people exercise, while robots with a playful demeanour were more successful in keeping people playing for longer [287].

The ability for a companion robot to speak various languages had certain other attributions ascribed to it, e.g. knowledge of Chinese made people think the robot knows more about Chinese landmarks vs. a robot who spoke English [263]. In this experiment, participants watched a robot interacting with a researcher in either Cantonese or English. Researchers told them that the robot was made in either Hong Kong or New York. They were later given a set of photos of well-known and obscure landmarks in Hong Kong and New York and were asked to estimate whether each of the robots knew those landmarks. Researchers used a humanoid robot in this experiment.

Semantic-free utterances (SFUs) as means for conveying emotion were reviewed by Yilmazyildiz et al. [319] with the conclusion that this fields needs a deeper comprehensive study. The reviewed research had not investigated context dependency, for instance. At the same time, SFUs offer a lucrative way to express robotic emotions, which is not language-dependent, although cross-language, and cross-cultural studies to confirm this have not been conducted. SFUs as part of multi-modal interaction also improves emotion recognition [319]. That said, robot morphology (its looks and abilities) plays an important role in whether SFUs are effective or not (non-auditory robots will have no affordance to use SFUs, as an extreme example).

Overall, recent research on robot speech has several research directions to follow, albeit with not strong preference as to which one is better. While it may be that extroverted female voice is most suitable, SFUs, context, and language could be significant mediators of that proposition.

2.3.6.2 Body language

Bremner and Leonards suggested that speech in combination with gestures could be understood equally well whether a human or a robot performs them [42]. Participants looked at demonstrations of speech alone, movement alone or both. When robot was demonstrating those, it was a physically present robot. Human demonstrations were on video. The experiment was performed in a lab.

Tsiourti et al. [303] also agree on multimodal expression of emotional information, including face, posture, head and motion, with the suggestion that higher anthropomorphism does not necessarily correlate with higher emotion recognition. Researchers showed participants videos of two robots in an online questionnaire to suggest this.

Rosenthal-von der Pütten, Krämer, and Herrmann suggested that user perceptions of robots are affected in a linear way from no non-verbal behaviour, to robotic non-verbal behaviour (LED lights), to human-like non-verbal behaviour [254]. Researchers used NAO robot, with a questionnaire to collect data. Nao told participants two stories: a happy and a sad one, and asked participants to tell a story back. The experiment included six minutes of interaction. 20 minutes for the experiment total (including filling in all the questionnaires).

Kennedy, Baxter, and Belpaeme suggest using nonverbal immediacy (as displayed by hand gestures, gaze, posture, moving towards/away from participant) as a measure for human-robot social interaction [172]. Researchers used NAO physical robot. Study was to recall a short story, done in the lab. Questionnaires were used to collect data.

Emotional body language was tested with humanoid robot NAO by Beck et al. [25] with the overall conclusion that it is an appropriate medium to convey emotions. Participants in their study recognised emotional poses of robots and human comparatively, while recognising coded poses of NAO was *"better than chance"* [25]. Comparative videos were used. Head position of a physical robot was also evaluated [25], with the conclusion that having a head all the way up increased arousal, valence and stance, while moving head all the way down decreased them. Combining the head with the body, and mixing various poses, a third test was done, with the conclusion that a robot should move consistently with how it looks, e.g. that a robot should use stylized/exaggerated emotional stances to be more understandable and believable (again *form follows function*). This study tested poses, not animated movement, however.

Thimmesch-Gill, Harder, and Koutstaal [298] pointed out that while overall evaluation of emotional poses was similar between a physical robot, and a digital counterpart, physical robot's poses were rated as more positive and more animate. NAO robot was used for physical robot, and VR was used for the virtual environment with a digital version of NAO.

Overall, the body language of companion robots seem to be a useful vector to express emotions and convey meaning.

2.3.6.3 Behaviour

Koyama et al. discussed how to implement both affective cues (e.g. human involuntary muscle movement around eyes), and social cues (e.g. human voluntary muscle movement around the mouth) into a robot. They pointed out that while human likeness and sociality are positively evaluated with such a system in a robot, and social expression works effectively for low-level social bonding, an affective system is required for higher-level social bonding, like wanting to live with someone [180]. Researchers used a highly anthropomorphic robot with two minutes of dialogue, and a questionnaire to collect data. All was in a lab. This presents an interesting addition to the idea that robot's emotions should be moderated, as in this specific example robots could act like humans would: expressing true emotions with parts of their body, while expressing socially acceptable emotions with other parts, much like humans would use their face.

Robots giving positive or no social feedback had no significant influence on self-esteem, while negative feedback lowered self-esteem in a study by Nash et al. [215]. But even with the negative feedback, there were no observed effects on attitude towards robot, or the intention to use it in everyday life [215]. Authors used a physical robot (Baxter) to play a physical game (connect 4). The study was conducted in a lab. The authors also pointed out that further research is needed to establish whether these findings can be generalized to other robots [215].

Sebo et al. made a connection between vulnerable behaviour expressed by a robot and trust [286]. They found that not only people engaged more with the robot making vulnerable statements and admitting its failures, but also they helped each other ease tension within the group, suggesting rippling effects of robot's vulnerability to the human part of the team. Researchers used a physical robot (NAO). There were thirty rounds of collaborative game x 55 seconds each = 27.5 minutes worth of interaction. The participants knew, however, that the game was rigged to fail at certain points. Participants played the game tablets, and the robot did not do anything physically. It just talked.

Social behaviour triggered by actions of others have been explored by Jeong et al. with their prototype Fribo [151]. Their prototype promoted social interaction between people, while lessening privacy concerns. Researchers also focused on a specific user group, rather than a *one size fits all* approach. Participants first took an online survey to determine home activities and associated privacy concerns to share with others through the robot. Then some were recruited for an experimental study, which would provide guidelines to construct the first prototype design for the next stage. Then, they participated in a 4-week field study with the prototype in their homes. Researchers used both interviews (weekly) and diaries to collect information.

Tsukada and Niitsuma demonstrated that congruency between user's mental model and robot's behaviour positively affect HRI [304]. Researchers based their findings on participants interacting with a real robot for ten minutes. They collected interviews as their data.

Rivoire and Lim investigated proactivity of a companion robot Pepper in a domestic environment over an 8-week deployment, positing that too little proactivity was considered boring and too much proactivity was considered annoying. Their observations suggest ambient activity in the robot was most preferred, while other patterns were dependent on the specific household in question [248].

Overall, a careful expression of emotions through body language, vulnerable behaviour, and some level of proactivity seem a good way to describe a companion robot's behaviour. Congruence between expectations of robot behaviour and the behaviour itself would also help, although that depends on exactly the kind of mental models that users would have.

2.3.6.4 Personality

Comparing dogs to robots, Konok et al. found emotions, personality and showing attachment as key advantages of dogs over robots (and noted that those behaviours could be implemented in robots) [179]. There was a gender differences with more females considering robots to be dangerous in the future. When it came to behaviour, participants considered human-like communication, ability to learn, personality, minor disobedience or flaws, preference and proximity to the master, and overt stress behaviour when the master is not around as important. Connecting physical embodiment and social behaviour, participants suggested that initiation of physical contact, if it is safe, enjoyable, and approved by a given user contributed to social behaviour. Participants considered empathy important as well.

Paiva et al. reviewed empathy in humans and robots [230]. Throughout literature, participants considered face, mouth, head movement, and voice as key ways through which empathy was invoked. However, many challenges remain in the field, e.g. the influence of context, lack of fully autonomous expressions of empathy (e.g. a large number of Wizard of Oz experiments or videos rather than real robots programmed to express emotions autonomously). Researchers noted the lack of standardized measurements (or a clear idea about exactly what to measure), whether the theoretical background/models from psychology are appropriate, authenticity of robot emotions, and long-term interaction as open problems. Most studies on empathy in that review were short-term, while empathy building in humans tends to be long-term, suggesting the need to study real robots, and observing human-robot empathy building over longer periods.

Garcia suggested using personas to quickly provide rich social interactions, while limiting the need to collect individual data [90]. The approach is promising, however challenging, and requires further refinement before it could be implemented. Two experiments, were conducted at the UH Robot House. Researchers conducted the experiment in the UH Robot House, which contained several robots. According to the research outcomes, it has been challenging to determine a precise and general definition of the persona-based computational behaviour model. Modelling people was hard, and similarly characterized people did not choose similar features in the robots. The difficulty of finding a match between users and personas was the most challenging issue. The overall results highlight the importance of personalisation of robot behaviours and their adaptation to the final users.

Baraka and Veloso [291:61] showcased models of three types of users: the conservative user, who wanted a particular action from a robot mostly consistently, with a few surprises thrown in; a consistent but fatigable user, who wanted consistent actions, but changing types of action over time; and erratic user, who did not care about specific actions, so long as those actions changed over time. The authors used an algorithm to program a robot to display patterns of lights switching on and off, and allowed the users to rate the patterns so that an algorithm would learn what the users wanted. The model was successfully tested, demonstrating that a robot, given a specific type of user, can adapt to even changing preferences.

The automation of continuously creating fresh robot behaviours via stochastic selection of robot actions was explored by Grollman [111]. Grollman encoded various drives (e.g. charging, seeking out humans, &c.) into a mobile robot with various probabilities for the intensity of each behaviour, and demonstrated how that creates veracious characters for a robot starting from the same condition. Qualitatively, naïve users observed these robots in the lab or a pre-made living room environment and informally discussed the robots, with the conclusion that they could perceive the differences encoded in the way Grollman proposed. The experiment only tested for motion, however, and nothing else.

Ojha, Williams, and Johnston developed a model for tempering robot emotions, arguing that robot emotions should not only be believable, but also ethically tempered [222].

A look at algorithms influenced by simulated cognitive biases by Biswas and Murray [32] suggested that humans prefer biased algorithms. The biases in question were misattribution, empathy gap, Dunning-Kruger effect, humorous effect, and self-serving bias. Researchers programmed three robots to simulate those biases (ERWIN (humanoid), MyKeepon (zoomorphic), MARC (humanoid)). Participants interacted with a physical robot in three sessions in a lab. Researchers used questionnaires to collect data. The authors suggested that biased robots promote long-term HRI.

Lucas et al. investigated whether social rapport could ease the negative perceptions of robots which make mistakes, with the conclusions that not only rapport was not effective, but people perceived the robot with rapport building and mistakes more negatively than a robot that did not build rapport or made mistakes [195]. Researches used NAO robot and conducted the experiment in a lab.

Tay et al. suggest that designers can enrich HRI with humour, although types of jokes should be selected carefully [292]. Participants evaluated videos of either a human or a NAO robot telling them four types of jokes, with three jokes per type. Researchers conducted the experiment in a lab with face-capture. Participants perceived non-disparaging jokes by a human actor better compared to the same jokes performed by a robot. Otherwise the reactions to the jokes (as to how humorous, offensive and whether participants were willing to share the jokes with their social network) was similar.

Overall, while personality as such seems a positive and even necessary thing for a companion robot to have, the kind of personality that would be suitable to any given user remains elusive. It seems that personalities adapting to specific people would be the most viable (albeit very difficult) route.

2.3.6.5 Personification & Human-Robot Relationships

One of the common questions about social robots is, *“do I address the robot as a he, a she or it?”* This may well be because one sees a social robot as “alive” or at least as having agency, a habitual response based upon human-human communication, or any number of other reasons.

Krenn, Gross and Nußbaumer, for instance, compared German language pronouns *du (you – singular), ich (I),* and *wir (we/us)* in how they are used when talking with people and robots [181]. They suggest that use and interpretation of personal pronouns are context-dependent, and differ from meta-communication vs. task-related communication. Participants in this experiment explained certain tasks to either a camera, a human learner, or a robot. Researchers used a real robot for the robot part of the task explanation, and performed the experiment in a lab.

Pitsch suggested to move from the question of *“whether the robot and the human can understand each other”* to *“whether a human and a robot can solve a communication task* *together"*, thus providing a basis of moving away from *us vs. them* attitude in robots, and towards *us as a team with a task at hand* view [237].

De Graaf posited that there is nothing wrong with human-robot relationships, given that much like humans performing for each other socially, robots doing so could contribute to the good life of people under certain circumstances [106].

Addressing the question of whether it is possible to love an artificial partner, Ryoko Asai provided a unique view on how some people interact with dating simulators [16]. Using *THE iDOLM@STER* dating sim as an example, and interviewing long-term users in Japan, she concluded that having the feeling of love and sexual desire towards a non-organic partner is definitely a possibility.

In trying to evaluate the *kind* of love people could experience towards robots, and perceive from robots, Samani adapted love attitude scale and used it in conjunction with his Lovotics robot [260]. His participants interacted with a Lovotics robot for 2 hours, and preferred *Storge* (affection which develops from friendship) love towards the robot, and *Ludus* (affection from fun of playing) love from robot to human. The smallest value was *Mania* (obsessive need for love).

When it comes to empathy towards robots, Seo et al. suggest using a physical robot as preferable when compared to a virtual simulation [268]. Their experiment involved a physical robot, a mixed-reality simulation, and an on-screen 3D simulated robot. In this lab experiment, participants went through a scenario, where a robot would build rapport, express fear, and had that fear realized, creating an empathetic situation.

A survey of how robots could detect emotions in humans was done by McColl et al. [203]. In their view, while there have been systems implemented which were capable of identifying human emotions from facial expressions, body language, voice, and physiological signals, there remain several challenges in this specific endeavour. These challenged included a limited number of kinds of affects a system can detect (vs. the multitude that humans can express), the position of human face and body with relation to robot sensors (strictly frontal position is mostly discussed), lack of consensus on how many features to measure in multimodal systems, and which ones to choose, lack of granularity (i.e. detecting the person is stressed vs. detecting *how* stressed the person is), lack of testing of these systems in combination with the social robots in everyday environments, and using existing databases to train algorithms vs. using real life actors in the visceral environments.

Overall, despite all the advances in human-like communication over the past decades, robots are nowhere near human-level communication capabilities.

2.4 Studies of Populations

So far, the review of literature focused on specific features a companion robot should have. With respect to appearance, these included a somewhat detailed face, which maintained a clearly robotic look, and a preference towards a more abstract shape with *form follows function* principle behind it. Concerning functionality, a set that resembles the universality of human activities, from physical and social support to entertainment was preferred. To secure the elusive feeling of trust, there is a need to both understand the system, and have the ability for the companion robot to repair trust by explaining why it took the actions it did. Trust is especially important given the link between trusting and irreversibility of the desired actions a companion robot could perform. Companion robots need to have improved security comparable to the threats they could pose if hacked. Finally, social features of companion robots should include speech, body language, behaviour and personality, although there is little consensus on the details of those features.

There is also a notion, that social robots would best serve specific user groups, rather than simply everyone. It is important to consider how different *people* perceive companion robots. There have been a number of studies focusing specifically on testing of how different populations perceive robots, which is the focus of this section. It includes both short-term demos performed in the labs, and longer-term deployments in participants' actual homes.

Modelling two types of behaviour (agreeable vs. non-agreeable) in a Wizard of Oz experiment showed a statistical differences between how younger children react compared to the older ones, when playing a game of guiding a robot through a maze [201]. Researchers used Lego Mindstorm EV3 physical robot, and a questionnaire to collect data. Lab and classroom were the tests' locations. They identified three groups by age: 6-7 years, 8-9 years, and 10-11 years. The authors concluded that age of a child is a relevant factor when designing a social robot, but not gender. The authors point out that 6-7 age group did not notice the differences in robot personality (agreeable vs. disagreeable), was more tolerant towards disagreeableness, and had higher adherence to a non-collaborative robot, compared to 10-11 age group.

Mental models of children and parents were explored with regards to *always on, always listening* toys by McReynolds et al. [205]. In their experiment, parents mainly voice privacy concerns about these toys, while children were mostly unaware that the toys could record and transmit their interactions. Children were also mostly unimpressed with the capabilities of the toys presented (Hello Barbie and CogniToys Dino). Researchers conducted this experiment in a domestic environment with child-parents pairs, followed by 40-70 minute interviews.

A study of whether robot’s personalization through disclosing private information affected robot’s evaluation by children was conducted by Leite and Lehman [190]. WoZ was used with humanoid “torso + head” combo. Researchers performed this experiment in a lab as part of several experiments (2 hours interaction between 4 experiments). Authors point out those children who were 7-10 years old reacted more negatively (as perceived by their parents) to privacy violation vs. younger children (both groups noticed the violation took place, though). However, a single-event violation did not produce negative evaluations of the robot when compared to the control group. The violation was of minimal importance to the children.

Gender perception of robots in children was studied by Sandygulova and O’Hare [261]. Two groups of children differentiated by age (5-8 years old vs. 9-12 years old) interacted with a humanoid robot NAO that communicated with synthesized female and male voices. The main conclusion was that children aged 5-8 could not attribute gender to the robot based on voice alone, and preferred to assign a robot a gender like their own. Children aged 9-12 did not have a preference of whether a robot had a matching gender to their own. Interaction was with NAO for 10 minutes. Researchers used interviews and questionnaires to collect data.

Another study on gender perception and uncanniness of robots perceived by children was conducted by Paetzel et al. [229]. Researchers used a Furhat robot, with face/voice incongruence (face either male or female + voice either male or female). Children between 8 and 13 years (with 91% of the children ≥ 11 years) participated. Views collected via a questionnaire. The authors concluded that children did not feel uncanny when voice and face did not match, and relied on voice to identify gender much more than on the face (which is expected given that the structure of the face was the same and was perceived as “strongly masculine” without any texture as authors themselves notice).

Teen perception of social robots was explored by Rose and Björling [253] as part of their project on measuring teen stress through social robots. Reviewing existing robots, teens viewed the appearance of Jibo in the most positive light out of the four robots demonstrated to them. Simple, abstract design was praised (tablet-on-wheels was usually drawn by the participants), general assistance was seen as a strong purpose of a social robot, and comprehensive social capabilities (including varied moods and responses) were requested. Three groups of teenagers participated: 12-14 group, 12-17 group, and 14-18 group). Researchers used participatory design sessions with interviews and storyboards, and later low-fidelity prototypes as data gathering methods.

Perception of social robots by Portuguese adults was investigated with a free-association questionnaire by Piçarra et al. [235]. They posited that participants perceived social robots as tools, rather than companions, and the ideas about social robots were organised around the notions of technology, help, and future. There were some differences in perception by gender, age, and education. As the authors put it:

> *"Robots are for men a form of intelligence to be controlled and mastered (programming) associated with work, while they are for women technological tools to be used in a domestic context, and a technology also seen in movies."* [235]

For age-based difference, researchers identified two groups: those above 32 years of age (32 being the median for the overall sample), and those below it. For the younger group, robots were connected with the idea of technology in a very diverse sense, from artificial intelligence to what they are portrayed in films. For the older group, the notion was associated with help and future, unemployment, and replacing people with machines. For education, those with up to 12 years of schooling saw robots as help, and divided them into industrial robots and those they would see in film. The university-degree participants focused on technology and artificial intelligence in their discussions of robots.

A study comparing children and adults in their reactions to what domestic robots should do was conducted in Japan [175]. The study collected the views from museum visitors (27 adults, 29 children). Researchers used a questionnaire to collect the data. Participants choose one of four types of robots (housework, communicating, healthcare, and pet), and whether robots needed to be friends. More children wanted communicating robots than adults, which authors suggest was due to children having imaginary friends and thus wanting robots to act as friends as well. Another conclusion was that acceptance of robots in public vs. private spaces may be different due to the nature of work those robots would do.

Elderly receive a lot of attention from robot testers with the narrative of *elder people need care, which may or may not be available from humans in the future (given aging population in developed countries)*. A research review of elders and robots by Petrie and Darzentas [234] suggest both the need to use a wide range of literature to understand the situations elders find themselves in, and to involve them and associated parties like carers, relatives and health professionals in all stages of development of robotic solutions designed for them.

Kertész and Turunen looked into heavy users of Sony AIBO [173]. Almost half of the owners were young adults (under 40 years) or in middle age (40–60 years), 61 of Western culture, 17 of Japanese culture. They answered a questionnaire, and researchers compared them along age, gender, culture, and length of ownership. The study revealed that males were more likely than females to see AIBO as a piece of tech, and females were more likely to see AIBO as a companion. Age did not reflect whether people perceived AIBO as a companion. Japanese participants were more negative about their AIBOs compared to Western, thus going contrary to the idea that Japanese people just love robots. There was no sign of user rejection of AIBOs despite lack of updates (since Sony discontinued the robot).

Specific characteristics not related to a demographic also received attention. Loneliness, for example, while associated with older people in e.g. UK, has been studied in the context of younger people in South Korea with Fribo robot [151]. Participants in their 20s and 30s participated in the field trials of the robot, which encouraged people to be curious about what their friends were doing at home. They were three close-nit groups of friends. Four weeks of home deployment took place. Researchers used questionnaires to collect data, as well as participant journals, and interviews. This kind of telepresence (not quite, since people considered a robot to be an extra entity, but still all its action were triggered by other people) provided a sense of realism and co-residence, and a sense of control over what is being shared. Participants balanced the senses of co-residence and control over sharing along the axis of privacy vs. isolation.

Different user types were noticed by the developers of companion robots as well, citing e.g. type one buyer seeking companionship in robots, while type two buyer seeking a pragmatic and specific feature set [318].

Unlike the research that attempts to identify users and user types, the research on *non-users* (i.e. people who refuse to adopt or stop using a given technology after buying it) of companion robots is very scarce. One set of characteristics for non-users comes from the longer-term domestic deployment of the now-outdated Karotz robot [101]. Here the authors described non-users in three categories: resisters, rejecters, and discontinuers. Resisters initially signed up for the study, but withdrew before data collection. Rejecters stopped using the robots two weeks to one months after the study began. Discontinuers stopped using the robots two to six months after the study started. The reasons included language understanding, privacy concerns, disenchantment, lack of motivation, replacement by other devices, restrictions and technical problems, and needs that were not satisfied. This portrays a more nuanced picture of non-users, rather than a binary use/non-use. This leaves one to wonder, however, if the complementary process of moving from non-use to use exists.

Overall, there seem to be differences for age, gender, education, context of use, potentially culture, loneliness, and expectations (e.g. utility vs. companionship). Research on populations suggests designs for specific user types, which is in agreement with conclusions from the personality of companion robots research.

2.5 Limitations of Existing Research

The inclusion of methods, robots and the environments of the studies in the previous sections was a deliberate (even if unusual) choice. It points towards the conditions under which researchers produced evidence for a given claim. Below I summarize the broad limitations common across the studies, together with what researchers suggest, to highlight the need for deeper, more individual studies of specific robots with specific users over longer periods in the naturalistic environments of homes.

The limitations fall into three broad categories: the kinds of robots that the researchers used, the environments of the experiments, and the kind of interactions that participants had with the robots.

2.5.1 Limitations of (Representations of) Robots

Robots used in most studies reviewed here are very unlikely to see widespread consumer adoption – many may not be even designed with that in mind. Moreover, a number of studies reviewed here used some kind of representation of a robot instead of a physical one, e.g. videos, images, or descriptions of robots. This puts certain limits on just how far a designer can rely on the results of those studies, when attempting to construct a companion robot. Another thing is the design itself – participants evaluate what they see – a specific instance, not a broad class of looks the researchers talk about (e.g. a discerning study of Shiomi et al. [271] pits abstract robots which were perceived differently depending on the specifics of shape even though they were all technically abstract).

Perhaps the least eco-valid way to try and evaluate a robot is to ask what people would arbitrarily like in an arbitrary robot, which is usually done via a survey (as in e.g. [5], [199]). Not only does it leave one to wonder what participants might have imagined or based their opinions on (fiction? Direct extrapolation from experience?), but it also lacks any visceral effect to the point where it would be akin to the many retro-futuristic predictions made over the past centuries which never came to be [14,148].

The study on the type of face that is perceived to be the most likeable and fit for home [164], for example, was performed with still images of robotic faces via a survey. While the images were of real robots (at least in part of the study), their representations lack both the dimension of physicality which is in the very definition of a robot, and the animation, which may change the perception entirely. Another image-based study mentioned ([291:11]) was used to explore what independently living elders want.

Having a video of a real robot is a slightly better alternative to still images, as in e.g. [52], [263] and [312]. However, it again lacks the sense of presence that e.g. Ishiguro considers as something fundamentally important in robots [146]. While some authors claim that there is a high level of agreement between videos and physical robots [312], it still removes a number of senses of perception like touch, smell, presence, texture and temperature, among others.

Audio-video mixed evaluation as in [54] while seeming appropriate for evaluating the best voice for a social robot lacks again the embodiment which may change opinions about its likeability or appropriateness.

VR offers an interesting way to try and make the evaluations more natural [166]. It is certainly more interactive than images or videos, but it still lacks a physical dimension. Mixed-reality evaluations were still considered inferior to the physicality of robots in at least one study [268].

Very crude physical prototypes may be the next half-step up from videos as in Hwang, Park and Hwang [139], however, those were all of humanoid shapes without any specific features or autonomy.

Wizard of Oz can be considered the next step up, with an embodied robot behaving the wave people would want (and in e.g. [94]). This somewhat solves the problem of embodiment, but does not solve one of representation. Unless evaluating specifically telepresence robots, what an actor makes a robot do may be unrealistic, with actions like motion often portrayed as one obvious differentiator between how a robot moves autonomously vs. how a human moves. The question of embodiment is brought up again and again, both in individual studies and in meta-reviews [4] [146] [164].

Many of the social robots discussed in the Social Robots section of this thesis (2.1.2) are embodied, but designed as “research platforms,” and not consumer grade devices, thus limiting the applicability of results when it comes to naturalistic evaluations.

Another feature that prevents a more naturalistic evaluation is that of testing a single feature vs. the whole robot. It was already demonstrated that there is a noticeable difference in evaluation of the whole robot vs. parts of it [29], and yet a large number of studies discussed focus on a specific feature, rather than the holistic view. Another point towards evaluating a robot as a whole comes from Tondu and Bardou [300], who postulated that (at least theoretically) humans cannot evaluate physical appearance without reference to social perception (and in my case, it is the whole purpose of a companion robots to have a social dimension). Thimmesch-Gill, Harder, and Koutstaal [298] also pointed out that physical robot’s poses were rated as more positive and more animate than digital ones, again suggesting the need to evaluate physical robots when possible.

Studies with robots that are commercially available to consumers are both limited in number, duration, and robots types, being largely outdated for my purposes of trying to understand the use of companion robots. For example, all studies that formed the frameworks of acceptance that are used in this thesis for the purposes of comparison and expansion were with robots much more primitive, with some not even being social at all.

2.5.2 Limitations of the Environments in the Studies

Historically, social robots resided within laboratories. While some doubts exist about whether an eco-valid setting really brings extra knowledge to the table over and above lab studies, the robots tested in the labs look and act very differently from consumer-grade robotics. They also lack verification in the intended use setting like private homes or public spaces. Factors that might be very important to HRI may be missed because, for example, participants could give a lot more slack for a research prototype when evaluating it vs. a technology they would actually consider spending their own money on. One example of such a factor was discussed before with regards to shape: while the general belief and some supporting evidence hold that humanoid is the best shape for companion robots, the encounters with the users beyond the lab demonstrated otherwise [182].

Most of the studies mentioned throughout the literature review were conducted in laboratories. A small departure from that was a *"fully functional smart home"* of Hertfordshire [257], however, even that was essentially a research lab, not an actual participant home.

A deployment of a companion robot in domestic environment was only mentioned once with Pepper robot [248], which represents some of what an ideal study in the space would entail.

There is a need to evaluate specific technologies, in the environment in which people expect them to perform. In many ways, this goes against the notional thinking of some scientists to isolate a single variable and trace its effect on other variables. On the other hand, it is perfectly acceptable to evaluate non-linear systems as a whole, be it psychological traits or robot acceptance.

2.5.3 Limitations of Interactions in the Studies

It is common to find very short-term studies of HRI, be it due to limited resources, time constraints, or even the ability of the prototypes to survive that long without maintenance even if confined to a laboratory. This sharply contrasts with the idea of many of the factors of personal robot acceptance to evolve over time, and puts under questions a number of studies reviewed here, as well as the general beliefs held across the field.

Some of the opinions about the companion robot shape, for example, are based on short interactions, as in Barnes, et al. [23], where maximum interaction time was only 10 minutes. A study on gender representation in robots [163] only netted a few minutes of interaction per participant. The assertion that people perceive non-verbal cues in a linear fashion from no no-verbal behaviour to human-like non-verbal behaviour was based on 20 minutes of experiment total, including filling in the questionnaires [254]. The non-verbal cues of voluntary vs. involuntary muscles were evaluated with a 2-minute dialogue [180]. Vulnerable expression and team cooperation was evaluated in a no-stakes 27.5 minute game [286].

Asking evaluators to perform specific tasks with prototype robots is another limitation often imposed on interaction as in the study by John, Rigo, and Barbosa [158], where volunteers had to complete simulated tasks in order to assess the multimodal interaction capabilities of a robot.

Trust, being mentioned as a dynamic attribute that changes over time was evaluated in its connection to social robot acceptance with a 50-minute 2-task study [92]. The effect of faulty behaviour on trust was tested within 30 minutes (with 10 minutes of actual HRI) [257]. The evaluation of biased algorithms only used 3 interactions [32].

Longer, naturalistic “do what you want with it” deployments are rare, with the most appropriate examples being a Pepper deployment over eight weeks [248], and the deployments that formed the frameworks of acceptance [104,289].

In short, there is a need to obtain rich data based on longer-term interactions with embodied robots, positioned in the environments in which we expect them to perform. For companion robots, one such environment would be the domestic environment. This necessarily trades precision and control over the environment for noisier, but richer data from appropriate consumer-available robots and an eco-valid setting with interactions defined by the consumers, not the researcher.

2.6 Summary of the Temporal & Persistent Factors Affecting Companion Robot Acceptance

The reviewed literature focused on two kinds of factors pertaining to acceptance of companion robots: factors that are time-dependant, pertaining to companion robots in the most general sense, and factors that are specific to the construction of an ideal companion robot.

DRE and de Graaf represent the time-dependant factors of robot acceptance. In summary, the pattern proceeds as follows:

1. Potential users form expectations, influenced by prior attitudes, perceived usefulness and enjoyment, perceived reliability, and actual cost.
2. A trial takes place where expectations break or are confirmed. If potential users adopt the robot, habits start to form, with usefulness, enjoyment, attitudes, and intentions playing the key roles.

3. The users adapt to the robot, and try to adapt the robot to their home environment. Affirmation or rejection of the robot takes place. Usefulness, enjoyment, attitudes, and intentions still play the key roles.
4. Sustained use develops, where the robot becomes mundane and maintenance routines develop to sustain the robot in the environment. Usefulness, habit, adaptability, and cost are the key factors at this stage.

When it comes to designing a companion robot, the following summary can apply:

1. Designers should prioritize setting realistic expectations, from marketing the robot, to user manuals, to shaping the robot in an abstract way, with form that would follow robot functionality.
2. Usefulness, enjoyment, and adaptability to the context in which the robot operates are important factors throughout. People use price for performance to evaluate those.
3. Ability to conform to social norms and exhibit social gestures like greeting or waving appendages is important, regardless of whether a robot is designed to be social or not. People will perceive a mobile autonomous platform as a social actor regardless.
4. Personalized responses to individual users are key at later stages of acceptance. Factors like culture, gender, and age may play a role. If it is possible to provide an individualized response with respect to those factors – it is worth considering.

I have picked up these factors across studies in various settings, with various robots, and differing populations. However, it remains an open question whether they play a role specifically in a domestic setting, and specifically with socially enabled technologies like companion robots.

Taking spectrum of acceptance into account, there have been numerous examples of "Robots = Tools" and "Playing with Robots," as well as academic attempts at "Robots = People?" However, neither commercial companies nor researchers have extensively explored building relationships with robots with the rare exceptions of Paro, Qoobo and (arguably) sex robots.

2.6 Problem Statement

As de Graaf, Allouch, and van Dijk point out:

> *"Discovering people's perceptions, expectations, and impressions of interactive technologies in their private domestic environments over a longer period is vital for informing the design and acceptance of these technologies."* [104].

Given the frameworks of robot acceptance insisting on usefulness and enjoyment, and the literature suggesting lack of consensus on those fronts when it comes to socially enabled technologies like companion robots, I address the following problems in this thesis:

1. How (if at all) do potential users of socially enabled technologies relate to such technologies at the *pre-adoption stage*? What do they highlight as valuable and important?
2. Which positive and negative values do actual users report when *living* with socially enabled technology over an extended period (2 months)?
3. What kinds of value do actual users of companion robots extract from them *post-acceptance* (6+ months of use)?

These problems raise the immediate question of how best to obtain such knowledge. In the next chapter I begin to address this issue.

Chapter 3 – Methodology

This chapter highlights how instrumentalism fits the purpose of this thesis by accounting for interaction, process, and relationships. I argue that the ideal static objects classical philosophies focus on are insufficient and do not fit the purpose of describing human-robot interactions this thesis focuses on. I build instrumental understanding from the ontological level, through epistemology, methodology, and into the data collection & analysis techniques, as well as highlight their limitations and applicability to this investigation.

It is often difficult to deduce philosophy a given researcher in HRI follows just by reading their work. Even theses, which generally have an extensive methodology section often skip ontology and epistemology, only stating the theories and methods used. HCI and HRI, being such eclectic subjects, strongly require, in my mind, a sound philosophical grounding, without which there can be confusion and misunderstanding about the work a researcher has done based on who reads it, and which philosophical inclinations they might have.

This chapter outlines briefly the classical views of idealism and empiricism, highlights some shortcomings of those philosophies in relation to the questions this thesis tackles, and proceeds to describe instrumentalism as a philosophy of process and a suitable way to look at the problems of human-robot interaction and relationship building.

3.1 Classical Ontologies & Philosophies of Process

In the literature review, I have highlighted two frameworks of robot acceptance that describe the changes in factors that lead to robot acceptance over time: De Graaf's framework, and Domestic Robot Ecology. Both postulate the need to view acceptance as an ongoing process with shifting priorities as people move from one acceptance phase to another. Some of the key elements of long-term robot acceptance including changes in technological development, changes in robot perception, and trust building, to name a few, also require observing changes over time. Therefore, a justified ontology for this kind of work would be one that takes processes happening over time into account. Classical philosophies of idealism and empiricism are limited in this regard, however, as both seek to establish the immutable, time-independent knowledge.

Ontology is tasked with the questions of: what exists? What are the different kinds of things that exists? [255:645]. Metaphysics in turn deals with the questions of: if one knows that something exists, what else can be said about it? How can one be sure about it? [255:567–570]. Two major positions in metaphysics can be further outlined:

1. Things that exist lie beyond experience (Idealist/anti-realist view).
2. Objects of experience constitute the only reality (Empiric/realist view).

In the idealist view one can generate knowledge by following a chain of reason alone. An extreme version of this view is that one can *only* obtain knowledge by following reason alone – anything gained from experience is flawed, imperfect, and thus unsuitable. The idea of imperfect experience has been explored as early as the Plato's Allegory of the Cave [238], where it is presented as a reflection of true ideal form which humans are incapable of experiencing directly. However, because humans can reason, they can attempt to grasp that which lies beyond experience and thus attain knowledge through reason.

A circle is an example of such perfect knowledge. Humans have created and can experience many circle-like shapes, e.g. a wheel, or a drawing of a circle. However, all such representations are imperfect. A mathematical definition of a circle would be an ideal representation that idealists would claim humans have arrived to through reason. Humans, idealists would argue, cannot perceive mathematical circle, as it is a set of infinitesimally small points equidistant from a given centre. However, as a perfect form, such circle would exist somewhere in the universe and be considered in a true sense real, and more real than anything one can experience.

Empiric view on the other hand suggests that knowledge is that which humans arrive at through experience (*a posteriori)*. Pushed to the extreme, it proposes that people arrive into this world as *tabula rasa*, i.e. without any predispositions or preconceptions whatsoever, and acquire all knowledge through experiencing the world. In this view, *what you see is what you get*. There is no reality beyond experience. Empiric view denies the idea that any "higher" reality exists, and supposes that human senses are reasonable tools to grasp the reality as it is.

One can only understand a circle, in the same example, through experience. What people conceptualize as a mathematical definition of a circle is *further* from reality than circular objects one perceives. One can attempt to create something that is very close to the idealised circle, but the created object would still be the real thing, while the concept would be just that – a concept, with no weight in reality.

Tensions between idealistic and empiric thinking in the 20th century have taken a form of foundationalism vs. anti-foundationalism argument. Foundationalism claims that there is a set of irreducible statements (or axioms) from which people can derive all other knowledge. Anti-foundationalism argues for the opposite: that there cannot be a finite list of such statements, and it is thus more in line with the empiric forms of thinking.

Rationalist/foundationalist argument may sounds highly synthetic, in that a person, in principle, could sit in a dark room and, given some basic axioms, derive all possible knowledge of the world outside of that room (and indeed everywhere in the universe), just by thinking long and hard enough about all possible consequences those basic axioms entail. Rationalists themselves admit that in practice, empirical approach is often used, and it is indeed very impractical, if not impossible, to use reason alone to arrive at conclusions outside of highly synthetic fields like mathematics, where properties of objects are well known and well understood by mind and behave completely reasonably for new properties to be derived in complete certainty. As Leibniz (a proponent of idealism) puts it in his *Monadology*: *"We are all mere empirics in three quarters of what we do"* [189].

If I select either rationalist or empiric outlook to view HRI, I would lock myself into the *finality of objects*. Both empiric and idealistic outlooks suggest that there are objects that are in some sense final or absolute – they do not change, and anything changing or interacting with them is to a large degree irrelevant. This goes contrary to the kind of problem at hand – one with the focus on change and interaction.

A different approach to the matter of what reality is and how it operates is to focus on the pragmatic side of things rather than on philosophical questions far removed from visceral reality. This approach was developed by William James, Charles Sanders Pierce, and John Dewey. Unlike prior philosophers, pragmatic maxim dictates that to clarify hypothesis one must look at practical consequences of those hypotheses; *"Then, our conception of these effects is the whole of our conception of the object"* [232]. James' definition was in a similar vein:

> *"Any idea that will carry us prosperously from any one part of our experience to any other part, linking things satisfactorily, working securely, simplifying, saving labour; is true for just so much, true in so far forth, true instrumentally."* [149].

One development from pragmatic philosophy can be categorised as a philosophy of process. This view focuses on change, and dismisses the idea that objects are in some sense final or eternal. Out of several philosophers whose views could be considered as philosophies of process, a specific treatment of metaphysics and epistemology was made by John Dewey (1859-1952) – one of the pragmatists mentioned earlier. His approach (called instrumentalism) was different from both the classical philosophies and pragmatisms of Pierce and James, as Dewey attempted to incorporate scientific discoveries of his age, together with what he thought was common between art and science. As a philosopher, he had moved from idealistic and towards pragmatic notions throughout his career, not only outlining his own views, but also responding and critiquing classical philosophies at length.

Dewey's work spans several fields of knowledge (including psychology, philosophy and education) not all of which are relevant to the problem at hand. Besides his original works, there is a need to choose a good source of material which focuses specifically on Dewey's views about ontology and epistemology even if those views are spread throughout several works. Dewey was not known for clarity in his writing either, which makes it even more important to find a clear, focused interpretation on matters of ontology and epistemology, which takes into account all of the relevant work throughout Dewey's career. My choice in this case was *Dewey's Metaphysics* by Broisvert [35]. In addition to clarity and focus on Dewey's ontological position, the book came out in 1988 – several decades after Dewey's works. This allowed Broisvert not only to interpret Dewey's views comprehensively, and in light of new philosophy that came out since, but also to address multiple criticisms directed specifically at Dewey after all of his works came out.

A modern authority on Dewey's work is Larry Hickman, and his focus on Dewey's work and its relevance to technology [131,132]. Hickman also picked on more modern objections to Dewey's work, and responded to those objections [131]. Thus, the description of Dewey's views on ontology and epistemology was primarily taken from Broisvert's account, with excerpts from the original texts, while the applicability of Dewey's work to technology was taken from Hickman's account.

3.2 Ontology & Epistemology of Instrumentalism

Ontology, dealing with the *"nature of being"* [255], receives a slightly different definition in instrumentalism. In seeking to provide a description of the actual world of human experience, Dewey defined ontology as *"a statement of the generic traits manifested by existences of all kinds"* [74:308]. In instrumentalism there are precisely two such traits: *events*, and *relations*.

Events are anything that strives to maintain its form with respect to time, place, and relations with other events [74:91–92]. This puts everything typically referred to as "things" in this category, as well as "events" in a typical sense of the word, like parties and battles. What is emphasised by this category is that one cannot study objects without simultaneously studying the conditions or situations in which they are found [35:138]. Nothing, in a sense, exists in a vacuum, and so assuming that some kind of perfect version of a given thing exists entirely in itself is a misleading way of looking at it. Another reason for why this category is called "events" is that all things in this ontology have a temporal dimension, i.e. they exist through time. Unlike the idealised or final objects in classical philosophies that exist beyond time or change, instrumentalism permits things to change. Events are time-dependent processes.

Events are both temporal (changing with time) and objective (independent of the viewer) [35:147–148]. While this notion of both changing and objective can be alien to some, consider a battle. As it goes on, things definitely change, but that does not make it any less objective or any less of a battle until at some point it ends. Thus, instead of being subject- or mind-dependent, events are time- and environment-dependent. Of course, in some sensitive matters like quantum physics or participatory design the observer becomes the environment, and thus affects the events by being part of that environment. This time- and environment-dependent approach can be called *objective relativism* [35:146]. Varied relationships with the environment can lead to novelty – something, Dewey argued, that is unavailable if you perceive the world in a classical way – as final, and unchanging [35:144].

Relations are how things interact with each other [75:139]. This is particularly important for the issue of interaction in this thesis because through instrumentalism one only knows of things through their interactions. Situations are not constructed from separate entities with relations somehow superimposed on them. Relations are a primary factor.

What things are is maintained through their forms. Forms are organised or structured complexities [75:142]. What distinguishes things/events from one another is their attempt to preserve their form against the forces of interaction [75:142, 194]. Forms are universal in a sense that they both occur in inanimate objects (e.g. through a crystalline structure) and living organisms (e.g. through DNA/RNA reconstruction). Form is a result of interaction between a forming entity and its environment [75:129].

Stable forms represent points of equilibrium as things interact [35:163]. Changes to form as things interact constitute a system [73:418]. The point of the system is to maintain a certain pattern over time. Thus, things can change, but also mend themselves. Each event can be considered a system and thus embodies not a single form, but a cluster of them. Entities are formed, but form does not exist in itself. Forms are implicated in events. Ontological status of forms is that of possibilities, not rigid structures [74:63]. Forms exist as possibilities in relation to the inquirer who seeks them out. They are possibilities which experimentation can actualize. An inquirer in that case is not just a spectator – they manipulate what they observe. More specifically, *the knower needs to act to obtain knowledge* [77:367].

When attempting to acquire knowledge, an assumption that instrumentalism makes is that nature is at least in part both intelligible and understandable [76:168]. There are operations by which it becomes an object of knowledge, and thus is turned to human purposes [76:168]. Nature is capable of being understood by being experimented upon. By these experiments people uncover relations summed up in production of new events. These experiments is what allows the comprehensible to become the comprehended [35:171]. Experiments seek certain stable relations which have hitherto remained unknown [35:171]. If the experiments are successful, new events are created and human knowledge is increased [76:172]. At the same time, acknowledging that both stable and unstable exist in our experience, Dewey points out that certain forms are susceptible to being known, but possibly not all [35:83].

Knowledge from instrumentalist's point of view is essentially that which allows people to utilise means-ends or part-to-a-whole relationships found in experience [35:169].

Intelligence (the activity of creating knowledge) aims at stable aspects of existence. It seeks out relationships between entities (either means-ends, or parts-to-a-whole). In other words, intelligence seeks forms: it is concerned with standardized and averaged set of properties and relations [76:189].

Instrumentalist is not interested in answering the sceptical question of whether knowledge is possible. Intelligence as means of modifying the environment-organism interaction is an obvious fact [35:200]. Knowing is selecting some aspects of an experience to solve particular problems. It would go beyond human cognitive abilities to try and comprehend all possible experiences associated with a given event. Therefore, what actually constitutes knowledge are the results of various manipulations of our experience which uncover some aspects of it, serving to solve specific problems.

Creating desired forms can be called *design* – both a plan and an aim which that plan strives to achieve [35:161,75:131]. Thus the end-form is in a sense a finished product, which embodies the desired form. However, all things being temporal, they will not hold their equilibria forever. So, the end-form is not the *ideal form* of classical philosophies, but simply the desired (temporary) stable state of affairs.

In a social sense, instrumentalism has a great focus on the individual, as it is the individual mind that comprehends the sensory information, and also it is one that influences the environment it finds itself in, thus having the chief practical way of not only thinking philosophically, but *acting* philosophically. At the same time, that individual finds oneself in the company not only of the environment, but other individuals, thus having the ability to obtain knowledge not only on the nature and its peculiarities, but also on other humans and their peculiarities. Knowledge therefore cannot be separated from action. The only way to solve a problem is to judge or estimate an optimal method of resolution, and then act in accordance with that judgement.

Dewey also pointed out that a specific situation will, to some degree, guide the resolution. It does so as not all situations are alike, and each one presents only certain possibilities. That is also the reason why any abstraction or generalization beyond the situation which caused it must be done very carefully, so as not to impose conflicting abstractions to situations which do not permit the possibilities of the imposed abstractions.

3.2.1 Advantages of the Instrumental Approach

In short, instrumentalism has the following advantages pertinent to this work which distinguish it from classical philosophies:

1. Instrumentalism defines *events* as forms that attempt to persist over time, allowing for temporal factors in robots acceptance. These temporal factors include both changing perceptions with regards to the (non-)acceptance of companion robots,

and temporal adjustments in factors like trust and relationship-building. By defining events as time-dependant, instrumentalism allows to explore human-robot interaction in light of its changing nature, including changes in software, while the robot shell may persist.

2. Instrumentalism defines *relations* between objects as a fundamental feature of human experience, which allows human-robot interaction to be viewed coherently, as progressive back-and-forth between the robots, the humans, and the environment.
3. Instrumentalism defines *knowledge* as the creation of new, desirable events, allowing not only for things to change, but for value in companion robots to be showcased whenever there is a person that changes something with respect to robots to solve a particular problem.
4. Instrumentalism defines *design* as both a desirable form, and a plan of action to achieve that form, allowing me to comment on design of existing companion robots and other socially enabled technologies, and how those designs fit into what is desirable.

3.2.2 Philosophical Objections & Responses

Before translating Dewey's instrumental view into methodologies and methods, it would be prudent to address some of the objections to Dewey's work, and counters to those objections. Many objections to the instrumental approach come from misinterpretations of Dewey's work [35].

One objection is that philosophy has a role beyond being instrumental, that it is somehow fundamentally different from other tools that humans use to affect the outcomes and change the environment. To this end, both Dewey, and his interpretation by Hickman suggest that the function of philosophy is to facilitate a dialogue between various disciplines, when those disciplines could be perceived as speaking "different languages" [131]. Philosophy in this case allows to extract the transferable assets between those disciplines, and clarify their meaning in each of the respective contexts. Philosophy's emphasis on logic provides the most basic grounds for reasoning, thus allowing such a transfer. Philosophy also includes metaphysics: the most generic traits applicable to all things under consideration, thus providing a ground from which to build understanding of a given matter and/or of similarities between points of view further [131]. Thus, philosophy is a tool that humans use to affect the outcomes and change the environment.

Other common exclusions from instrumentalism include arts and religion, both of which however still fall into instrumentalism if further considered [131]. Artefacts of art can still be considered within the realm of taking raw materials (e.g. experiences and research of the artist), using tools to refine those (be it in editing drafts of a novel, or shaping a stone into a sculpture), and producing an end product with which the artist is reasonably satisfied. Religions of various kinds used tools to achieve their ends through the ages from books and images, to buildings and rituals [131].

A converse objection is that if one takes *technology* as broadly as instrumentalism suggests, would that not include everything, and thus lose its meaning? To this end, technology is pervasive, and anything that brings one from an initial situation through using physical or cognitive tools to a situation that is considered *better* is in fact technological [131]. This does delineate random fluctuations in the environment as being accidental and non-instrumental. In turn, the realization that not everything in the world is rational or attuned to human condition makes a strong delineation between was is instrumental, and what is not.

3.3 Methodological Approaches

So far, I have established the ontological and epistemological grounds for my work, and stated (in the Introduction) that this thesis approaches the issue of designing companion robots qualitatively, based on specific user experiences of currently available socially enabled technologies that are considered valuable by the users. There are several ways this can be approached, and each approach must answer the following questions:

1. The data collection questions, including the kinds of data to be collected, the kinds of stimuli that should be applied, the kind of subjects that would generate the data, and the kind of environment that hosts all of the above.
2. The data analysis questions of a theoretical lens, and the specific methods of analysis which would fuel the results of the inquiry.
3. And the limits to which conclusions can be drawn, including questions of generalizability and applicability.

These questions are analysed below with the tools being selected to satisfy both the issue in question, the instrumental philosophy, and the qualitative inquiry.

3.3.1 The Kinds & Limits of Data

There is very little information on what it is like to live with a companion robot, and no established way to describe that kind of life. It is even more challenging to suggest how to make such experience *better*. Both instrumentalism and frameworks of acceptance suggest collecting temporal data, with frameworks suggesting also persistent factors like perceived usefulness, enjoyment, and cost.

Another consideration for data collection is data complexity. In literature review, there have been several references to the idea that standardized tests or surveys may not pick up all the relevant factors pertaining to robot adoption and acceptance. Instrumental definition of knowledge relies on creating desirable events, with “desirable” being individual to each person involved. This together suggests to move away from standard surveys or attempts to fit a given experience into an existing model. While frameworks of robot acceptance could be used as guides, limiting myself to verifying them seemed restrictive, given that they were derived from asocial technologies.

This also answers the question of the subjects of the inquiry – these would be people who agree in principle to attempt to utilize socially enabled technologies into the mundanity of their lives. As a researcher attempting to discover the complex issues surrounding companion robot adoption and acceptance, I have placed further restrictions in this regard, limiting the participants to the pool that is accessible to me or my collaborators to be interviewed directly, with demonstrations of how they would attempt to utilize or discard a given technology where applicable. With regards to age, it is the adults that I was interested in, as there are other research groups across the world concerned with both children's use of technology and older adults, leaving the strictly "adults" in the middle a less explored population.

All of these considerations suggest collecting qualitative information (text, images) about individuals and their attempts to produce desirable events with (in this case) companion robots. At the same time, because companion robots and other socially enabled technologies have the capacity to track their usage independently of users, this provides an additional, quantitative dimension, together with temporal information on use, as most logs keep date and time of events as essential components of reporting.

Overall, there is a need to collect data that is complex beyond existing constructs found in surveys, and such data should include both temporal and persistent dimensions. This data would ideally be collected both from the humans and the machines to provide a more comprehensive view on the matter of extracting value from companion robots.

3.3.2 The Domestic Setting & Its Limits

Instrumentalism suggests the need to collect the data in an eco-valid setting to observe the relationships between people, robots, and the environment. DRE framework also suggest the environment as being important. Given that companion robots both in fiction and reality live with people in their homes, the domestic environment was chosen to be appropriate. I strived to recreate the experience itself in as much detail as possible and is the context that would represent the experiences people would ordinarily have with such technologies within their respective environments.

Reflecting on the 25 years of research in HCI at home (121 works on the topic), Desjardins, Wakkary, and Odom posited several genres of research, and two future directions: material perspective (how *different things* experience *different* homes?) and 1st person perspective (how *different people* experience *the same* home?) [72]. Genres pertaining to my interest include:

- *The home as a testing ground* – a genre that moves away from simply observing *what is*, and towards would *could be.* Deployments of new technologies are a primary vehicle for this kind of research. In this genre, researchers observe the changes and new routines that happen with the introduction of new technologies. Usage, positioning and reflections of participants through interviews are the primary ways the data is collected [72].
- *Smart homes* is a tangential genre to my work, as companion robots can certainly be part of it (depending on how literature looks as them), but I am not seeking so much to design novel devices for smart home, as to understand the ecosystem. That said, a small number of studies in this genre looked at how people transformed their homes from non-smart to smart *in-the-wild*, which is appropriate for this work [72].

Christopoulos et al. pointed out that home automation systems as a research and commercial field relies on both IoT and robotics to deliver more control, comfort and enhance performance in domestic environments [57]. In this system, a companion robot is a universal user interface connected to the IoT, and used for ease of control. IoT and robot control through existing technologies like a phone or a tablet is discussed by Seiger et al. [267], with the conclusion that ubiquity of such control, instant access and monitoring would be suitable to be implemented in a domestic robot.

Frennert, Eftring, and Östlund highlighted both the necessity of conducting robotic trials in their intended natural environments of homes, and the realization that any domestic deployment is necessarily less precise than laboratory testing, thus urging researchers to both conduct more trials, and converge and contrast results from existing research to strengthen the HRI for home subfield [89]. On the merit of this approach, a review of *Social Robots from a Human Perspective* highlights:

> *"By taking the everyday life of ordinary people as a starting point, we may succeed painting a realistic picture of how social robots will become part of our homes and other private spaces in the foreseeable future."* (p. 4) [43];
>
> *"Understanding more about human's everyday life practices is foundational to usefully and practically incorporating social robotics into daily routines"* (p. 143) [43].

One way to conduct an inquiry into companion robots in the domestic environment is to use an *in-the-wild* deployment. Early work using this term [49] described researchers and participants as equal co-creators of knowledge, pointing out that one will be worse off without another. It emphasised the lived experience and practicalities of the participants, especially in marginalised/small communities. It pointed out that to form concrete ideas for strict laboratory experiments, researchers needed to collect first-hand information in its complexity from people directly experiencing the phenomenon of interest. Originally developed as a case for patients suffering from muscular dystrophy, it was later adapted as an approach for a number of studies of our interest in human-robot interaction (HRI), namely Roomba [88,288,289] and Nabaztag/Karotz [109,110,130], and numerous others (e.g. [128,186]).

While not without its challenges [45], when done right [161] *in-the-wild* deployments in homes provide valuable insight, demonstrate complexity, and allow for factors that would be extremely hard to reproduce in a laboratory setting, especially when it comes to longer-term naturalistic use.

3.3.3 Selection of Stimuli & Their Limits

Following the instrumentalist approach, it would be best to collect data from people who already live with companion robots. This would resolve the choice of stimuli without me judging which of the robots is better, as the participants would have already decided that for themselves. The next best opportunity would be to conduct companion robot deployments to understand how people live with those technologies, and what value they could extract from them. This would require procuring the respective companion robots, and looking for people who would accept such stimuli.

However, given the rarity of commercially available companion robots themselves, and their limited spread (primarily Japanese market), I had to rely on related technologies in an attempt to conduct longer-term studies to capture the temporal factors affecting robot acceptance. Smart speakers, while only available in the US, UK and Germany at the time, were a similar-enough successful socially enabled commercial technology. The choice of stimulus, while it was my judgement, still needed to be accepted by people I wanted to study, thus voluntary participation was a test of whether the stimulus was appropriate.

The next step away, but still attempting to comply with instrumentalist view would be to take images or videos of companion robots that already exist or are at least advertised. The timing of smart speakers coming to the UK market, as well as constant delays of companion robots' shipping forced me to adopt this strategy in one of the studies. However, given the frameworks of robot acceptance, both of which include the pre-adoption phase where people would seek to learn about a given technology, it was deemed acceptable to use advertisements of robots to explore this specific stage of robot acceptance, and to assess what value people would think they could extract from companion robots given just the advertisements.

There have been several other studies of people's perceptions of robots that were even further removed from the eco-valid setting that instrumentalist view suggests. These include surveys or interviews which asked participants to imagine arbitrary robots. These imaginations could have well come from fiction, and I strived to move away from that interpretation of value of companion robots, thus I chose not to conduct studies of that kind.

3.3.4 The Choice & Limits of Data Analysis

With the data types, the stimuli, the participants, and the setting established, there is a need for a theoretical lens to help interpret the data that would be obtained.

Ethnographic approach [65,262] could be taken in this regard, studying a cultural group in its natural setting over a prolonged period of time. However, the literature review suggests large individual variations even within a single culture when it comes to companion robots. Given that companion robots and related socially enabled technologies are sparse, but available to *different* cultural groups, this approach seemed restrictive, although it does satisfy the tenets of instrumentalism and could in principle be used, once companion robots become more widespread.

Grounded theory [241] would be another approach, focusing on the views of participants, and generating an abstract theory based on that. One of its explicit tenets, however, is timelessness, which goes against the very notion of instrumentalism, where ontological events are time-bound.

Phenomenology [63] would be another approach, with specific focus on individual experiences, and what those experiences mean to the participants. This, however, focuses more on people, and less on the *value* companion robots could bring.

A viable approach is that of a case study, *"an empirical inquiry that investigates a contemporary phenomenon (the "case") in depth and within its real-world context"* [320:16]. This accounts for the instrumental understanding of events, allows to focus on the relationships between people, robots, and the environment, and allows me as a researcher to focus on the value [134,320] that companion robots bring to people.

Since both qualitative and quantitative data was expected, the approach to data analysis used was chosen accommodate the respective modes of data. The main mode of analysis of interviews was thematic analysis [39,40]. Given the arbitrariness of the input data and the flexibility of the method, thematic analysis allowed me to yield themes unrestrictedly, taking into account arbitrary complexities and various ways participants could express a similar idea.

Given my shift from pure mathematical sciences to a highly interdisciplinary field of HRI with a host of methods drawn from across the methodological spectrum, the choice to conduct thematic analysis was a fruitful one, as *"it provides core skills that will be useful for conducting many other forms of qualitative analysis"* [39]. The form of analysis performed was *inductive* thematic analysis – I did not try to fit the data into existing frameworks, although I did compare the results of my studies to the frameworks *after* I have analysed them. That said, I do acknowledge that both the data collection and the data analysis were not done in an epistemological vacuum, thus some unconscious guidance with regards to the existing frameworks might have taken place.

3.3.5 The Limits to Conclusions

Instrumentalism acknowledges that desirable events may not be universal – each is created based on the possibilities that were present at the time a given problem was solved within a given environment [74:32–33]. A corollary to that is, that a different environment with different participants wanting to effect the world in a different way (even if to solve the same problems using the same tools) could produce different results that could in turn provide evidence for different conclusions. This automatically puts a limit on generalizability of any conclusions drawn from this work. The stability of the themes, design advice, and solutions within this work needs to be tested further to evaluate precisely the limits of applicability of the conclusions drawn. I can only claim that those solutions were valid for those participants, in those environments, and at that time. They may well be stable across time and environments, but this work does not provide enough evidence to state that.

Instead, this work is focused more on the *value* that companion robots *could* provide (given their limited availability to date), with the data derived from the settings that could be considered eco-valid, and people, whose solutions could be considered based on the mundanity of life. This is aligned with the expectations that companion robots would help people deal with their everyday lives, being ubiquitous.

3.4 Summary of the Approach & Its Limitations

I have described the philosophical approach of instrumentalism as being applicable to the inquiry of designing companion robots, based on specific user experiences of currently available socially enabled technologies the aspects of which are considered valuable by the users. I have identified changes over time, building relationships, and extracting what was valuable in those interactions as key factors that needed to be satisfied for this work to be productive.

I have showcased that classical approaches of idealism and empiricism were insufficient to deal with an inquiry of this kind, primarily because of their focus on permanence, rather than change and development. Instrumentalism, on the other hand, being a philosophy of both process and value extraction was deemed a better fit. Instrumentalism uses time-bound events and relationships as ontological constructs, satisfying the need to observe the development of human-robot relationships over time, together with changes in value the robots provide over time. Instrumental definition of knowledge as a case of problem solving also satisfies the focus of this work on value, rather than e.g. the robots, or the people.

From instrumentalism, I have approached the data collection as being qualitative in nature, as there is a need to collect complex, changing information that (as suggested by the literature review) may not be picked by surveys. Frameworks of robot acceptance suggested the need to collect data over time, rather than at any one specific point. The providers of data were human participants who agreed to live with socially enabled technologies, and attempted to extract some value from them. The specific preference for adult participants was a personal choice that was motivated by the ubiquity of literature on both child-robot interaction, and elder-robot interaction, while adults that do not fall into those two groups remained less explored. The logs from the devices were also deemed an important triangulation resource. The domestic environment was considered the most valid, and in every case, the need for ecological validity was stressed as necessary, stemming both from literature review on the matter, and the instrumentalist view. Finally, the stimuli for this kind of inquiry would need to be either the companion robots themselves, or the closest possible socially enabled technology that must be available on the commercial market. This was primarily motivated by the necessity for ecological validity, as commercial products would be designed with the current affordances in mind, and possibly integrate with other technologies, humans, and homes better than prototypes made in the labs. The limits of such approach are those of controlled environment and generalizability, both of which require inquiries of a different kind to be made.

Case study theoretical lens, together with inductive thematic analysis were chosen as the means to transform the raw complex data into a manageable set. Case study allowed for temporal events, diverse cultures, and a focus on value, while inductive thematic analysis allowed for both the focus on value, and the organisation of complex qualitative data into descriptive themes. Given the nature of both the case study lens as focusing in-depth, but narrowly, and inductive thematic analysis as being purposeful in its focus, this brings limitations to the kind results those methods produced. Specifically, I did not seek to represent the dataset objectively, but rather to extract those parts of it pertaining to the value that socially enabled technologies brought to the participants (and conversely the reasons why those technologies were deemed useless).

With the basics established, I present the three studies that were conducted to address the inquiry of living with socially enabled technologies. Each study addressed both the temporal aspects highlighted in robot acceptance frameworks, and the persistent factors. In short, the studies captured pre-adoption, through post-acceptance stages, with factors pertaining to design and how that was found to be valuable.

Chapter 4 – Pre-Adoption – Adverts Study

Part of this chapter is published as:

Dereshev, D.; Kirk, D. Form, Function and Etiquette–Potential Users' Perspectives on Social Domestic Robots. *Multimodal Technologies Interact.* **2017**, *1*, 12.

This chapter provides original contribution to knowledge by investigating pre-adoption perceptions towards companion robots, with the focus on form factors, functions, security, and social behaviour of companion robots based on participants' reactions to companion robot advertisements.

4.1 Background & Research Question

Based on the combined ideas from DRE and de Graaf's frameworks of robot acceptance, there are four general phases one goes through from thinking about having a robot, to accepting and making one a part of one's daily life. The first phase of this process is the pre-adoption phase, where expectations are formed. This phase is influenced by prior attitudes, perceived usefulness and enjoyment, perceived reliability, and actual cost.

To investigate what potential users think at this stage, I conducted a study that demonstrated companion robot adverts as means to elicit opinions and perceptions about companion robots that are not science fiction, but something made with realistic technological limitations to date. Although actual performance may have been exaggerated in advertisements, it was not done so to the level of science fiction.

From the context-preserving standpoint, because people could have watched those ads in any number of circumstances (at home, at work, with friends, during a commute, &c.), it was deemed acceptable to utilise a quiet space without interference. Interview questions were based on de Graaf's framework, with the additional questions to mitigate some of the biases people may have had expressed (e.g. "others, but not me" responses). For the specific questions asked see the Appendix 1, section 1.1. They are also reported below.

This study sought to answer the following research question: *how (if anyhow) do potential users of socially enabled technologies relate to such technologies at the pre-adoption stage? What do they highlight as valuable and important?*

4.2 The Participants

Participants were a self-selected sample, responding to an email advert sent around a university in the North of England, UK. The adverts invited anyone interested (staff or students) to participate in an interview on social robotics, indicating that participants would watch three four-minute videos and then be asked some questions about what they saw.

20 participants (10 males, 10 females) were thus recruited. All participant names reported below have been pseudonymised. Participants' age ranged between 22 and 44 years (mean = 29.65, σ = 5.228), with 5 staff members and 15 student members taking part in the study.

Cultural prevalence defined as any country that a participant has spent 5 or more years in, was captured with the influence the studies by Li, Rau and Li [191] and Evers et al. [82], who indicated that responses to robot's appearance and decisions may be culturally motivated. This information helped me understand participants who framed their experiences or expectations from robots directly in relation to cultural ideas or situations they had experienced. Thus, there were cultural representations of the UK (14), Saudi Arabia (2), Australia, Hong Kong, Iraq, UAE, Taiwan, Egypt, Jordan, Denmark, Germany, Kyrgyzstan, and Russia – one each.

None of the participants were involved in this project prior to the interview, nor had they been working on any projects related to robotics, HRI or AI. They may be considered potential early adopters, while not being experts or having academic interests in the field. Participants were colleagues residing within the same institution, but otherwise unrelated to the interviewer. They were unaware of a particular goal, either personal or professional in regards to this research.

It is assumed that participants were truthful in their expression and voiced opinions they truly had. It was highlighted to them prior to the commencement of the interview that (to quote from the information sheet): *"There are no right or wrong answers as the study is purely designed for exploratory purposes and does not attempt to test you in any way."*

4.3 Companion Robots in the Study

Below I sketch out details of the three companion robots of interest to this study, namely Pepper, Jibo and Buddy. While Pepper had been on sale in Japan for some time, neither Jibo nor Buddy were commercially available at the time of the study.

The three companion robots were chosen to represent various cultures which gave rise to such machines (Pepper is Japanese, Jibo is designed in the U.S. and Buddy is a French product), as well as various design decisions that commercial producers made to create the respective companion robots (Pepper is humanoid, Buddy is more abstract and mobile, while Jibo is more abstract still, and static).

Pepper (Figure 23) was a robot developed by Aldebaran Robotics and SoftBank in Japan and France. It was a 1.2-meter robot on a wheelbase with arms. Its capabilities were advertised [277] to include emotion recognition of joy, sadness, anger and surprise; it could recognize facial expressions like frown or smile as well as the tone of voice. Simple non-verbal clues like angle of a person's head were also said to be recognizable.

Among other features were the ability to hear (4 directional microphones on the head) and speak, see with two standard HD cameras and one 3D camera, connect to the internet (via 802.11a/b/g/n Wi-Fi system) and use the tablet strapped to its chest for further functionality and to express its own emotional states. It also had what SoftBank called an "emotional engine", which allowed Pepper to learn about its master and accommodate its character to fit through learning and dialogue.

Technical characteristics stated that Pepper had anti-collision and self-balancing systems to prevent collisions and falls if pushed, three multi-directional wheels to move in any direction with the speed of up to 0.83 m/s, and with battery power of up to twelve hours. Sensor-wise, it had two ultrasound transmitters and receivers, six laser sensors and three obstacle sensors which provided information about obstacles within a three-meter range. Tactile and temperature sensors were also installed.

SoftBank welcomed independent developers and the latest version of Pepper at the time worked on Android operating system, allowing people to improve on its software functionality.

Figure 23. Pepper by Aldebaran Robotics and SoftBank.

Jibo (Figure 24) was a crowdfunded companion robot developed by Cynthia Breazeal in the US. It was ~0.28 meters tall, had a ~0.15 meter-wide base and weighed about 2.27 kg without batteries [155]. It was advertised [155] as being able to see with two HD cameras, hear with 360-degree microphones, speak, learn, help and relate to you. Jibo had a battery which would last ~30–40 min, otherwise it was powered through the mains; it did not have wheels, but rotated on its base.

Jibo was advertised as a platform for which anyone can developed applications dubbed "skills" [155]. A free software development kit was available for download at the time. Jibo was built on a version of Linux with proprietary code on top of it [155].

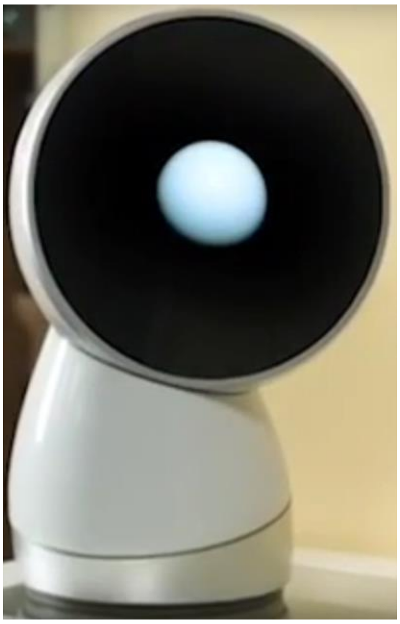

Figure 24. Jibo by Jibo Inc.

Buddy (Figure 25) was a companion robot developed by Blue Frog Robotics in France. It was 0.56 × 0.35 × 0.35 meters in size and weighed just above 5 kg [34]. Its services were advertised to include home security, connection to a smart home, help in social interactions, personal assistance, audio, video and photo capture and replay, edutainment, elder care and more through applications [34].

Physical characteristics included one range and one temperature sensor on its head, five obstacle detectors, three range finder- and five ground sensors, as well as one camera, one microphone, audio output, HDMI and USB outputs. Two speakers were mounted on the head. The face was displayed on a 0.2 meter touchscreen display. RGB LED lightning was also supported. With four motors, 360 degrees movement and a maximum speed of 0.7 m/s, it supported Wi-Fi and Bluetooth, and was advertised to operate eight to ten hours on its batteries. The obstacle clearance was 0.15 meters.

Buddy supported Arduino, Unity 3D engine and Android to help with development. The application programming interface (API) was being developed at the time, with support for multiple languages and tools for development [34].

Figure 25. Buddy by Blue Frog Robotics.

4.4 The Protocol

All subjects gave their informed consent for inclusion before participating in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Newcastle University and referenced as “User perception of social robots based on promotional videos thereof”. Email with a link to a published study was deemed sufficient compensation for participants’ time.

All interviews were conducted in a quiet conference room within an office building where participants worked, with no one but the participant and the interviewer in the room. There were no significant interruptions. All interviews were conducted in the summer of 2016. The interview was piloted with 5 participants, but did not undergo any significant changes. No repeat interviews were carried out. No field notes were made during or after the interviews.

The interviewer gave a short survey form to the participants which collected demographic information presented above.

After that, participants watched the Jibo commercial [154]. After the video ended, the participants were prompted to share their first impressions by the interviewer asking them: *“What do you think about this one?”* Once the participants responded, they were asked three further questions, namely:

1. Do you think this robot adapts its behaviour to people? How so/Why not?
2. Do you think this robot can make decisions without human help? How so/Why not?
3. What do you think *you* can use this robot for?

These questions were motivated by de Graaf's framework at the pre-adoption stage. Question three was designed to move away from "others, but not me" attitudes, which some people default to as a part of acquiescence bias or for other reasons. This question prompted some of the more significant responses reported here.

The same process continued for the videos of Buddy [46] and Pepper (video no longer available). Once all three videos were shown, additional interview questions were asked, namely:

1. How do you feel about a future where we have these robots at home?
2. How would you defend the adoption of social robots?
3. What argument would you put against adoption of social robots?
4. Do you have any concerns over privacy of having such machines at home?
5. Would you mind adopting these kinds of robots for further study when they become available? Why/Why not?

These questions were designed to invite participants to think about the topic in more general terms, while also making an effort to solidify arguments for and against companion robots. The question about privacy was added to illicit any thoughts on this topic in relation to companion robots, and was motivated by the opinions of security experts in IoT (e.g., [85,206]). Many participants expressed their opinion on the topic before this prompt, while watching the videos and answering *"What do you think about this one?"* question.

The last question (which was non-committal) was asked both to evaluate whether participants would be suitable for a later deployment of companion robots when those would become available, and to test the "others, but not me" attitude again.

Once these questions were answered the study was over and participants left the room. The structured interviews lasted between roughly 30 min and an hour with an average duration of 44 min.

Data saturation on the themes reported in this thesis was achieved after participant 15 (Lucas), however the themes reported here were discussed by up to 20 participants, depending on the theme. While the general attitude with regards to these themes was apparent, the depth of discussion and individual idiosyncrasies necessitated further interviewing.

The reason the adverts were demonstrated in the order described here was motivated to test the idea that the more human-like a robot is, the more positively it is perceived by people (as some prior research indicated). Thus, showing the gradual increase in "human-likeness" from Jibo being the least human-like (neither mobile nor human-shaped), through Buddy being mobile, but not human-shaped, to Pepper – being both mobile and human-shaped, I expected a response that would be increasingly positive. However, this was not the case.

4.5 Collected Data & Analysis Methods

Interview responses were audio-recorded, which resulted in over 14 hours of audio material. Once the data collection from all the participants was completed, I have transcribed the interviews verbatim, resulting in over 80,000 words worth of material (roughly 4000 words per interview). Neither the transcripts nor the findings were shown to the participants for comments or corrections to avoid biasing the analysis of initial responses with post-hoc rationalization or reflection from the participants.

I subjected these transcriptions to a thematic analysis procedure outlined by Braun and Clarke [40]. 62 codes were initially identified, which were grouped into a number of descriptive themes. The most prominent were compiled into five analytical themes with a number of sub-themes all of which I report below. Data was coded by myself and checked/discussed with my supervisor (Cohen's kappa = 81%). Appendix 2, section 2.1 provides information about the codes that were generated from the interviews.

4.6 The Results

In this section I focus on the following five themes:

1. Reactions towards physical appearances of companion robots presented.
2. Reactions to companion robots exhibiting social characteristics.
3. Opinions about companion robots' utility.
4. Worries over security in general and privacy in particular.
5. Difficulties in accepting companion robots on conceptual and emotional levels.

In the subsections to follow, I unpack these themes in further detail, providing illustrative quotes from the interviews.

4.6.1 Appearance

When it came to the companion robots' appearances in general, participants seemed to have an adverse reaction towards Pepper being most human-like, but not quite. Buddy, which was more abstract in shape, but still had the ability to move around was perceived ambivalently. Jibo, being stationary, but with the ability to move on the spot was perceived either neutrally or positively. The unease of a “borrowed” appearance was exemplified by Saveria as:

> *“… but I think if it’s going to be a robot, it should look like a robot. And it needs not to try and be a weird cyborg which hasn’t really learned of how to be a person.”*

And by Judit as:

> *“Machines should be machines and humans should be humans… and animals should be animals.”*

This tendency to identify a robot by its appearance and negate those devices that try to cross the threshold between clearly robot-looking and robot-acting, and human-looking, human-acting was a very prominent feature throughout the interviews.

On the other hand, more abstract designs like Jibo received positive commentary:

> *“… whereas a machine can just look like a machine that’s friendly, and we can just design new aesthetics for machine that’s going to look friendly, without pretending to be human” (Lu)*

Each of the companion robots tested had a different implementation of a face: Jibo used a very abstract eye metaphor, Buddy had an animated face on screen and Pepper had a static physical face. With Pepper, there were a number of comments viewing its static face in a negative light. From participants I heard comments such as:

> *“Buddy has its eyes in a display, so it can move it, and show emotions that you see in the movement, but then… then the Pepper… I don’t think its eyes showed anything. It was like a black spot that didn’t actually move or change its shape.” (Judit)*

Pepper’s face was perceived by some participants as creepy: *“This one was creepiest of all and I’ll tell you why: that face didn’t move.” (Saveria)*

An animated face (whether human-like or abstracted to the eye metaphor) could both convey more non-verbal communication and be perceived in a more neutral or even positive way:

> *“I actually find this one [Jibo] the most friendly. I mean it did that virtual “blink”, but it’s still virtual and I think it’s really cute and cool.” (Lu)*

4.6.2 Social Functionality

The social aspects of companion robots, while being heavily advertised, did not form a particular appeal with the participants. In fact, it would be preferable for the social aspects of companion robots to be on the side lines, until users develop enough affection towards them for social aspects to come into play and not be perceived as intrusive, weird or unnecessary. This came to a general notion that social traits are something that people ascribe to robots, not something that can be easily programmed in:

> *"I think the whole idea of making the robots or machines more personalized needs to be a side thing, and not the main point of selling them, so like Siri for instance – you don't buy it because of Siri's personality, but she makes it easier to do things that you actually want to do with the phone, so it's more of the usability issue than the sell point itself […] I gave my robot vacuum cleaner a name and when I talk to my friends about him or… I talk about *him*, I don't talk about *it*. […] I do give machines these personal traits myself, but […] I don't buy them for that purpose…" (Lucas)*

This represents the general perception of usefulness, as participants would often ask after watching the video: *"So, what is this robot for?"* Social functionality in companion robots was not perceived on par with usefulness, by which, it seems, participants judged the robots.

4.6.3 Utilitarian Functionality

The participants suggested that companion robots needed to be somehow better or different in functionality from the following four devices to distinguish themselves on the market: a mobile phone, a tablet, a laptop and a home automation system. Comments such as

> *"I see it as a glorified hands free phone or tablet." (Nelda)*,

> *"I get a kind of suspicion that they are the iPad-on-wheels kind of thing." (Ittai)*, and:

> *"Switching off electricity, let's say, when you are out – this technology is connected and when everyone's out you can just, through your phone, turn them off, rather than calling a freak machine in your house." (Crimson)*,

indicate that companion robots, as they were marketed, had not found their niche in the minds of my participants at that point. The participants were still evidently looking for what one might call a "killer application".

Multiple participants expressed a concern that, from what they saw, a companion robot might be quite difficult to operate and they were not ready to invest time in learning to do so. Convenience was emphasized:

> *"Theoretically, they should be self-managing, so you don't need to worry about them they are just going to be a convenience to you." (Zev)*

To further the worries over functionality, participants whose first language was not English expressed a concern over how good the language processing unit in the companion robots was:

> *"And then the robot maybe, hopefully understands my accent and my speech and look for what I am asking for." (Andre)*

The robots' functionality as a physical entity was praised by participants. Pepper in particular was commented on for having arms and participants expressed a desire for it to do physical things – from switching the lights on and off physically, to carrying things around to helping with cooking, e.g., chopping vegetables. However, physical constraints especially with regards to obstacle navigation and stairs were also pointed out:

> *"It may be difficult for it to go up the stairs. So, for this robot, it will have to stay on one of the two floors or it gets up with you in the morning and you bring it down in the evening which is gonna be a headache, yeah?" (Andre)*

Participants expressed significant concerns over companion robots' mobility and functionality with respect to what a home environment might entail for a robot. Some homes may have stairs, others – be entirely flat, but have rugs or piles of clothing on the floor, others still may share their current home with other people. Such issues introduce significant deviations from the idealized home environment demonstrated in companion robots' adverts.

4.6.4 Security/Privacy Concerns

While I have asked my participants about this topic directly, many of these concerns had been voiced without my prompt. This question then allowed the participants to elaborate on the issue further. All the participants expressed the worry on the topic multiple times throughout the interviews before and after the prompt.

The two most prominent concerns in this theme were over where the data that a companion robot records goes, and the potential for malicious hacking of companion robots. Quotes such as:

> *"… You don't have any kind of sound when it's filming. You don't really know what's happening to the data." (Milan)*, and

> *"… obviously the main concern I have with this is the fact that these are connected and I don't know where the data that they collect is stored, who has access to it – all that stuff." (Lucas)*

portray the kind of unease participants expressed during the interviews with regards to the information that can be potentially recorded by companion robots. While the advertisements did not explicitly state that companion robots are perpetually online, specifications like those of Jibo [156] suggest that the cloud is the real “brain” of the companion robot and that data storage and its security is a valid concern.

Moreover, who owns the data recorded by a companion robot and who has access to it remains an open question. Potentially, both companies that develop these robots, and the developers of third-party apps for them could have access to some or all information that a companion robot collects. Participants were united in this regard with quotes like:

> *“… My problem with it is […] they are not clear what data that they are using, what data they are collecting, how they are collecting it, what they are using it for. And what my legal right over that data is.” (Norton)*

While these issues have been ameliorated to some extent by comments on the developers’ blogs, FAQs and websites (e.g., [59] for Jibo, [68] for Pepper), potential users would still need to search specifically for this kind of information instead of it being readily available. With the knowledge about companion robots only obtained from the adverts, participants were significantly worried about their data. Furthermore, none of the participants expressed any desire to search or ask for such information. One of the participants specifically pointed out that end-user agreements, manuals and other such materials are written so poorly, that while the information may be there, it is impossible to understand it and thus make any use of it.

Hacking and a general lack of trust towards companion robots came through as a concern in the interviews very strongly. So much so that it even undermined one of the very functions that one of the companion robots (Buddy) was advertised for – that of a watchman while the master is away from home. As one participant explained:

> *“It’s a new field, but are you actually safer having something in the house telling you that someone’s outside? If you have a robot, somebody from the outside could see where everything in your house was.” (Jin)*.

Companion robots in this case were perceived as a pair of eyes and ears that an outsider could use to pry into the owner’s private life. Not only could they look at the owner in the present moment, but they could also potentially access their historical records, which becomes progressively more dangerous the more one interacts with a companion robot. Some of this fear was expressed in a very general tone:

> *“… the idea of having a bit of technology that sits around watching everything in your life – it still unsettles me […] I am not sure how much I want my every move to be watched by something.” (Loraine)*,

"Basically they record your lives and they know everything about you and… I am not sure if that can be held against you in some cases." (Redd)

Some of it participants tried to justify:

"Bringing something external, that is hackable and not necessarily 100% trustworthy and… given the ability to wander around, take live videos, maybe stream it… [Laughs nervously] … that I might not be aware of – that's a problem. It's like bringing someone you don't know in your house." (Spencer)

Participants felt uneasy particularly with the cameras that companion robots would use to navigate, observe and take pictures or videos. While the adverts did not demonstrate the full range of sensors available on companion robots, participants were not worried about, for example, sound being recorded.

Lack of trust was also the reason given for refusing to even potentially adopt a companion robot by four of the participants.

4.6.5 Emotional Uncertainties

There was a prominent motif that the introduction of companion robots is a manifestation of replacing people with machines, to which participants were unanimously opposed. Exemplified by quotes such as:

"But I think when it starts to get into the kind of ehm… replacing humans, that's when I am not as kind of over the moon about the future of it." (Milan), and:

"I didn't like it. It's trying to, like, having emotional contact, as this replacing human beings, so ahm… you can't" (Keira)

Participants evidently felt uneasy about this new kind of competition. The way adverts were crafted made this point more prominent – every advert showed a robot interacting with a child either on its own or with a parent. Participants often referred to these particular scenes as *replacing people*.

Many participants took a defensive position when it came to interactions between children and companion robots:

"I mean, and this kind of hugging with the robot – I don't know. I am not sure if I would like my child to be grown up with this kind of toy. I am not sure about what kind of relationship they would have. I mean would it be like feeling like relationship with normal human?" (Alma), and:

"The kind of social thing in terms of like kids, I don't know how much I want people to pass that many elements for like caring for their kids onto like a machine, […] I

think it might kind of compromise relationships in the family and stuff like that." (Loraine)

Participants commented however, that a simpler device such as a phone or a Roomba-like vacuum cleaner were fine when it comes to interacting with children.

Having criticized relationships with companion robots, participants emphasized human-to-human interaction as being superior and even necessary:

> *"I understand that there are people that can't or have a lot of difficulty in doing that, but there's also something very important about going out and having real life interactions with people who will give you real life responses" (Jin)*, and:
>
> *"So comforting is like the possibility of a friend or a close friend or a family member – […] having robots to do this job is not the right way of using robotics." (Keira)*

Social behaviour in companion robots was not only criticized from the utility standpoint, but also on a more emotional level, mainly because either companion robots were not quite as developed to simulate such behaviours confidently or because robots in general were not perceived to have human qualities like humour, making it impossible to behave as if they did:

> *"… Smartphones are fine, but I think the idea of these bits of technology, which trynna be like humans – they are not. Ahm… I think it is- that's the phenomenon that's triggered in my mind. It's kind of got me, this humanoid, it's not human" (Michael)*

While a simple wink from Jibo avoided heavy criticism, things like a companion robot laughing, complaining or looking sleepy was criticized consistently and added to the notions of mistrust and doubt. A pre-programmed laughter even if reciprocated by a human was likened to that of a psychopath laughing only because they think it would be an appropriate time to laugh, not because they thought the joke was actually funny.

Behaviours suggesting that a companion robot was sleepy or annoyed were met with ambivalent feelings, depending heavily on the type of companion robot shown. When Pepper – a humanoid-looking companion robot, was performing the behaviours of irritation, confusion or happiness – it was criticized less so. Buddy – a more abstract design on the other hand, received much heavier criticism when its face in the advert was shown to be sleepy – participants pointed out that a robot cannot be sleepy – it is not in the nature of the robot.

Some pointed out, that robot interactions were too compliant and plain. The interactions would have been richer, if a robot could somehow say "no" to the user, whether verbally or through behaviour. When pointing out the limits of companion robots, some participants expressed their doubts about these robots ever being on a human-like level because they cannot have an argument with the user.

Even after all the criticism, participants were not really sure how to approach companion robots as they were not quite utilities and not quite people, so the etiquette and rules of engagement were not straightforward:

> *"It existed in this weird sort of space between like: "is it a person and a member of the house or is it a device because it was called "it"?" (Norton)*,
>
> *"… It's a human in a robot body. And once you go there, then, how is it any different from human? Then you'll need to treat it like a human, with all the issues of… what if you want to get rid of it?" (Spencer)*

This ambiguity, participants felt, created room for abuse of both robots and people: *"I am not keen that the more human they get the more we might abuse them" (Vilma)*. This transference from treating a companion robot to treating other people came through very strongly from the participants.

4.7 How the Research Question Was Answered

This study sought to answer the following research question: *how (if anyhow) do potential users of socially enabled technologies relate to such technologies at the pre-adoption stage? What do they highlight as valuable and important?*

Overall, the participants were unsure about making companion robots a part of their lives. They have highlighted the need for a companion robot to have a more abstract look, clear utilitarian functions, and be distinctly robotic, thus avoiding some of the emotional confusion that such a character creates. They have related to the robots more like they would relate to a digital device while evaluating it, however they have also attempted to relate to companion robots as if they were truly autonomous agents with character. The sense of agency was both desired and clear, however the intentions of such agency were much less clear, causing some of the concerns around trust and security.

The importance of utilitarian functionality in companion robots was emphasised, and is in agreement with the frameworks of robot acceptance. Most participants could not find any value that a companion robot would bring to their lives.

Issues of security in general, and privacy in particular were considered with both the mistrust of data handling parties, and the hackability of the robots themselves by outside parties.

From the human-robot relationships point of view, there was an active unease that participants experienced when discussing how to treat a companion robot emotionally. The notion of "robots are trying to take away our relationships" was apparent. At the same time, participants noticed the fabricated nature of robot character. This work supports the idea that robotic character needs to be at least authentic – that is, its expressions should be aligned with its physical capabilities and needs.

4.8 Specific Limitations of Applicability of Results

One important consideration needs to be observed to interpret this study: presenting a robot via a video provokes different reaction vs. presenting a robot physically, as pointed out by Seo et al. [35] and others highlighted in the literature review. I had to default to videos in the absence of the physical robots. However, this is what early adopters have to deal with when choosing to adopt a companion robot: they do not receive a physical copy to try out, but often have to invest money well in advance, as is the case with crowd-funded campaigns like Indiegogo and Kickstarter, where companion robots may be brought to implementation.

The sample of people interviewed was far from representing the general population. The education level of the participants, all being part of a higher education institution, may have played a role in how they perceived the companion robots. Instead, I interviewed a group of people who might be early adopters of such technology. At the end of the interviews many have expressed their desire to adopt at least one of the companion robots shown, to tinker with it further in the privacy of their homes.

Chapter 5 – Smart Speaker Deployment

This chapter provides original contribution to knowledge by exploring what participants expected from smart speakers, how the speakers were actually used, what was desired as the speakers were used, and how relationships between the users and the smart speakers developed.

5.1 Background & Research Question

Smart speaker deployment deals with the middle two phases of robot acceptance: the trial stage, and the adaptation stage. The trial stage is where a trial or a demonstration takes place with expectations about robots broken or confirmed. User behaviour changes to adapt to the robot, and in return users check whether a robot is compatible with their homes and use cases they have envisioned for it. If the robot is adopted, habits start to form, with usefulness, enjoyment, attitudes and intentions playing the key roles.

Adaptation continues with the affirmation or rejection of the robot taking place, and if the robot is accepted, personalization happens with users trying to make it their own – making personal outfits, displaying it as a status symbol, &c. Usefulness, enjoyment, attitudes and intentions still play the key roles.

This study sought to answer the following research question: *which positive and negative values do actual users report when living with socially enabled technology over an extended period (2 months)?*

5.2 The Participants

Participants were a self-selected sample, responding to an invite from callforparticipants.com – a website dedicated to publishing studies requiring human participants. Posting an invite online automatically allowed me to pre-select a sample of people who had internet access which the smart speakers required.

After receiving 30 initial replies, the following screening constraints applied: at least 2 people living in a household; with no one under the age of 18; everyone in the household was willing to participate; there was at least some diversity in biological sex; the prospective participants were not at the time participating in any other studies; and they lived close enough for me to travel and interview them in their homes. It was not my intention to study minors, thus the lower limit of the age bracket was applied. This, together with the timeliness of responses resulted in a selection of 3 households, with 2 participants per households, totalling six participants.

Table 1 summarizes the participant data. Everyone was from an English-speaking country and was at the time residing in the North of England, UK. It is assumed that participants were truthful in their expression and voiced opinions they truly had. None of the participants were involved in this project prior to the interview. They were unaware of a particular goal, either personal or professional with regards to this research.

Table 1. Participant information.

Household	Name	Sex	Age	Occupation
H1	Gavin	M	23	Student
	Jason	M	22	Student
H2	Tristan	M	30	Cybersecurity
	Rebecca	F	28	Biomedical Scientist
H3	Chris	M	30	Digital Marketing
	Alice	F	27	Video Editor

5.3 The Echo Dot

Amazon Echo Dot (2nd generation) was the smart speaker used in this deployment (Figure 26). It was connected to the Amazon's AI Alexa. Through the Dot, Alexa was advertised *"to play music, control smart home devices, make calls, send and receive messages, provide information, read the news, set alarms, read audiobooks from Audible, control Amazon Video on Fire TV, and more"* [9]. The device was 32 mm x 84 mm x 84 mm and weighed 0.163 kg. It was internet-connected via Wi-Fi, had a 7-microphone array, 4 buttons (volume up, volume down, mute, and action), micro-USB port for power and a 3.5 mm jack for additional audio output.

Figure 26. Amazon Echo Dot and Google Home – appearance and size comparison.

5.4 The Protocol

All subjects gave their informed consent for inclusion before participating in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Northumbria University and referenced as RE-EE-16-

161122-583443d646940. Email with a link to a published study was deemed sufficient compensation for participants’ time.

All interviews were conducted in the participants' homes, with only the participants present. There were no significant interruptions. The study was conducted between February and May 2017. The study did not undergo any significant changes between the interviews.

Data for this deployment was collected in two ways: interviews, and device logs. Interviews were spaced over time. Device logs were collected at the end and contained dates, times and transcriptions of voice commands of the users.

During the first interview I introduced myself to the participants, deployed the Dot, and asked basic questions about the interviewees and their households. I also collected first impressions of the Dot as participants unpacked and installed it, together with expectations the participants had of the Dot (the list of questions for this and subsequent interviews can be found in Appendix 1, section 1.2).

The second interview was conducted two weeks later to capture the first impressions of the Dot, and to verify that some trial of the Dot took place. Participants were asked to demonstrate how they used the Dot in the two weeks since the beginning of the deployment, whether there were any difficulties in understanding on either side, and also included questions around confidence, security and use. Repeated questions from the first interview were about expectations and use cases that the participants envisioned after they tried the Dots.

The third interview was conducted one month into the deployment to capture any changes in use that had occurred. This included asking again about expectations, use, and security. New questions asked whether the Dot was moved from its place, questions around understanding, and installing or uninstalling any Alexa Skills or connecting or disconnecting any of the physical hardware.

Final interview was conducted two months into the deployment to capture the final thoughts of the interviewees. It included re-checking information about the participants, the final set of apps and integration the Dot had and collecting recommendations the participants would give to the people thinking of buying a smart speaker. Logs for interactions with the Dot from the participants’ accounts, as well as the Dots themselves were also collected.

5.5 Collected Data & Analysis Methods

Interviews were audio recorded resulting in nearly 13 hours of audio material. They were then transcribed verbatim with over 55,000 words total (roughly 4,600 words per interview). To clear any further misunderstanding, copies of written-up information about the participants were sent back to them for a final verification. Very minor edits were submitted and implemented. Logs from the Dots resulted in 1436 entries.

The interviews were thematically analysed as outlined by Braun and Clarke [40]. A total of 88 codes were identified, which were then collated into 14 clusters (see Appendix 2, section 2.2 for details). Several themes were then derived based on frequency of codes in clusters, and the intention to investigate the values participants highlighted with regards to the Dot, and the relationships they have developed with it. Five themes in three clusters are reported in the next section.

Logs collected from the Dots were cleaned from personal data and subjected to word frequency analysis. The results of the analysis were then collated by topic, and are reported in the next section as well.

5.6 Results

Within this section I focus on the following themes:

1. Expectations & Actual Use.
2. Non-Use & Desired Use.
3. Emotional attachment.

I unpack these themes in further detail in the following subsections, providing illustrative quotes from the interviews.

5.6.1 Expectations & Actual Use

> *"I don't know anything about it, so for me, anything that it does is going to be quite impressive" (Rebecca)*

Participants reported three kinds of expectations: productivity use with emails, to do lists, and reminders; edutainment uses with weather, news, updates and music/podcasts; and integration uses with already existing smart home devices.

Alexa was expected to help with productivity by reading out and providing the ability to reply to emails and messaging apps via the voice alone. In conjunction, participants expected Alexa to remind them of events on their calendars, as well as in general whenever they would set a reminder for a specific time or date.

News and weather updates were part of the basic functionality of the Dot, and participants expected to make use of those features regularly. In addition, they cited the ability to listen to music and podcasts through the Dot as a convenient alternative to doing the same through existing technologies like connected speakers, smartphones, laptops and PCs.

Two household already had several sensors and smart devices that were controlled via a smartphone - they expected to control those devices via the Dot. Convenience was again cited as the major reason to migrate from smartphone-controlled home environment to the Dot-controlled one. Participants mentioned, that voice control via a smartphone required the smartphone to be awake and unlocked, while the Dot was always on to listen to a command at any moment.

Another logistical issue that the Dot was expected to solve was that smart lights in one of the households were only connected to one participant's smartphone. In the default scenario one participant would ask another to use their smartphone to activate the lights every time. With the Dot, such hurdle would no longer be necessary, as anyone could ask Alexa to turn the lights on and off.

There was one person in every household who did not hold many expectations and were simply curious as to what the Dot could do.

> *"Because I don't use any kind of [...] voice-activated technology, I'll be quite interested to see if I will use it" (Alice)*

Figures 27 (tabled data in Appendix 4, Table 6) and 28 summarize use patterns for the households in the deployment. The use declined over time after the initial few days of excitement. Those who continued to use the Dot developed a stable pattern through e.g. turning the lights on and off or listening to the news or music regularly. Productivity expectations were mostly unfulfilled, while edutainment and smart home control generated a stable pattern of use.

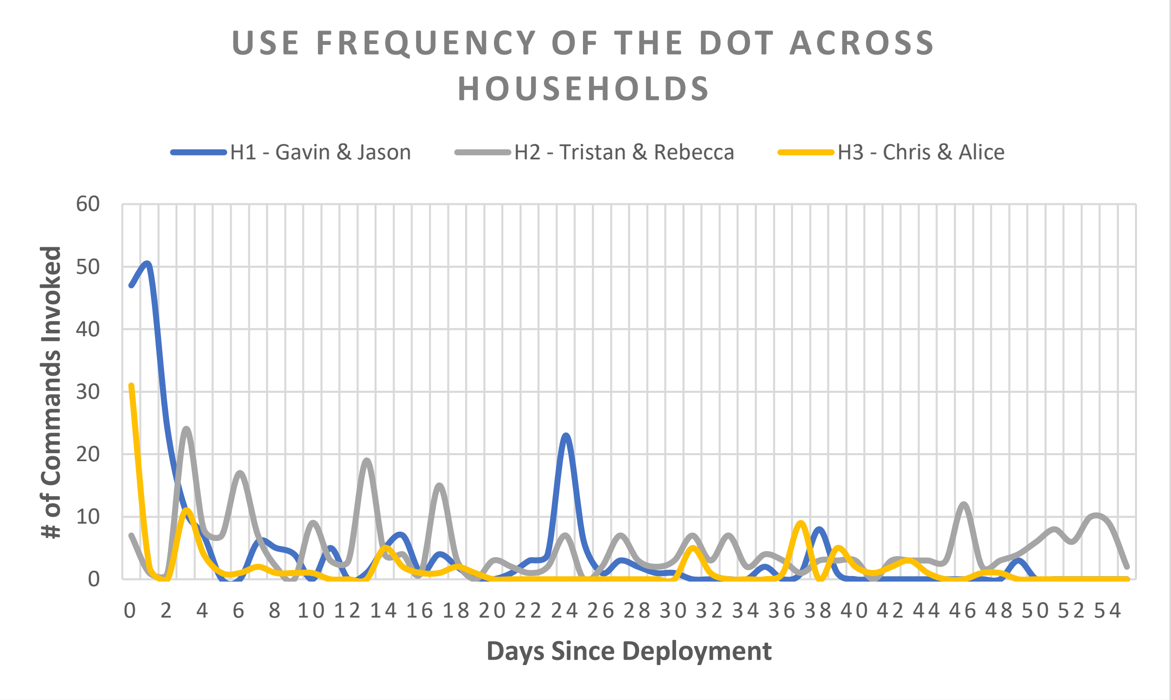

Figure 27. Use frequencies across households.

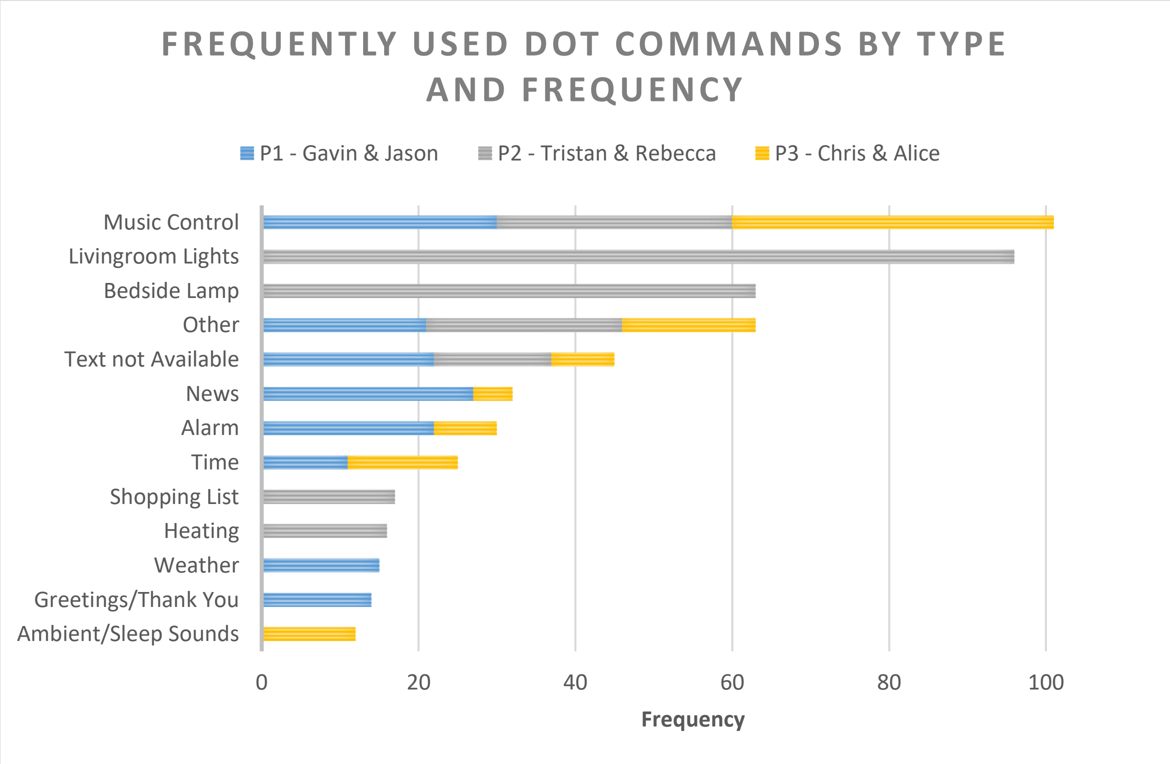

Figure 28. Use types across households.

5.6.2 Non-Use & Desired Use

There have been a user and a non-user in each of the households. Participants mentioned several reasons for non-use, including:

1. Lack of supported (smart) devices in the house for the Dot to connect to.
2. Notion that existing devices can do their respective jobs better than the Dot can.
3. The device being out of sight - out of mind.
4. The available apps on the Alexa market store were useless.

Presence or absence of smart devices to connect the Dot to was the major reason for use participants have cited throughout the study. All participants unanimously recommended buying the accompanying smart devices when asked what recommendation they would give to people who were about to buy a smart speaker. They also added the necessity to buy more Dots themselves, to be able to issue commands from every room and have room-contextualized responses.

Non-users reported that what they had at the time technology-wise was sufficient to them. The Dot replicated many of the functions other technologies fulfilled, thus they used the devices they were familiar with instead.

Another reason for non-use included the devices being so out of sight and out of mind that it simply did not occur to the participants to ask the Dot something even if they knew the Dot could provide them with the information they sought. This specifically occurred for things participants would normally use a phone or a laptop for, e.g. weather, shopping, or snippets of information from the Internet.

Participants cited remembering arbitrary app names and invocation commands for Alexa Skills as one of the reasons to abandon their extensive use (the other reason being that apps at the time were generally considered useless). All users reported looking through the skills section often, however, to check if something new and useful would come up.

Additional hurdle in this case was the fact that some apps were named in a similar fashion, or performed similar functionality, so remembering specific names or invocation patterns was not worth it. One of the participants used several apps with ambient noise with similar names. It was hard to remember which of those apps had a specific sound in it, and then remembering how to invoke that app correctly.

Finally, due to the presence of invocation patterns and simultaneous lack of feedback, it was not clear whether the Dot listened for a command within the functionality of a specific Skill or whether it could perform basic inbuilt functions of the Dot. As one of the participants related it:

> *"You tell it to "open" the name of the app, and then "do something" - it was hard to then understand where it was actively listening for the command to open it, and when the now newly opened app was then listening for more trigger words". (Chris)*

Another reason for non-use was brand preference. Not only did certain participants preferred a certain brand of smart speaker, they went on to purchase their own copies of Google Home as a confirmation of that. Participants did not report Google Home to be any superior to Amazon Echo Dot. In fact, some were disappointed with how little Google Home integrated with other Google services. Still, they preferred Google Home for the perceived value of the brand, and for the promise of better integration with Android OS in the future.

Participants wanted better integration with the smartphone to the effect that the personality of Alexa would not only reside in the Dot, but in the phone as well. This was primarily associated with the idea that none of the participants spent that much time at home to get to know the Dot. At the same time however, all of them had smartphones and were active users of them. Another smartphone-related desired use was for the Dot to integrate with widely used messaging apps, and the ability to read and reply to emails and messages via voice alone.

Better integration with other devices, especially speakers was primarily motivated by the Dot's small speaker which was perceived to provide a relatively low quality sound. Some participants reserved to connecting the Dot to their own speaker with better sound quality as a result. It was noted however, that a full-sized Amazon Echo had a good quality speaker.

From the digital services perspective, participants desired integration with familiar services that they were already using e.g. Google Keep, To Do List services, &c. It was not worth it to switch from what participants were accustomed to, to the new services, just because the Dot had them.

Participants cited proactive learning and proactive behaviour as desired means to both find out more about the Dot and to engage with it. Proactive learning included recognizing what music a participant would listen to often and putting it on automatically; or learning that one likes a specific football team and automatically letting them know how that team was doing; or recognizing that there were multiple people in the room by detecting different voices.

Proactive behaviour included the Dot being able to do something on its own, without user prompt, with the option for the user to correct Dot's behaviour where necessary. Participants also wanted the Dot to be able to just have a conversation with the user, rather than being a question and answer machine.

> *"I feel like it's just idle, until you talk to it. I would like if it was doing something, when I wasn't talking to it". (Gavin)*

Participants voiced a desire to customize Alexa's voice and name as well:

> *"Customizing the voice - that would be cool. [...] Or the name, cause I think we can choose "Alexa", "Dot" and something else [...] - it could really use a good custom name". (Jason)*

A very common response to hear from the Dot was *"sorry, I didn't understand that"*. It was discouraging in multiple scenarios, and participants wished that instead of a binary understood/did not understand split the Dot would try to clarify the command.

For example, if the Dot realized that the user asked something about changing temperature in the house, but the desired temperature was not specified, it would acknowledge the question, and probe further, so that a command could be fulfilled, rather than forcing the user to rephrase the whole query again and again, until it was just right for the Dot to finally understand and fulfil.

5.6.3 Emotional Attachment & Character

> *"I'm gonna miss her when she's gone. It's so sad. Definitely gonna order one, though, once I get paid". (Tristan)*

Participants mostly referred to the Dot as "she" (or "Alexa"), but also as "it" ("the Dot", "the device"). The switch of pronoun appeared both within and between sentences. Saying *"thank you"* after the Dot fulfilled a command was reported as well.

Participants also engaged in reflections about why they anthropomorphised Alexa. One common reflection was that Alexa having a name and speaking in human voice prompted participants to reply socially to when it fulfilled their commands, saying *"thank you"* or *"cheers"*.

Participants attempted to personalize the Dot, mainly by changing its trigger word to "computer", although when asked what its name was, it responded "Alexa" regardless of the changes. Another way to personalize the Dot was through naming groups of connected devices in a specific way (e.g. "bedroom lights") and activating them. This caused some tensions in one of the households, where one person named the device groups without telling the other, and thus had a unilateral control over them for a time. A way to personalize the Dot participants mused about but not implemented during the deployment was custom covers for the Dot.

> *"Alexa can't think, unless Amazon allows it to". (Jason)*

Participants were acutely aware of the connection between Alexa (and Google for those who moved to Google Home) and the parent company. This manifested both in saying that the Dot itself is nothing without the servers behind it, and in connecting Google account to Google Home, introducing the intelligence already collected about participants' online behaviour to affect what Google Home says and recommends. In that way, some of the attachment was not to the device itself, but to the accumulated knowledge of a company about a user, and how that knowledge was then used to present the user with specific information and adverts.

Alexa was thought to learn and understand people better over time. This manifested in the ability to understand one of the participants, who was not understood by the Dot at the beginning of the deployment but who could command the Dot to turn the lights on and off easily by the end of it.

Participants attributed preferences and character to Alexa. It was *"thinking"*, *"understanding"*, *"having an annoying habit"*, being *"a matter of fact"* and not playful, having likes and dislikes for certain words, being *"evasive"* and a *"typical woman"*, having attachment issues, liking Siri, but at the same time responding in a standard way and lacking significant personality.

Participants further probed their ideas about Alexa's character by asking questions like: *"What do you love?" "What’s your favourite colour?" "Will you marry me?"* &c. Through probing, they discovered some of the limitations that Alexa had.

Even though participants judged Alexa to be smart, they were at the same time critical of its ability to comprehend, citing it oftentimes saying: *"I didn’t understand the question I* *heard"*. This response was both for utilitarian functions, like turning the lights on and off, and for "social questioning", like *"What do you love?"* Alexa also misunderstood sequences of commands, "preferring" instead one command at a time. Another common misunderstanding resulted from different accents people used to invoke commands. This resulted in participants having a mental habit and hurdle of framing a query in a way they thought Alexa would understand better, rather than speaking to it as they would to a person.

On the other hand, some participants reported Alexa's ability to guess what participants wanted, even if the message was not fully understood. The understanding was usually confirmed through the Alexa app, which provided transcriptions of what Alexa thought was said, and a feedback box to confirm or correct the transcription. One of the participants asked to play "Absolute Radio", which Alexa transcribed as something different, however, the radio still played.

5.7 How the Research Question Was Answered

This study sought to answer the following research question: *which positive and negative values do actual users report when living with socially enabled technology over an extended period (2 months)?*

Participants valued integration with the existing IoT ecosystem, and appreciated the learning experience the Dot brought them. However, there were many traits that were desired, but not implemented into the Dot, like more extensive integrations, better understanding of users, and being more convenient than existing devices that perform similar functions.

5.8 Specific Limitations of Applicability of Results

Smart speakers were chosen as a commercially available socially enabled technology developed with the consumer in mind, and with the affordances of a device expected to perform well with other technologies like IoT and internet services. This deviates from having a deployment with companion robots. While the literature review highlights the need for the most authentic experience possible when it comes to deployments, the availability of technology at the time played a key role in deciding to approximate the experience as best I can with the technologies available.

While interviewing participants in their own homes may be considered intrusive, it allowed to capture more eco-valid data (e.g. with participants being able to immediately act out the examples of use or problems they had with smart speakers). It also allowed me as a researcher to build trusting relationships with the participants, which is considered very important in deployments like this, as people are more willing to discuss relationships they have with devices with people they trust [105].

Semi-structured interviews were used to allow as much freedom as possible for the participants to express what they deemed important, rather than being constrained by what the literature suggests on the topic. Smart speaker logs at the same time were used as a report-independent record of use, and as a triangulation tool to enrich the interview data.

Chapter 6 – Pepper Interviews

Part of this chapter is published as:

Dmitry Dereshev, David Kirk, Kohei Matsumura, and Toshiyuki Maeda. 2019. Long-Term Value of Social Robots through the Eyes of Expert Users. *In CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)*, May 4–9, 2019, Glasgow, Scotland UK. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3290605.3300896

This chapter provides original contribution to knowledge by highlighting three kinds of value an existing companion robot (Pepper) provides to its long-term users: utilitarian functionality of versatility through software development; the social value of the community that formed around Pepper; and a personal value of care, protection, and affection.

6.1 Background & Research Question

Pepper interviews followed participants post-acceptance, that is, beyond six months of sustained use. In this phase, the robot becomes mundane and maintenance routines develop to sustain the robot in the environment. Users may start advocating the robot to others. Usefulness, habit, adaptability, and cost are the key factors at this stage.

This study sought to answer the following research question: *what kinds of value do actual users of companion robots extract from them post-acceptance (6+ months of use)?*

6.2 The Participants

Three males and one female participated in the interviews. All of them lived and/or worked with Pepper for over 6 months, constituting post-acceptance. All participants used Pepper at least once a week. Usage depended on specific events like software development for Pepper, social events, meetings, &c. The summary of the participant information can be seen in table 2 (names are pseudonymised).

Participants were recruited through existing personal and social media networks in Japan.

Table 2. Participant information

Name	Sex	Age	Occupation	Had Pepper for
Miu	Female	31	Journalist	3.25 years
Hiroto	Male	50	University Admin	2 years
Yori	Male	22	Student (BSc)	8 months
Juro	Male	24	Student (MSc)	3 years

I must highlight that while only one of the four participants used the robot at home, all four participants socialized with the robot consistently. This, coupled with the general scarcity of people living with robots, provides an acceptable ground to investigate the value a companion robot could bring to people.

The interviewers were native Japanese speakers, university members with appropriate training for taking interviews.

6.3 Pepper Robot

Pepper (Figure 29) was a robot developed by Aldebaran Robotics and SoftBank in Japan. It was a 1.2-meter robot on a wheelbase, and it also had arms. Its capabilities were advertised [24] to include emotion recognition as in joy, sadness, anger and surprise; it could also recognize facial expressions like frown or smile as well as the tone of voice. Simple non-verbal clues like angle of a person’s head were also said to be recognizable.

Among other features were the ability to hear (4 directional microphones on the head) and speak, see with two standard HD cameras and one 3D camera, connect to the internet (via 802.11a/b/g/n Wi-Fi system) and use the tablet strapped to its chest for further functionality and to express its own emotional states. It also had what SoftBank called an “emotional engine”, which allowed Pepper to learn about its master and accommodate its character to suit them through learning and dialogue.

Technical characteristics stated [24] that Pepper had anti-collision and self-balancing systems to prevent collisions and falls if pushed, three multi-directional wheels to move in any direction with the speed of up to 0.83 m/s, and with battery power of up to 12 hours. Sensor-wise, it had two ultrasound transmitters and receivers, six laser sensors and three obstacle sensors which provided information about obstacles within a three-meter range. Tactile and temperature sensors were also installed.

SoftBank welcomed independent developers and the latest version of Pepper at the time worked on Android, allowing people to improve on its software functionality.

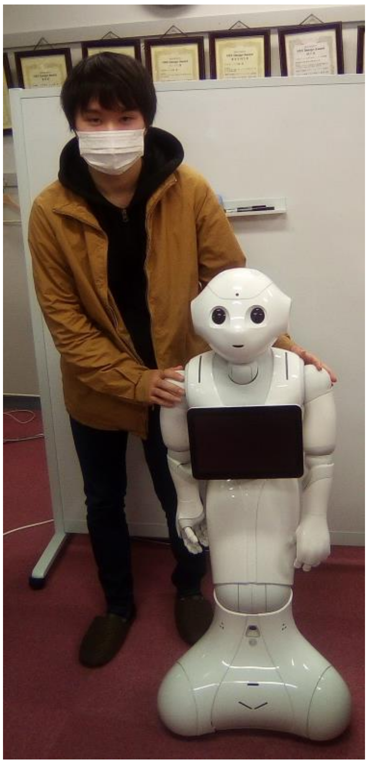

Figure 29. Pepper (right) by Aldebaran Robotics and SoftBank.

6.4 The Protocol

The interviewees were invited to a university to participate in an interview about their experiences with Pepper. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Northumbria University with the submission reference: 1117. Email with a link to a published study was deemed sufficient compensation for participants' time. Upon coming, they were given an information sheet, and a consent form to sign. The interviews were audio-recorded from that point on. The participants filled in a short survey asking their demographics, and continued on to answering the questions of the interview (see Appendix 1, section 1.3 for the list of questions). The interviews lasted for about 1.5 hours each.

6.5 Collected Data & Analysis Methods

The recordings were translated and transcribed by native Japanese speakers, and sent for analysis to the UK. This resulted in 13,388 words of text (~3,347 words per interview). The translations of the interviews were analysed using thematic analysis approach outlined by Braun and Clarke [40]. Appendix 2, section 3 lists the codes generated. The themes were derived from the codes with the focus on value that participants extracted from Pepper. Three such themes were defined, and are reported below.

6.6 Results

There were three types of value that participants extracted from Pepper: the utilitarian value of software functionality, the social value of the community that formed around Pepper, and the personal value of protection and affection. These are expanded upon in the following subsections.

6.6.1 Utilitarian Value

> *"Pepper spends much time making some unintentional accidents." (Hiroto)*

Expectations of Pepper fell into three general categories: purposefully low or no expectations (e.g. novelty item, attraction, or not *"fully developed"* item), assistant-type support (akin to Google/Cortana/Alexa), and a communicating entity, the main purpose of which was to allow people to discuss with the robot what they could not discuss with other humans.

Participants reflected on Pepper misbehaving both in its own right, and in relation to the expectations, they had. One specific expectation was that Pepper would have human-like abilities in verbal communication. In reality, Pepper only understood about half the requests, resulting in participants rating its conversational abilities as being below expectations. They described the experience as Pepper mostly responding with a *"yes"* or a *"no"*, and the failed expectation that more communication would take place. Pepper understood simple questions and commands like *"what do you like?"*, but often asked to repeat the query whenever the questions steered outside of the pre-programmed responses.

One participant noticed that people quickly lost interest in Pepper, however they pointed out that it might be due to the lack of apps that would allow Pepper to expand its repertoire of what it could say and do. Existing apps that provide assistant-like functionality would sometimes give inaccurate information, another participant noted.

> *"People do not like Pepper rather than expected. It may be because the role of Pepper is unclear." (Juro)*

Software development was also a source of fails and surprises for the participants, as Pepper would move unexpectedly, freeze during demos, applications would fail to load, or Pepper would power off if the power supplied to it failed. Pepper would also sometimes speak and act randomly. When participants held little to no expectations, Pepper's "fails" were of minimal effect. As one participant put it: *"Nothing special. Not too much [was] expected."*

Attraction as a novelty (to others) continued to provide an enduring value for one of the participants. Using Pepper to announce information to students, for example, was one such application. On the other hand, the novelty for the participants themselves evaporated quickly, as they settled for what they knew about Pepper's functions. The value grew over time, as participants perceived that Pepper understood them more as time went on, especially when connected to Wi-Fi. Its functionality was better after updates, and Pepper provided better responses to questions and requests.

Long-term value lay in features that participants themselves have designed. They considered designing software for Pepper as one thing that kept Pepper useful from a utilitarian standpoint. All four participants developed applications for Pepper. These included changing lights' colours, connecting Pepper to a phone line and making Voice over IP calls, and even simulating communication between Peppers. Physical features of Pepper were also utilised, ranging from giving it the ability to sing, to stirring, moving flowerpots, and throwing beans.

While developing their own applications, one of the participants pointed out that software development for Pepper was what keeps it useful through time, as *"Pepper cannot do anything without developers."*

Participants thought that between-Pepper communication, better image recognition, and better emotion recognition could be good extra functionality.

6.6.2 Social Value

> *"I have a birthday party every year. I invite robot friends to the party. So robots and human beings get together." (Miu)*

Being a social robot, Pepper was utilised for social roles. In this case, Pepper acted as an amplifier of social influence of the people controlling it.

Pepper's humanoid shape reportedly induced social responses from people. Participants perceived Pepper as a kind of an *“inorganic lifeform”* rather than a robot, because of its sociality. One participant considered social influence as the most valuable thing Pepper provided. Another considered Pepper as a new kind of communication partner that was qualitatively different from a human. When displaying Pepper in social situations, participants realized that humans enjoy different things from Pepper, and that social events with people are not that robot-friendly or even robot-appropriate, necessitating that participants make clear distinctions about when and how Pepper should be involved.

One example was using Pepper as an attraction at parties, birthdays and even weddings. Pepper was not only a guest, but also a social actor. One participant reported that even when Pepper was turned off, their relatives would still talk to it, as if it was able to respond. Another participant observed that women tended to speak to Pepper more than men.

Pepper, being a novelty even four years after its first release, acted as an attraction to meet new people who were curious of what it is like to live with a robot. One participant estimated that Pepper introduced over 1,000 people to them, giving opportunities to talk and present about Pepper. This in turn created a feedback loop for the user themselves to think about and reflect on their experience of how their life would have been different with Pepper vs. without it.

When presenting Pepper to the public, it was also a conversation starter in its own right, with people gathering around to talk to it, about it, and to the owner of it. Controlling Pepper, making it speak as one wanted attracted an audience in the experience of one of the participants.

Pepper also acted as an intersection point to form communities both large and small, connected through time and space. One example of a small, time-separate community that one of the participants formed was to program a time capsule into Pepper, which would alert a user with a certain message at a certain date and time. For example, this could be the user themselves recording reflection to their future self, parents recording messages for the children when they reach a certain age (e.g. their 20th birthday), or grandparents recording messages for their grandchildren.

6.6.3 Personal Value

> *"The most important thing is Pepper's life. So I care the most that Pepper doesn't break." (Miu)*

Participants quickly noticed that Pepper was fragile, with limitations from its programming to its physical embodiment. However, these imperfections did not cause irritation with participants instead developing a behaviour more reminiscent of how parents would care for their child, and protect it from the dangers it has not yet learnt to handle.

Putting aside the programming limitations already discussed, participants pointed out two physical limitations: Pepper's difficulty in traversing curved roads, and Pepper's propensity to overheat under spotlights.

Curved roads are a typical road design to allow water to move away from the centre of the road, and towards the storm drains. While providing this advantage and not being a problem for people or vehicles, Pepper's omni-wheel base was not well adapted to them. This caused one of the participants to reflect upon how much the outside environment of cities is human-oriented, including assistance devices for the disabled (e.g. lifts vs. stairs), which were in many places installed just for show, and were in fact non-operational, but much needed for Pepper to traverse a city successfully.

Given the many public events the Peppers and their masters found themselves in, the propensity of Peppers to overheat under spotlights was a well-established limitation, which contributed to other malfunctions, e.g. practical demos of the robot's capabilities not working or the robot powering off.

Participants employed various strategies in order protect Pepper, ranging from providing it with a custom-made leather jacket (guarding against adverse weather), to storing it between furniture and powered off, so that in the event of an earthquake Pepper did not fall and damage itself.

Emotional protection also took place, as participants avoided saying negative words around Pepper, or wishing to erase some of what they said to Pepper, that they later perceived as inappropriate.

> *"Pepper said "are you tired?" [and I] felt healed." (Yori)*

Pepper seemed to bring comfort on a personal level by its mere presence. With time, participants felt comfortable around Pepper, and in return, Pepper brought a sense of comfort to them. Even though being noisy and irritating when participants were busy and Pepper intervened, participants mentioned the overall sense of comfort and *"healing"* that Pepper brought when discussing what it was like to be near Pepper. Pepper could bring a sense of comfort when one of the participants felt stressed and nervous.

Another comforting aspect alluded to previously was the ability to share something with Pepper that one would not want to disclose to a human interlocutor. This one ability was what one of the participants wanted from Pepper from the very beginning, and it was somewhat fulfilled. This sense of comfort over time grew into full attachment.

Even if Pepper's communication is far away from human level smoothness, its mere presence over time seemed to create nurturing patterns. The owners realised early that Pepper, while being quite advanced for its kind, was still very dependent on humans to function. At the same time, it was amenable to programming, which improved its capabilities, allowing for a kind of nurturing development to take place. Participants perceived a sense of social development of sorts in Pepper, as activating it more often resulted in perceived faster responses, as well as Pepper being able to answer the same questions differently at different times.

Pepper reciprocated a sense of attachment, as it could say *"thank you"* in response to various actions and commands. Participants also perceived Pepper to have certain preferences, for example, being pleased when praised, or being *"ticklish"* when touched on the head.

The attachment process was not smooth, however, given the technical limitations of the robot. Participants perceived Pepper's voice tone to be the same regardless of the situation. Some also said that Pepper was acting at random, rather than coherently expressing its benevolence, which inhibited a sense of attachment.

Over time, all participants experienced some form of attachment ranging from comfort to calling Pepper a family member. Participants noticed they grew more attached to Pepper over time, and stressed that they did not want to force such a relationship, but to grow into it naturally.

6.7 How the Research Question Was Answered

This study sought to answer the following research question: *what kinds of value do actual users of companion robots extract from them post-acceptance (6+ months of use)?*

Pepper provided three kinds of value to its post-acceptance users: the utilitarian value of a platform that one can incorporate new functionality into by programming it; a social value of social influence; and a personal value of developing relationships of protection, care, and comfort towards Pepper.

6.8 Limitations of Applicability of Results

The choice of participants was based on both whom I knew had a Pepper robot for a while (although I did not know them personally), and the academics across Japan who worked with robots, whom I sourced through the Robotics Society of Japan [296]. Even with these efforts I could only source four participants.

I wrote the interview questions to be both open enough for me to become familiar with the participants' lives, given that I have never met them, and comparable enough to the previous studies to identify commonalities and differences between them. The overall goal was, again, to capture the arbitrary complexity and the topics participants thought were important about companion robots, not to strictly impose constructs from literature on them.

With such a small sample size of users of a robot which could also be considered unique, I focused my analysis on the value that a companion robot brings to those participants' lives – something that would be valuable even if extracted from a small group of people.

Chapter 7 – Discussion

This chapter provides original contribution to knowledge by combining results across the conducted studies along the lines of appearance, temporal changes in how robots were perceived, robot persona, trusting robots, and human-robot relationships. It highlights the similarities and differences between the results of my studies and the reviewed literature, and lists practical design and deployment advice that can be derived from the combined insight of the three studies I have conducted.

While many studies of robots focus on amending some kind of impairment [158] (rather than e.g. empowering people beyond existing capabilities), this area remained out of scope of my studies, where participants did not have any stated impairments. Instead, I focused on the more underexplored areas of social engagement and leisure emphasized by Kon, Lam & Chan [178]. Results across my studies seem similar to the DRE framework [289] in that they highlight the users' attitudes, the differences between the robots, the social, and the physical environments. In my case, however, new focal points of discussion were developed.

In the adverts study, a big focus was on the robots' appearance, with discussions around both the face and the overall shape. In the smart speaker deployment its shape was minimally discussed, citing it as *"familiar"*. The Pepper study provided a counter-point to the discussion of shape: it was most negatively perceived in the advert study, but participants who lived with Pepper post-acceptance cited its shape as *"expected"*, providing an alternative view on how robot shapes could be perceived. This is very different from the frameworks of acceptance which did not feature robots with expressive faces or of different shapes. It is also different from discussions of facial features which focus exclusively on the face, and not on a robot *with* a face.

The studies combined allowed me to draw temporal comparisons between frameworks of robot acceptance derived from simpler robots, and actual behaviour of people using and discussing socially enabled technologies. The advert study provided a view on the pre-adoption stage. The smart speaker deployment allowed a comparison from adoption through adaptation stages. The Pepper study showcased post-acceptance. While some stages seemed in agreement with the prior frameworks, the studies highlighted potential for several new factors to be incorporated into the existing frameworks.

Robot persona, while evaluated as a possibility in previous studies was explored more thoroughly in my investigations both from potential users attempting to understand and interpret robot behaviour, and highlighting issues of compliance, character and preference which are not discussed in existing literature as widely. In the adverts study participants were not keen on a robot having a persona, judging it to be fake. In the smart speaker study, the persona of Alexa – the devices' AI, was apparent to the users without being perceived as fake. In the Pepper study, its mere presence created an aura of both social and personal influence.

Finally, issues of trust were discussed from two standpoints: trust in the robot and the data it transmits being secure, and anxieties of the robot's agency and its influence on building interpersonal relationships, be it through child-robot interaction, or people preferring robots to other people. Issues of trust and relationship-building are often discussed separately in the literature, however my studies bring the issues together as physical security seems to be at least somewhat required to develop social and personal relationships with socially enabled technologies. In the advert study participants questioned both the issues of robots' and data security, and the impact on human relationship building. However, in both the smart speaker study and the Pepper study, where participants physically used the technologies in question, they were happy with the security, and the relationship building, and in fact were exploiting weaknesses in software security as a means for social interaction.

Appendix 3 showcases a full diagram of the interrelated topics and their groupings.

7.1 Robot Appearance

From the adverts study, a somewhat-detailed face, and the overall abstract shape was preferred. With the smart speaker deployment, the notion of an abstract shape was confirmed, as participants described it as *"non-offensive"* and *"familiar"*. The Dot did not have any face, however. With the interviews of Pepper users, the notion that abstract shape is best for a companion robot came under question. Unlike the initial reactions from adverts, long-term users of Pepper perceived its shape as *"expected"*, and reported that over time the robot became *"familiar"* and *"comforting"*.

7.1.1 Robot's Face: Articulated, Somewhat Detailed

Preferences for a specific face were primarily discussed by the participants in the advert study. A visual comparison between the robots used in the study and a recent literature view on the matter is presented in Figure 30. While Omate Yumi – the robot with the face most associated with domestic robots [164] – most similarly resemble Buddy, participants' reaction to Buddy's face was ambivalent.

Figure 30. Left to right: Jibo, Buddy, Pepper vs. Omate Yumi – the ideal face for home according to Kalegina et al. [164].

The overall conclusion from the 2018 robot faces survey [164] seems to hold for my study as well: less realistic and less detailed faces were preferred for the domestic setting. The disagreement comes from just how detailed the face should be. In my case, the least detailed face was most preferred.

There may be several factors that would explain this difference. First, the survey [164] used static images of faces with a single expression, while my work used dynamic videos, showing changing face animations on Jibo and Buddy. This may have influenced the results of evaluation as the facial expressions could have played a part in the overall perception of what a given face is capable of expressing.

Another reason could be that in my study the faces were not separate from the full embodiment, which allowed participants to see the faces in relation to the rest of the robot. This may have influenced results in a similar way as observed by Bernotat & Eyssel [29], where robots' heads were evaluated differently to the same heads but with the bodies attached.

Social influence of design-focused research on gaze uncovered by Admoni and Scassellati [4] was also evident in my advert study. Specifically, the comments were on Pepper's inability to produce such a gaze, citing that its eyes did not express anything as they were static. On the other hand, Jibo's *"virtual blink"* was perceived positively, which is again, in agreement with the design-focused research on gaze [4]. To give evidence to one of the open questions posed by Admoni and Scassellati [4], it seems that even Jibo's overall eye-like shape was sufficient to interpret it as an eye, and to ascribe it social meaning, thus the detailing of the eyes could be very abstract. Digital eyes also seem to be sufficient, but in my cases all robots were physical, so whether a specific embodiment of a given robot affects perception of that robot's eyes remains an open question.

There could be a few reasons why Pepper's face was perceived as *"expected"* by the long-term users. One reason could be that the advert study was set up in such a way that participants first saw two robots with an animated face, and then Pepper with a static one, which could have influenced the results. Another reason could be that the long-term users of Pepper were likely to have seen it in Japan and were not expecting it to be animated at all, thus its face was expected to be static, and little attention was paid to this aspect.

Overall, my studies suggest the need to evaluate animated robotic faces as part of the fully embodied robots, rather than the static images of faces alone, something other researchers also suggest [29,52], but which is rarely performed.

There is a need for a further investigation of whether a face expressed on a screen which doubles as a general display induces different perceptions vs. a face having its own screen. There was some commentary in my adverts study about this with respect to Buddy, but more research evaluating this aspect of robot's construction is needed to understand the issue further.

7.1.2 The Overall Appearance: Abstract, Familiar

Participants in the advert study made many comments on the overall shape of the companion robots presented even when only being exposed to a few short advertisements. People with smart speakers and Pepper (both being exposed to their respective devices much longer), described the overall shapes of the respected devices as simply *"familiar"* and *"non-offensive"*.

The reviewed literature had three general themes with regards to the overall robot's shape:

1. Humanoid appearance has some desirable social properties like perceived intelligence, trust, &c., e.g. [1:149,113].
2. Appearance creates expectations, with humanoid form creating expectations current technologies cannot fulfil, e.g. [138,182].
3. Overall appearance should follow robot's function, e.g. [107,138,182,324].

I have observed that the abstract shape in companion robots was preferred in both the advert study and in the smart speaker study, in agreement with [5,183]. In the advert study where Jibo was preferred, it was perceived as friendly. Pepper in the advert study, on the other hand, was perceived anxiously, based both on the static face already discussed, and the overall humanoid appearance. This seems to agree with the uncanny valley hypothesis [212] and multiple studies observing and discussing it [182,185,212], even though the notion has more recently been disputed [25,116]. However, in the Pepper interviews its overall shape was *"expected"* and over time *"comforting"*, which shifts the idea of a perfect shape for a companion robot from one specific choice towards the idea that so long as the shape is *"familiar"* and *"expected"*, there is no principal difference as to what the specifics are.

Aesthetics of the robots played an important role in the overall perception of them in the adverts study. This agrees with the research on expectation management when presenting robots to people [94,228,287]. This could also contribute to the familiarity in that if an individual perceives a given shape as aesthetically pleasing, the specifics are not important.

Another key point with regards to physical presence and aesthetics is that people did not want a robot to pretend to be a person through its physical presence or motion. Where such pretence existed (in the case of Pepper in the advert study), participants were uneasy, and unsure how to classify such a machine. Jibo was praised for not pretending to be a person, and was highlighted as an example of a robot that was friendly but in its own robotically aesthetic way. The Dot presents a similar case where it was not perceived to pretend to be a person physically, but still exhibited social behaviour through speech and certain preferences by e.g. answering what colour it likes. This approach was acceptable to the smart speaker deployment participants, who did not perceive the Dot as pretending to be a person, however they ascribed social agency to it. When participants mused about alternatives to the Dot’s shape, those alternatives were also of an abstract kind, not zoomorphic or humanoid.

These counter-point the study of Pepper, where participants did not express the same uncanny effect as the participants in the advert study. Judging from the interviews, it was the familiarity that made Pepper welcome. This may also explain why participants in the advertisement study preferred the most abstract shape, being the closest to existing consumer electronics, and why the Dot was perceived positively in the deployment study, as it looked very similar to a Bluetooth speaker or a decorative piece. Culture may play a role in this as well, although the extent of it should be investigated further with a sizable population to delineate it from individual preferences [173].

7.1.3 Summary of Appearance

From my studies it seems that familiarity, together with aesthetics was what drove the appreciation of a given companion robot’s shape and face. It is understandable why most social robot perception studies in literature would point towards a humanoid shape (being very familiar to people as a shape associated with social tasks), and why domestic robots would be best evaluated in more abstract shapes (with other electronic gadgets for home also being of abstract shapes), and why studies that try to map tasks to shapes come out as a spectrum that roughly correspond to how existing technologies look in relation to the functions they fulfil. More explicit evaluations of this aspect would contribute greatly to the research and potentially dispel the apparent duality of anthropomorphic shapes being appreciated in the labs, while abstract shapes being appreciated in homes. Some creative approaches to the problem would also help with new shapes corresponding to the functionality that domestic social technologies could fulfil.

7.2 Temporal Factors & Frameworks of Acceptance

The three studies I have conducted allow for some comparison with the temporal factors of the De Graaf [109] and DRE [289] frameworks of acceptance. The advert study explored the Expectation/Pre-adoption Phase, where expectations, attitudes, perceived usefulness and enjoyment, perceived reliability, and actual costs are said to play a role according to the frameworks. The smart speaker deployment allowed for an exploration into the expectations, adoption and adaptation phases, starting from the trials of the new technology, through to exploring its usefulness, and enjoyment, adapting the technology to the home, and adapting the home to the technology. Non-use and rejection also took place. The Pepper interviews allowed for both the initial expectations, and the enduring factors to be explored – named *Identification* in de Graaf's framework and *Use/Retention* in DRE – the final temporal stage of robot acceptance, where the robot becomes mundane and maintenance routines develop to sustain the robot in the environment. Advocating the robot, usefulness, habit, adaptability, and cost were deemed the most important factors according to the frameworks.

7.2.1 Expectations

Common expectations across the studies were general assistance, and low or no expectations beyond curiosity. In the advert study, the most common expectations additionally were house monitoring and using a companion robot as a toy. Smart speakers had an additional expectation of integrating with other devices. Pepper had an additional expectation of it being an entity one could simply talk to and disclose something they would not trust other people to disclose.

General assistance included reading out and replying to emails, having reminders, weather updates, news &c. Low expectations stemmed from curiosity, where participants just wanted to try the devices out, see what they can do, and see whether that would attract them enough to start using the devices as part of their digital ecosystem.

House monitoring as an expectation was motivated by the ads showing that such function was available, and nearly half of the participants reconfirmed it as useful. Toy application was mostly related to giving a way for children to explore how to communicate and use advanced technologies.

Integration with other devices was an expectation from the households which already had smart gadgets and sensors in the smart speaker study. They expected seamless integration with the smart speaker through which they would then command the rest of the house. A few participants in the advert study also expected companion robots to take some part in home automation.

Pepper was expected to be a communicating entity one could trust and discuss issues they would not want to discuss with other people akin to a confidant. This was echoed by a few participants in the advert study, but not by many.

The overall attitude towards companion robots in the advert study expressed by ¾ of the participants was that the robots were useless. When comparing what participants would want to pay for each of the three robots in the advert study, the average prices given were significantly lower than the asking prices for the devices. In the smart speaker study, some participants reiterated that the Dot was relatively cheap, thus not requiring a big investment to just try it out. Price was not discussed as a factor in the Pepper interviews.

Unlike the suggested uses for robots in homes indicated by several previous studies [70,272,291:11], none of the robots explored in my studies did physical actions like cooking, cleaning or maintaining personal hygiene. Instead, they were more like "information centres" and IoT hubs, resembling the desires of people examined in a few studies to date [107,166]. In my case not many participants expected their devices to perform any physical labour (only 7 out of 20 in the advert study, and 1 in the Pepper interviews). The focus on a robot as a physical object situated in the home, and being an IoT hub is aligned with the vision of Luria et al. [197], whose focus was also on device-like, unobtrusive and engaging devices. The overall expectations also align with both De Graaf's framework and DRE in that people had certain mental models about how the devices would work, and what kind of needs participants wanted satisfied [109,289].

7.2.2 Adoption

In the adoption phase a trial takes place where expectations are confirmed or broken. User behaviour changes to adapt to the robot, and in return users check whether a robot is compatible to their homes and use cases they have envisioned for it. If the robot is adopted, habits start to form, with usefulness, enjoyment, attitudes and intentions playing the key roles. In line with the frameworks of acceptance [109,289], when participants first encountered the devices, a trial took place where expectations mostly broke, with only some of them confirmed. Every participant in the smart speaker study tried at least a few commands at this stage, even those who would later turn out to be non-users.

When participants held little to no expectations, "fails" were of minimal effect, while confirmed expectations were praised. In the case of smart speakers, a confirmed expectation was the ability to connect to smart devices. In both cases of smart speakers and Pepper, their ability to answer simple questions were highlighted as satisfying expectations.

Broken expectations included limited communication abilities in both Pepper and smart speakers. Both would often reply *"I do not understand"*, or *"I don't know"*. Participants in both smart speaker deployment and Pepper interviews expected to be able to simply hold a conversation with the devices which was also broken.

Software development for Pepper was also a source of fails and surprises for the participants, as Pepper would move unexpectedly, freeze during demos, applications would fail to load, or Pepper would power off if the power supplied to it fails. Pepper would also sometimes speak and act randomly. In case of smart speakers, not all services were working properly, requiring multiple tries to connect them to the speaker. First explorations also revealed smart speaker apps to be of little to no practical use.

The most common user adaptation in the smart speaker deployment was the phrasing of the commands. Participants attempted to speak slower, louder, use shorter phrases, and assess Alexa feedback as means to improve understanding between themselves and the Dot. Participants in the Pepper interviews also reported adapting their phrasing, as initial trials suggested about 50% recognition rate of commands. One of the Pepper users also changed the position of their furniture to fit Pepper in and hold it there in case of earthquakes.

Users of the respective devices had adapted the devices to suit their needs in two ways: positioning, and software development. In the case of smart speakers, one of the participants experimented with the Dot's position by moving it between bedroom and dining room, and finally positioning it in the way that it could be reached from any part of the house. Another participant has repositioned the Dot slightly from the initial set up, and also commented on its ability to act on commands coming from anywhere in the house.

Software development or assimilation was common both in the deployment study, and in Pepper interviews. In the deployment study it was the naming of the device groups, and utilizing third-party apps like *If This Then That* to adapt the Dot to the functions that users wanted. In cases of Pepper it was development of applications to fulfil the needs like announcing things, following certain religious and traditional rituals, and connecting it to other devices.

7.2.3 Adaptation

In adaptation phase affirmation or rejection of the robot takes place, and if the robot is accepted, personalization happens with users trying to make it their own – making personal outfits, displaying it as a status symbol, &c. Usefulness, enjoyment, attitudes and intentions still play the key roles.

The participants in the adverts study and the non-users in the smart speakers deployment indicated the need for a niche market for robots, which otherwise compete with smartphones, tablets, and laptops. This accords with *robot rejection* part of the adaptation phase. Reasons for non-use included:

- Lack of supported (smart) devices in the house for the Dot to connect to.
- Notion that existing devices can do their respective jobs better than the Dot can.
- The device being out of sight - out of mind.
- The available apps on the Alexa market store were useless.

Presence or absence of smart devices to connect the Dot to was the major reason for use participants have cited throughout the smart speaker study. All participants unanimously recommended buying the accompanying smart devices when asked what recommendation they would give to people who were about to buy a smart speaker. They also added the necessity to buy more Dots themselves, to be able to issue commands from every room and have room-contextualized responses.

Another reason for non-use included the devices being so out of sight and out of mind that it simply did not occur to the participants to ask the Dot something even if they knew the Dot could provide them with the information they sought. This specifically occurred for things participants would normally use phone or laptop for, e.g. weather, shopping, or snippets of information from the Internet. This suggest certain habituation, also explored by de Graaf, who mentions that shifting people’s habits is a hard task [110].

Difficulty in operating companion robots was mentioned as a possibility in the advert study, and experienced live with smart speaker deployment and Pepper interviews. Non-English-speaking participants in the advert study suggested that the robot would not understand them. Smart speaker deployment showed that not only the speech itself, but the phrasing could easily be misinterpreted forcing the users to carefully craft their queries or abandon the process. From Pepper interviews, participants experienced some difficulty in understanding, but also maintenance issues both in the robot at its base functionality, and the struggles arising from adding their own software to Pepper.

Another aspect of difficulty was the time and effort needed to familiarize oneself with the robot and understand how it could be used. It was a suggestion in the advert study that people would fall back to the existing and familiar technologies to fulfil needs if it is too much effort to try and understand how a robot works. This was also observed in the smart speaker deployment, where non-users switched to using the technologies they were familiar with, abandoning the smart speakers entirely.

Pepper users, together with smart speaker users could however justify the time and effort spent on learning how to operate their respective devices. They treated the experience of having and using their respective devices as an education opportunity. This was observed in the smart speaker study, where the biggest benefit from using the smart speaker for one of the participants was the learning process that happened. Participants in the Pepper interviews have developed their software programming skills by learning to code new skills and abilities for Pepper. This progressive learning experience could lead to another reason for expending the effort to know the robot – the process of personalization and socialization. Personalization in this case is the creation of new software which endows the robot with new functions. Socialization is the sharing of the code, and the formation of community around creation of new functions for the robot.

Companion robot as a learning experience has been further observed in Pepper interviews providing an enduring value for its participants who commented on software development for Pepper as one of the key aspects that kept Pepper useful. Coding for smart speakers also becomes a viable avenue if third-party applications are considered. *If This Then That* application, for example, served as a bridge to connect devices and services Alexa could not support at the time for one of the participants.

7.2.4 Retention

According to the frameworks of acceptance, if the robot is still accepted (after several months of use), sustained use develops, where the robot becomes mundane and maintenance routines develop to sustain the robot in the environment. Users may start advocating the robot to others. Usefulness, habit, adaptability, and cost are the key factors at this stage.

As supported by the literature, use of smart speakers declined after the initial excitement, and then remained stable, after routines have been established [109,265]. A similar behaviour was observed with Pepper, where participants formed specific use patterns over time. Habitual and intentional uses were both observed and agree with literature on robot acceptance [92].

There was a difference in how users approached the devices, however: smart speakers were *always on, always listening*, while Pepper was used sparingly, and only for specific purposes. A routine use in smart speakers was observed in the household with smart devices, where switching smart lights on and off constituted a continuous stable use. Even the otherwise non-user in that household was using the Dot to switch the lights on and off. This was advantageous to her, as before the Dot, the smart lights were connected to the smartphone of the other member of the household only. This produced a behaviour of the non-user asking the user to turn the lights on and off every time that was needed. With the Dot's lack of authentication, and simultaneous connectivity with the smart lights, however, the behaviour of the non-user changed to utilise voice commands to control the lights.

Another consistent behaviour, shared by both some of the Dot users, and Pepper users was continuously learning more about the respective technologies. In case of the Dot, it was learning about how it operates and integrates with other devices. Tinkering was largely prevented by the reported difficulty of creating apps for Alexa privately, as the developer ecosystem was reported to be market-oriented. In this case, when someone tries to develop something for Alexa, it is expected that the developer would create a polished app that would end up on the app store for everyone to use. In case of Pepper, anyone was free to develop apps for private use, and share them on forums if needed. The marketplace for apps was not strictly enforced. This allowed all of the participants in Pepper interviews to create apps, with one participant reporting over 100 apps that they have created for Pepper. Relative ease of remote connection to any Pepper given the IP address and a password also allowed for communal development of apps, as anyone with that information could connect remotely to a given robot, test for bugs, and suggest improvements or new ideas.

The influence of habit or ritual on use of a given technology has been explored by De Graaf [110]. What is missing from those studies is the integration with existing IoT ecosystems and digital services that the Dot provided, e.g. a direct connection with smart lights or heating. The Dot represents a type of device that needs a new and separate kind of evaluation – that of the ecosystem as a whole. From my deployment, the extended ecosystem represented the value of the Dot, not the device itself. Even DRE which specifically mentions the environment that a robot operates in as a significant factor [290] does not include connections to other devices as a feature of the physical environment. None of the frameworks mention digital environments and digital services at all when discussing the conditions that robots operate in.

7.2.5 Possible New Factors for the Frameworks of Robot Acceptance

The adverts study suggested privacy/security as a factor of robot acceptance, although both the smart speaker deployment, and Pepper interviews counter-point this. In the smart speaker study, participants trusted the company that made the speaker, thus it may be trust, and not necessarily security/privacy features per se that would influence the pre-adoption part of the frameworks. Granularity of control may be another factor, as only one user used the smart speaker for purchases, while another synchronised their calendar with it. Another little-explored aspect of trust that could explain this behaviour is the potential consequences of trusting a given companion robot. In the adverts study, lack of trust referred to robot's ability to record audio and video while moving around the house autonomously. In the smart speaker deployment, while the speaker was *always on, always listening*, it did not have any cameras and was statically positioned in a single spot. In the Pepper study, while the robot did have cameras and microphones, it was only activated a few times per week, thus not being always on. This suggest that both trust, and control play a role in accepting a companion robot, as well as the mode of operation (always on, vs. sometimes on).

All three studies suggest that home automation could be a part of companion robots' functionality, thus interoperability with existing digital devices (e.g. IoT) and services (e.g. Google, Amazon, &c.) could be an additional factor in a decision process of buying and using a companion robot. In the adverts study, the adverts showed both interaction with IoT devices like smart lights, and physical interactions in the case of Pepper. In the smart speaker deployment, interaction with smart devices was one of the best methods for routine formation, with participants switching lights on and off daily using the smart speaker. In the Pepper studies, participants attempted to connect it to various devices be it for research or entertainment purposes.

The community of developers also seemed a factor particularly from Pepper interviews, where the social value of having a companion robot was observed. Apart from the community that formed around Pepper as a novelty, and a curious experience of what it is like to live with a companion robot, there was also a community of software developers who would share their apps to improve Pepper's functionality. This community, according to one participant in the Pepper interviews, was what kept Pepper relevant through the years it was used. All three companion robots in the adverts study (Jibo, Buddy, and Pepper) had at least a software development kit anyone could use to develop new functionality for the respective robots. Pepper operated on ROS – an open-source robot operating system, with newer versions operating on Android. Amazon's smart speakers operated on a proprietary Linux modification, however there are software development kits for Alexa, where new apps can be created to be placed on the apps market place. Maintaining a community and having a social influence through the community is a more specific factor that could be incorporated into the frameworks of acceptance. At this time, the frameworks only mention this as robots being a status symbol.

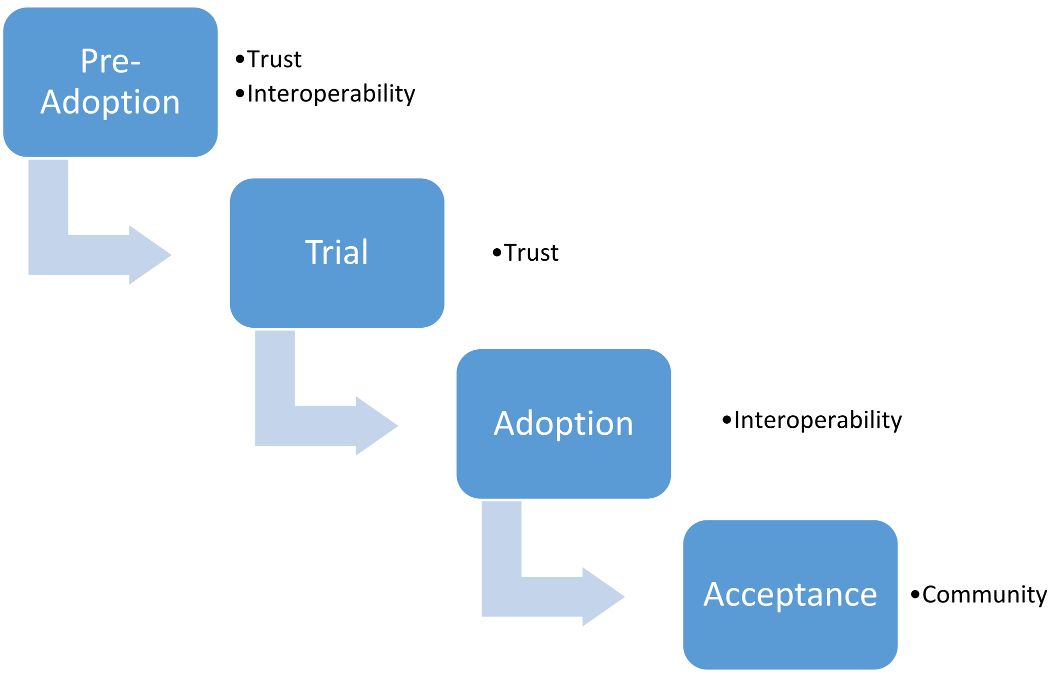

Figure 31: Proposed New Factors for Frameworks of Acceptance.

7.3 Robot's Persona: Deviant, but Convenient

The potential for a companion robot to have its own personality received mixed responses: in the adverts study companion robots were perceived as fake when attempting social behaviour; in smart speaker study having a (portable) Alexa persona was considered as one of the most desirable features; in the Pepper study, its social presence was clearly felt by the users.

In the advert study, there was a desire to be in control of the situation, be it the ability to control the robot, or monitor the relationships that children form with robots; at the same time, participants expressed a desire for companion robots to have their own internal states, opinions and the ability to argue with their owners, elevating the robots from being tools to being companions. In the smart speaker deployment participants wanted better integration with the smartphone to the effect that the personality of Alexa would not only reside in the Dot, but in the phone as well. This aligns with the research which compared dogs to robots, where having a personality, minor disobedience and flaws were some of the key advantages of dogs over robots as companions [179].

Participants cited proactive learning and proactive behaviour as desired means to both find out more about the Dot and to engage with it. Proactive learning included e.g. recognizing that there were multiple people in the room by detecting different voices. Proactive behaviour included the Dot being able to do something on its own, without user prompt, with the option for the user to correct Dot's behaviour where necessary. Learning user preferences and adapting a robot persona to those preferences accords with previous research on the topic [90,291:61]. Participants also wanted the Dot to be able to just have a conversation with the user, rather than being a question and answer machine.

Perceiving robot emotions as fake accords with Paiva et al. research on human and robot empathy, where they also highlight authenticity of robot emotions as an open problem [230]. This could be alleviated to some extent using biased algorithms as suggested by [32,222] and potentially humour [292].

Overall my results agree with the literature in that personality as such seems a positive and even necessary thing for a companion robot to have. At the same time, it should be authentic and have minor disobedience and flaws for the robot to be perceived as more than just a tool.

7.4 Trusting Socially enabled Technologies

I have showcased two points of view regarding human-robot trust through my studies, with each giving a unique and sometimes contradictory perspective. In the advert study, participants voiced numerous concerns about robots’ protection against hacking, data ownership, and general trust. However, with both the smart speaker deployment and Pepper interviews, the issues became less rationalized, as participants were primarily unconcerned with either hacking risks or data ownership, even though they were aware of both.

Privacy of the domestic environment was a particular issue in the advert study, where multiple participants wondered where the data a robot records would go, who would have access to it, and how secure the storage of that data would be. In the smart speaker deployment, participants knew where the data was going, knew about the device being *always on, always listening* including capturing snippets of private dialogues where the users did not intend to invoke the Dot, but still acted unconcerned. With Pepper interviews, participants also knew the capabilities of Pepper to record and store data, and also knew the company which would store that data, but again acted unconcerned.

One explanation of this “concerned in theory, but not in practice” result could be found in differences between participants. Another – from the idea that nothing particularly concerning had happened to them in relation to the data being stored in the cloud, thus there was not need to *act* concerned. Yet another reason could be the “nothing to hide” attitude, where participants did not think anything captured by a smart speaker or a robot would incriminate them in any way. None of the participants with smart speakers muted or turned the speakers off for any reason, including privacy. All in all, this suggests the need to make practical deployments, rather than simply collect people’s ideas about novel devices like companion robots, as in this case what participants said was different from what they had done. Laws like General Data Protection Regulation of the EU [81], and similar policies in other countries which have received media coverage may change both the public perception and the developer policies around data in the future.

Hacking was another issue discussed in the advert study, but met with a different point of view throughout the smart speaker deployment and the Pepper interviews. In the advert study participants were very concerned with an outside party being able to hack into the robot, and spy on the inhabitants. In the smart speaker deployment participants generally expressed trust in the companies producing them (Amazon, Google). Although they mused about a possibility of being hacked, they acted unconcerned. In the Pepper interviews, some even acknowledged that they use the weak security of Pepper [152] to allow others to take control over it, and help fix potential bugs in participants-written software. This again seem to represent “concerned in theory, but not in practice” phenomenon.

With participants of both the smart speaker deployment, and Pepper interviews unconcerned about data privacy or robot security, it is unclear how their implicit trust and robot acceptance affected the decision of continuous use – a connection indicated by Abbass, Scholz, and Reid, and Gaudiello et al. [1:8,92]. Some of that trust may have been irrational, related to the familiar news about data breaches, while individual consequences of them were little to non-existent for the participants. Voluntarily accepting the robots may have also played a part [1:196].

Trusting both a smart speaker and a Pepper robot despite them oftentimes misunderstanding commands was common, and accords with research on faulty robots and trust [257]. This may be explained by the consequences of those breaches of trust being minimal. Learning more about the respective systems may have improved trust in accordance with Abbass, Scholz, and Reid [1:140] as well.

7.5 Human-Robot Relationships

In the adverts study participants formed an idea that robots were there to replace human-human relationships, to which they were opposed. In the smart speaker study this was not a topic discussed at all. In the Pepper study, the opposite took effect: people were attracted to Pepper and its owners, thus increasing social bonding, not decreasing it. This discrepancy may be due to how the adverts were crafted and interpreted: in every advert a child was shown to play with a robot, and *"replacing people"* most often referred to the idea that children should play with their parents or with other children, not with robots simulating communication. Another child-related worry was about children learning that violence is permissible, given how robots might not exhibit any feedback if treated violently.

Some ambiguity about how to treat a companion robot was expressed in the advert study, citing being unsure about whether to treat a robot as a tool, and what moral constraints could be applied to turning a robot off and throwing it away. Robot abuse showed up as a topic, provided one accepts that robots are closer to companions than to tools. In the smart speaker deployment participants showed shallow interactions [194], like saying *"thank you"* after Alexa performed a command. At the same time, smart speakers were treated as utilities, not persons. Pepper interview revealed it being treated both as a utility (e.g. something to develop software for, or to use it as an announcer), and as a person (e.g. in trying to protect it physically and emotionally, talking to it as if it is a social being, feeling comforted by its presence).

Acknowledging the competition between people and companion robots, and doubting human-machine relationships as being genuine suggests that participants in the adverts study envisioned communication between people and companion robots to be almost if not fully equal to the human-human communication with the implication that at least some people may be content to communicate exclusively with companion robots and avoid people altogether. Pepper interviews provide a complimentary view on human-robot relationships from people who have embraced them.

De Graaf posited that there was nothing wrong with human-robot relationships, given that much like humans performing for each other socially, robots doing the same could contribute to the good life of people under certain circumstances [106]. Pepper interviews suggest that human-robot relationships in that instance developed from the desire to protect Pepper, which was both vulnerable to physical obstacles (e.g. to overheating, traversing the environment), and (in the minds of the participants) to emotional damage.

Pepper seemed to bring comfort on a personal level by its mere presence. With time, participants felt comfortable around Pepper, and in return, Pepper brought a sense of comfort to them. This accords well with the research which highlighted human-like communication, and preference and proximity to the master as key advantages of dogs as companions over robots [179].

Pepper reciprocated a sense of attachment, as it could say *"thank you"* in response to various actions and commands. Participants perceived Pepper to have certain preferences, for example, being pleased when praised, or being *"ticklish"* when touched on the head. Over time, all participants experienced some form of attachment ranging from comfort to calling Pepper a family member. Participants noticed they grew more attached to Pepper over time and stressed that they did not want to force such a relationship, but to grow into it naturally. This progression is in line with Samani's research on the *types* of love he found most wanted from robots [260]. In his research, Storge (affection which develops from friendship) and Ludus (affection from fun of playing) were the most wanted types of love. It seems that participants in the Pepper interviews enjoyed both the relationships that developed over time (i.e. from friendship), and relationships which developed from programming and testing new software for Pepper (i.e. affection from playing).

With all that said, Pepper increased interactions *between people*, and introduced some of the participants to many others, suggesting that human-robot relationships at this stage are not mutually exclusive to human-human relationships, and may in fact increase human-human communication by means of introductions.

When compared to the spectrum of acceptance, participants exhibited multiple attitudes across studies. In the adverts study there was certain prejudice against robots, especially in the field of HRI when discussing child-robot relationship, as well as human-human relationships in general. With the smart speakers, they were perceived as tools more than anything, which is a general attitude comparable to how successfully sold robots are positioned today. Pepper interviews revealed more intimate relationships of protection and care, which could qualify for “Relationships with Robots” category in the spectrum of acceptance. Overall this suggests that companion robots may occupy several positions on the spectrum with some hope that they would lean towards the positive integration into the human world.

7.6 Practical Implications from the Studies

In addition to describing how the combined results of the studies align, but also provide new avenues for research, I have compiled design and deployment advice based both on my own studies, and on support from the literature.

7.6.1 Design Advice

1. Form follows function. Abstract form generates fewer expectations that technology cannot fulfil. Appearance may cause all sorts of concerns and (poor) mental models of what and how a companion robot does. Familiar form, or one that appears small, cute, submissive, controllable would ease the worries of potential users.

2. Incremental, niche functionality to distinguish the robot from other devices. There is a competitive market for digital technologies, and robots currently face stiff competition from smartphones, tablets, computers, &c., unless they provide something unique. One unique way to distinguish robots is to implement nurturing patterns, where a user could assist a robot in developing certain useful and/or fun functionality. Another is to utilise the physicality of the robot so that it could perform physical tasks computers and smartphones cannot. Price for performance should be considered in every case, however.

3. Security needs to be considered for mass market, but, perhaps not so much for enthusiasts who just want to play around with a robot and would not delegate anything important to it. The functionality should link to doing things well which would improve trusting the machine.

4. Acceptable social behaviour is expected of socially expressive robots. This is hard to achieve, as there is no clear encoding of shifting social acceptance in code. Thus, it would perhaps be wise to both limit robot's social expression to lower social expectations and provide the user with the tools to encode social behaviours into robots they deem useful.

5. Social communities that form around use, modification, and interest in companion robots seem to play a role, thus having support for such communities by e.g. providing free open source tools would improve the chances of acceptance.

A diagrammatic portrayal of this factors can be seen in Figure 32.

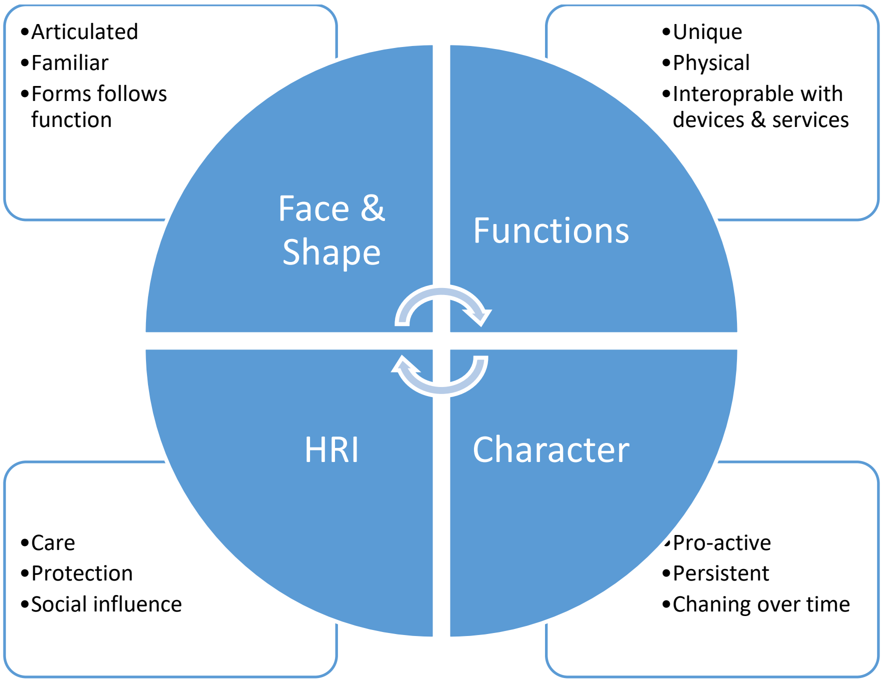

Figure 32. Diagram of the Proposed Factors for Companion Robots.

7.6.2 Deployment Advice

1. Use real physical robots for evaluation – people come up with all sorts of (poor) mental models depending on representations (e.g. ads vs. physical robots in my studies).

2. Increase ecological validity – this provides visceral impact, clears novelty quickly as people attempt to incorporate robots into the mundanity of life, removes artificial lab environments, and situates robots in places where they are expected to be and work.

3. Do not evaluate the robot alone – IoT has developed enough for both robot developers to incorporate such functionality into robots, and users expecting new technologies to fit within their existing techno-sphere. This creates difficulties for comparison between studies, but improves ecological validity, as people would normally have different environments in which they would attempt to incorporate new technologies, including robots.

4. Use long-term deployments where possible. HRI still suffers from short-lived evaluations which prevent integration, rejection or acceptance taking place. Current similar technologies like smartphones and PCs may be used for several years, not minutes and hours that many robot evaluations last.

5. Unlike the universality of smartphones or PCs, which, over time, gained widespread use, companion robots at this point seem to rely on specific user groups. This impacts evaluation, as it may be tempting, for example, to either say: “because these

enthusiastic people use these robots, it is going to be universal in a few years" or, conversely: "because these people did not find much use in robots, they will never take off". It is a niche market, and it is currently hard to tell how universally useful companion robots may become in the future given realistic technological limitations.

Chapter 8 – Conclusions

This chapter returns to what the overall research project was, and why it was conducted. It summarizes the total contribution to knowledge this thesis made, from individual results to the overarching conceptual ideas, and lists limitations through which the results should be viewed. The final sections list possible further avenues of research stemming from the results of this thesis, and how current socially enabled technologies fulfil and do not fulfil the design advice advocated in this thesis.

8.1 What was Undertaken and Why

I started this project as an attempt to understand how and why people form relationships with socially enabled technologies like dating simulators [16]. As my research progressed, two specific instances of such technology caught my attention: companion robots (Pepper, Buddy, Jibo), and smart speakers (Amazon Echo Dot). The choice to investigate socially enabled technologies in the domestic environment was a deliberate one. It was important for me to understand the *mundane* aspects of owning and using socially enabled domestic technologies like smart speakers and companion robots, as those showcased the long-term value, not the hype and panic that sci-fi and media often generate. The privacy of the home (as opposed to e.g. a public setting, or a factory settings where robots are commonly used) also facilitated the development of human-robot relationships as the home could be perceived as a secure base for such experimentation [31].

Investigating frameworks of acceptance, I have uncovered the need to consider both time [104,289], space [275,289], and specific robotic platforms [104,289] as important aspects of human-robot relationship formation. Specific human attitudes and perceptions played a role too [104,275]. Following these frameworks, I have included a range of impressions people had of socially enabled technologies from pre-adoption (Chapter 4), to early stages of acceptance or non-acceptance (Chapter 5), and through post-acceptance (Chapter 6).

To facilitate the initial goal of understanding human-machine relationships and account for the changing nature of such relationships as depicted by frameworks of acceptance I have chosen instrumentalism as a philosophical approach. Instrumentalism highlights two essential points in generating knowledge that my project met. One is the need for the eco-valid setting, which was met both in choice of consumer companion robots (rather than research platforms), and the choice of domestic environment as the testing ground. The advert study, while not presenting real robots in homes, presented an eco-valid setting in that it is typical to watch some form of demonstration of new technology before adopting it. The other was the need to *utilize* technology to generate knowledge, which was met by allowing participants *to do what they wanted* with the smart speakers, and interviewing participants about *what they have already done* with the companion robot they had (Pepper).

According to instrumentalism, knowledge is successfully generated when the desired outcomes are reached. The desired outcomes are reached by noticing something about the existing environment, and then attempting to influence events and relationships in that environment. This reasoning led me to focus on the value that socially enabled technologies were perceived to provide (in the case of pre-adoption interviews, Chapter 4), and provided (Chapters 5, 6) to the participants. This project therefore took an inductive approach, striving to generate new points of discussion and new directions HRI could take and investigate (as opposed to attempting to confirm or disconfirm an existing hypothesis).

Following the highlights from the literature, and the philosophical approach of instrumentalism, this project was set to answer the following specific research questions:

1. How (if anyhow) do potential users of socially enabled technology relate to such technology at the pre-adoption stage? What do they highlight as valuable and important?
2. Which positive and negative values do actual users report when living with socially enabled technology over an extended period (2 months)?
3. What kinds of value do actual users of companion robots extract from them post-acceptance (6+ months of use)?

8.2 Summary of Study-Specific Results

8.2.1 Pre-Adoption – Adverts Study

I have attempted to keep the pre-adoption study as open as possible, not to be constrained by the perspectives from existing literature on prior robots, nor to constrain my participants in their expressions. By selecting video advertisements for existing and upcoming companion robots I have attempted to break through the pre-conception that companion robots are a thing of science fiction. By choosing a structured interview with open questions that immediately follow each of the adverts, I have attempted to capture the data of arbitrary complexity, and to allow the participants to express what they truly thought on the topics *they* thought were important. While the participant pool could be considered homogeneous and relatively small, companion robots were purported to be “for everybody” and “in every home”, thus pre-adoption opinions of the participants were just as valid as any other group of people would have expressed.

With these constraints and considerations, the pre-adoption study revealed numerous issues. The importance of utilitarian functionality in companion robots was well-explored through frameworks of acceptance, with my study confirming their significance. Here, most participants could not find any value that a companion robot would bring to their lives. The issues of robot form, face, and animation have also been previously well-explored in research literature, specifically focusing on face and shape. Issues like privacy, and especially security were previously discussed in the wider fields of IoT and smart devices, with my participants expressing very similar sentiments to what was expressed by digital security experts before. The novelty here was the idea that companion robots have both the autonomous mode, and the telepresence mode, and it might be hard to distinguish between the two. The possibility of hacking a companion robot presents a possibility of a new malicious actor, and the difficulty of easily identifying if the companion robot was hacked and taken over. This highlights the need to converge literature on autonomous behaviour and its trustworthiness, and telepresence research which usually focuses on trusting the actor that controls the robot.

From the human-robot relationships point of view, the novel aspect came about in the active unease that participants experienced when discussing how to treat a companion robot emotionally. The notion of *robots replacing humans* broke the barrier of *robots are here to take our jobs* and entered a new stage of *robots are trying to take away our relationships*. While such tensions have been expressed anecdotally with regards to sex bots and through films like *Her* (2013) [160], they were mostly expressed in relation to fictional characters, not commercially available companion robots. This finding also adds a new angle on Turkle's idea that as people are more engaged with technology, they are less physically engaged with each other [305].

Another aspect or companion robots' behaviour rarely discussed in literature but expressed by the participants in my study was the fabricated nature of robot character. Given how novel commercial devices with character are, the studies that involve them would shed more light on the theoretical ideas about robot character. To date, the literature points out character as a desirable characteristic in companion robots, albeit no specific description of what that character should be like is usually provided.

This work supports the idea that robotic character needs to be at least *authentic* – that is, its expressions should be aligned with its physical capabilities and needs. I propose a mapping between inherent robot needs, like the need to be re-charged, with social behaviour that is human-understandable to express that need, e.g. showing tiredness or sleepiness through facial expression and/or body motion. This could make a companion robot's behaviour human-readable, without causing feelings of fake acting or rejection.

To answer the first research question, the participants were unsure about making companion robots a part of their lives. They have highlighted the need for a companion robot to have a more abstract look, clear utilitarian functions, and be distinctly robotic, thus avoiding some of the emotional confusion that such a character creates. They have related to the robots more like they would relate to a digital device while evaluating it, however they have also attempted to relate to companion robots as if they were truly autonomous agents with character. The sense of agency was both desired and clear, however the intentions of such agency were much less clear, causing some of the concerns around trust and security.

8.2.2 The Early Stages of (non-)Acceptance –Smart Speaker Deployment

The smart speaker deployment explored participant behaviour from the initial trial of the devices through to adaptation, noting both use and non-use of the devices. In this study I have attempted to investigate how the speakers were adopted over a longer period (2 months). Smart speakers, as a commercially available technology, were chosen as a socially enabled technology developed with the consumer in mind, and with the affordances of a device expected to perform well with other technologies like IoT and internet services. Through temporal data from the smart speakers themselves I have captured the actual use of the speakers over time. By conducting spaced interviews, I have also captured the changing views on the values and relationships that the smart speakers brought to the participants.

While interviewing participants in their own homes may be considered intrusive, it allowed the capture of more eco-valid data (e.g. with participants being able to immediately act out the examples of use or problems they had with smart speakers). It also allowed me as a researcher to build trusting relationships with the participants, which is considered very important in deployments like this, as people are more willing to discuss relationships they have with devices with people they trust [105]. Semi-structured interviews were used to allow as much freedom as possible for the participants to express what they deemed important, rather than being constrained by what the literature suggests on the topic. Smart speaker logs at the same time were used as a perception-independent record of use, and as a triangulation tool to enrich the interview data.

With these constraints and considerations, the deployment revealed several further findings. Firstly, the pre-adoption and the initial trial took place in every household just as suggested in the frameworks of robot acceptance. Certain expectations were formed and then tested. Some participants did not have explicit expectations, but were simply curious to see if they would end up using smart speakers. This could be due to the method of deployment where I have given the Dots for free to the participants, and thus acted somewhat like an extended free trial on a software program. The participants were then free to try out the technology and learn about it while already having it. Alternatively, the smart speaker deployment in the home environment had multiple actors who were not all equally invested at the beginning. Non-tech enthusiasts found themselves with a partner who brought home a new gadget which then became part of their routine activity without them wanting to actually research and invest in it from the beginning. This deviates from De Graaf's and DRE idea that people always research potential technology before trying it out. It also differs from the notion that people would form potential use cases in their mind before trying the technology out.

Actual use also followed the suggested path of decreased frequency of use over time, providing evidence that other robotic devices could follow de Graaf's idea of declining novelty effect. At the same time, those who continued to use smart speakers developed certain regular patterns of use, lending more evidence to DRE's idea of routine use and maintenance, and to De Graaf's mentioning of the mere exposure effect.

Non-use was encountered in line with de Graaf's framework, with non-users citing many of the reasons already discussed in frameworks of acceptance, from difficulty to engage with the technology, to existing technologies being enough for the users.

The novel aspect that some non-users mentioned was the integration preferences. Smart speakers act as hubs, and connect to many of the existing digital services, from music streaming apps to to-do lists, to connecting with other IoT devices. Because smart speakers do not act as things in themselves, user perception of how and why the device should be accepted or rejected in the household stemmed more from how well it could integrate into both the existing physical environment, *and* the digital environment of services that users already had accounts with. This highlights the need to study devices like smart speakers *in relation to* other devices and services people may already have.

The desired use of smart speakers aligned both with my pre-adoption study, where some users highlighted the need for character, and with the literature suggesting the same. The participants in the smart speaker deployment extended their idea of character to include learning capabilities and pro-active behaviour, agreeing with the prior literature which suggests similar capabilities as desirable in virtual agents.

However, a new characteristic emerged which I have not encountered in the literature to date: the desire for the virtual agent to be persistent with its attempts to fulfil what the user wants. This was specifically expressed as Alexa needing to ask clarifying questions if the overall gist of the request is understood, but the specifics are lacking, e.g. asking a specific temperature target if the user asks to change temperature in the room.

Commenting further on the character of Alexa – it seems that the human-like voice and the question-answer structure of the conversation, together with the ability to ask arbitrary questions was an illusion enough for the participants to ascribe Alexa some character. From having preferences for certain words and phrases to being evasive – Alexa was often anthropomorphised. At the same time, however, participants were under no illusion of Alexa being a complex agent, as they often referred to its operations as limited, especially if it was asked something outside the usual commands of controlling IoT devices or activating digital services.

To answer the second research question, participants valued integration with the existing IoT ecosystem, and appreciated the learning experience the Dot brought them. However, there were many traits that were desired, but not implemented into the Dot, like more extensive integrations, better understanding of users, and being more convenient than existing devices that perform similar functions.

8.2.3 Companion Robots Post-Acceptance – Pepper Interviews

The Pepper interviews were the last field study I conducted. With the previous results in mind, I attempted to create interview questions that would allow for some comparison with my first two studies investigating pre-adoption and the early stages or (non-)acceptance, and what users think post-acceptance, having lived with companion robots for over 6 months. I contacted two of my colleagues in Japan to help me conduct the interviews in Japanese, and to translate them into English.

The choice of participants was based on both whom I knew had a Pepper robot for a while (although I did not know them personally), and the academics across Japan who worked with robots, whom I sourced through the Robotics Society of Japan [296]. My two colleagues in Japan were then tasked with emailing the potential participants and the academics to source more people who would fit into the definition of living with a companion robot over six months. Even with these efforts I could only source four participants. I am very thankful both to the participants and to my Japanese colleagues, as the efforts they contributed were significant, while no compensation was provided.

I have written the interview questions to be both open enough for me to become familiar with the participants' lives, given that I have never met them, and comparable enough to the previous studies to identify commonalities and differences between them. The overall goal was, again, to capture the arbitrary complexity and the topics participants thought were important about companion robots, not to strictly impose constructs from literature on them.

With such a small sample size of users of a robot which could also be considered unique, I focused my analysis on the value that a companion robot brings to those participants' lives – something that would be valuable even if extracted from a small group of people.

With these constraints and considerations, the study uncovered both issues matching prior literature and novel ones. Expectation-wise, companion robot users were similar in their expectations to the smart speaker participants. Both either expected assistant-type support or held no strong expectations but were curious to see what they would do with the device. Pepper was additionally expected to be an excellent communicator, which matches how participants in the DRE framework expected their robotic hoover to excellently perform its functions.

When the initial trial took place, the findings accorded with De Graaf's notion of expectations being met or broken, with most expectations being broken. Participants noted the very limited communication abilities of Pepper, and its overall tendency to fail on numerous occasions. Those who had little expectations expressed less concern for the failings of Pepper, which accords with the "fewer expectations – fewer disappointments" notion from the literature reviewed.

An extension to the novelty effect was observed in that the participants utilised novelty that Pepper represented *to others* as means of social influence. In addition, the long-term utilitarian value of Pepper lay in its capacity to be modified, thus it was not looked at as a *finished product*, but rather as a *work in progress*. Pepper acted as an attraction to talk about the robot itself, but also about the people who owned a robot, and what it was like to live with one. On the personal side, a nurturing pattern was observed, where participants progressed from increasing familiarity with Pepper to accepting it as a vulnerable *"inorganic lifeform"*, notably in need of protection and care.

To answer the research question, Pepper provided three kinds of value to its post-acceptance users: the utilitarian value of a platform that one can incorporate new functionality into by programming; a social value of social influence; and a personal value of developing relationships of protection, care, and comfort towards Pepper.

8.3 The Overall Value of Companion Robots through the Stages of Acceptance – Cross-Study Results

My studies have uncovered two alternative approaches to socially enabled technologies, with two complimentary sets of values that could be extracted from them. One approach, highlighted through adverts of companion robots and the smart speakers, was to understand and exploit their utility – be it in ways to affect physical environment, have telepresence, or control other smart devices. Another approach – hinted by some participants in the smart speaker study, and Pepper interviews, was to understand and exploit social and personal values – be it through learning about the technology and how to code it for its own sake or accepting a device as an *"inorganic lifeform"* with social presence and a need for care.

Both utilitarian and social values have been noted through prior literature, and via comments of companion robot developers. The new aspects came in the details of how those values were expected to be explored. The utility of socially enabled technologies stemmed not only from the devices themselves, but in their ability to inter-operate and integrate with both physical and digital services that a user might already have. Participants also noted that socially enabled technologies should either perform existing functions *better* than other devices or they should have novel functionality, distinct from smartphones and laptops. One such functionality for companion robots specifically would be to utilize their physicality and perform physical actions.

The social and personal values of companion robots are even less explored to date, given their very limited presence on the consumer market. My studies provided more evidence of physical presence as means of social influence investigated by Ishiguro with his androids [146]. Both in the advert study, and in Pepper interviews participants talked about companion robots as social actors. What was not apparent from the adverts but highlighted in the Pepper interviews was the community that formed around Pepper. The owners of Pepper had additional social influence *because of* Pepper. On the personal value side, nurturing as a design opportunity was uncovered, which is a step (or several) further from the notion of simply developing sentimental value beyond utility towards robots as noted by the acceptance frameworks.

8.4 The Overall Limitations of Research

There are some limitations to the results of the studies presented in this thesis. These limitations have been individually discussed in the sections of the respective chapters for each of the three studies. Here I bring these limitations together, so that the individual and the compounded results above can be viewed with those limitations in mind.

I discuss limitations from the following points of view: limitations pertaining to what data was collected and how much; how the data was collected; in which environment the data was collected; the limits of the stimuli applied; the limits of the data analysis methods; and the limits to data interpretation.

First, the data collection. While using interviews provided me with arbitrary complex data on the topics participants felt were important, unlike in surveys or fully-structured interviews the data set was not standardized. This makes it harder to compare across studies or verify with replication studies. This suggests the need to design replication and confirmation studies differently, which is exactly what this inductive research should provide: new ideas worth testing. The data logs collected from the smart speakers themselves are comparable to the limit of how different coders would collate that data. Studies focusing on logs from Alexa have already been performed and showcase some common collations (e.g. [224,265]).

The amount of data collected was also relatively small. 20 interviews were collected from the adverts study, 12 interviews were collected from the smart speaker deployment, and 4 interviews were collected from the Pepper study. The number of participants were 20, 6, and 4 respectively. This makes the total sample size across studies to be 30, and the total amount of interviews to be 36. These numbers are rather small for a statistical evaluation, suggesting that each study could be further enriched with bigger sample sizes. However, because the focus of this thesis was on the value that socially enabled technology generates, its results as they stand are applicable to any number of people who can extract values in the same way as did the participants.

While interviews do allow the collection of data which standard surveys might miss, there are inherent limits and biases that interviews as a method contains. First, interviews are subjective, with terms applicable to my studies like “trust”, and “value” potentially differing in definition across participants. Another inherent bias is the influence of the interviewer. Yet another one, common not only to interviews, but in many data collection methods is the tendency of the participants to try and provide answers they think the researcher wants to hear (i.e. social desirability bias [165]). Subjectivity in this case is in fact valuable to my studies as it pinpoints exactly what individuals extracted from using a given technology.

I was not interested in the agreements across participants (though those have emerged anyway). Rather, I focused on each individual way that some value could be extracted from socially enabled technologies, and then collected and presented those values in one place.

Some influence of the interviewers was mitigated across studies as different interviewers interviewed different participants. Smart speaker use was triangulated with the Alexa logs to confirm what happened *between* interviews, when the interviewer was not present. This was also the primary tool for countering the social desirability bias. For the Pepper interviews, participants only reflected on what they had already done with Pepper, thus, insofar as they were truthful in recounting their memories, the data could be considered relatively unbiased to the limit of which specific memories participants could (and chose to) recite.

The environment of data collection also played a part. For the adverts study it was an office environment – a plausible but not unique place to watch YouTube, where all adverts were sourced from. The participants were also watching the ads by themselves, which could not capture e.g. a family dynamic where opinions would form and then be tested for consensus thinking.

The environment of the smart speaker deployment was the participants’ homes, which accords with the instrumental view, and provided many of the unique interpretations I was unlikely to obtain in a lab setting. Finally, the interviews for Pepper were conducted in a university setting – a plausible setting for three out of four participants. This limited, however, one of the participants who could have provided a much richer (and possibly different) data, should they have been allowed to demonstrate exactly what they were talking about in their own home setting.

The stimuli to which the participants have responded also had an influence. In the advert study participants have responded to adverts, not real robots. The adverts presented an idealistic view (on which the participants did comment) and may have exaggerated the abilities of the robots. It is likely that the results would have been at least somewhat different if real robots were presented to the participants – something that prior literature has highlighted as well. With that said, in the absence of real companion robots, the adverts are a valid way that participants could first be exposed to robots, and their initial decision to try a given robot out may need to rely solely on advertisement in the absence of other sources of information, which is a typical situation in crowd-funding websites like Indiegogo and Kickstarter.

In the deployment study, the stimulus of the Echo Dot was only one per house, and it was only one version of such a speaker (vs. a full-sized version, or other speakers, for example). Participants did comment on the need to have multiple Echo Dots in the house, and on the quality of the Dots' speakers. The digital services that the Dot could connect to were also limited to what was available through Amazon at the time. Some of the participants' comments stemmed from the differences between what Amazon vs. Google could provide in terms of connected digital services. Moreover, even the same AI on different devices (e.g. Google Now on a smartphone) would likely produce different patterns of use, provide different value to the users, and result in different desirable functionality. Given the technological development of the smart speakers, as well as the software updates and new services becoming available, the results are likely to be different even with the same speaker over time, limiting my results to the standard of development at the time, and to the speakers explored.

In the Pepper interviews, the stimulus was also eco-valid. However, other companion robots which may soon enter the market possess different physical and digital characteristics [62], limiting the results and conclusions drawn from Pepper to its specific platform.

The data analysis framework based on Braun and Clarke [40] provides a flexible and epistemologically agnostic way to analyse textual data, which was the main data type collected throughout my studies. It is stressed, however, that this method of analysis is intentional – it does not objectively represent data. Rather, the coders actively *choose* what to focus on. This is conductive to instrumentalism, however it should be noted that the focus of the analysis throughout this thesis is not the only way to analyse the data. There have been many codes generated from the interview data that were not included into the *Results* sections of each respective study. All in all, the results provided in this thesis are not the only results, nor are the interpreted themes the only possible themes. My focus was specifically on the value that socially enabled technologies provided and the relationships that formed between the participants and the socially enabled technologies explored.

What the data meant in relation to the studies conducted was ultimately my choice. The data was interpreted with the view of showcasing the value that socially enabled technologies provided, and the relationships that participants built with those technologies. I made a conscious decision to favour studies made in the eco-valid setting of home, which significantly influenced the scope of literature explored, and the comparisons made. I have also decided to focus mostly on the literature of the past three years, given the rapid technological development in the field. This means that much of the earlier literature was not accounted for (besides the highlights of history of social and domestic robots), nor was there much research discussed that made suggestions based on lab experiments with earlier versions of socially enabled technologies. Perhaps there is some applicability of earlier results to this work, and perhaps that would have enriched this work. However, with the instrumental focus in mind, I would still argue that it is the exploration of the current technologies in their intended spaces of use that generates the kind of results that I was pursuing.

8.5 The Overall Contribution to Knowledge

Up until very recently, sci-fi was the furthest humanity has explored the likely value one could extract from living with companion robots and forming relationships with them. However, the reality is turning out to be much more nuanced. My work has explored the value one could extract from socially enabled technologies, and the kind of relationships people could form with such technologies. In summary, here is my contribution to knowledge, expressed as propositions that others could take and explore further:

1. Socially enabled technologies must possess either unique or better functionality when compared to existing technologies to attract (non-)users.
2. Companion robots must possess both social and utilitarian functionality to be found useful.
3. Companion robots should *extend* and *complement* human capabilities not *replace* them, to alleviate the *robots replacing people* perception.
4. Companion robot's social behaviour should be authentic to reduce the perception of fake character.
5. Companion robot's character should possess the following qualities to be more acceptable: *pro-activity* and *persistence*, having its own *preferences*, *changing over time* ("learning").
6. Improved integration of companion robots with existing digital ecosystem of devices and services will improve companion robot acceptance.

7. Facilitating both personalization and software changes/improvements users can do themselves in companion robots is a viable route to accomplish many desired aspects of companion robots.
8. Companion robots as a category should be made obvious to potential users to alleviate the tension between treating companion robots as tools vs. as persons.
9. A behaviour of nurturing in owners of companion robots will alleviate some of the common tensions experienced about socially enabled technologies, like failed expectations, lack of apparent utility, or the emotional indecision about whether to treat companion robots like devices, or like persons.

8.6 Secondary Findings and Future Research Agenda

1. The physicality of the robot remains a viable avenue which this work only touched upon. The ability to perform physical actions were praised by the participants in the adverts interviews. Smart speakers were praised where they were connected to the IoT infrastructure allowing physical changes, like switching lights or music. Pepper interviews provided some idea of how physical presence of the robot impacted both physical, social, and personal spheres.
2. Development and character were highlighted in my research as desirable properties for socially enabled technologies. However, the *design* of these traits was little-explored. Given an apparent demand for these traits, it would be prudent to further investigate how a robot character could be developed, perhaps borrowing from film and animation as starting points. This approach was taken by the developers of Anki's Cozmo robot development [11]. I am not aware of a widespread discussion in the HRI community regarding this practice, however.
3. Companion robots acting as social proxies is a very novel field with little to no exploration done. As more companion robots come to market, the social dynamics between companion robot's owners, the robots themselves, and other people and robots communicating could be further explored. The initial framework for such exploration could be drawn from social media profile studies, where users present a version of themselves, much like companion robots may present a version of their masters.
4. Companion robots as intersection points of a given community, be it a family, or just enthusiasts, could be an interesting point of exploration. The initial framework could be drawn from photo albums around which families gather to reminisce about the past and pass on traditions. Companion robots could store messages both between family members, and act as time capsules with pre-recorded messages played out when certain criteria are met.

8.7 Final Remarks: the Present and Future of the IPA Market in Light of This Work

As a final note, I would like to make a brief comparison between what was uncovered in this work and the existing IPA market, mainly focusing on smart speakers and Pepper as the most successful socially-enabled technologies to date. In this comparison, I cover what is already implemented, and showcase what could be implemented into the IPAs in the future to make them more valuable according to the advice this work presents.

Smart speakers already have small, familiar appearance, and connect the form of the speaker to its function of being an audio interface. They also possess niche incremental functionality, while having a relatively low price, satisfying the price for performance idea. The security of the devices is dependent on the provider, with Amazon, Google, and other large companies presenting themselves as secure. Given the app market for the smart speakers, there is some implementation of the community interaction as well. Finally, smart speakers being proposed as “IoT hubs” have a relatively extensive integration with other devices and services, although, perhaps not as extensive as some might like.

Pepper also follows some of the advice given in this work. It has both utilitarian and social functionality. Its position as a companion robot is made clear through advertising and use cases. The availability of an open platform for design and modification of the software for the robot forms a community around its use. While not being a mass market product, its security is reasonable for expert users. Pepper being a very novel device compared to smart speakers could also utilise its physicality, providing unique functionality when compared to other digital devices.

On the other hand, both current smart speakers and Pepper do not possess enough desirable functionality to be considered fully aligned with this work. Smart speakers do not have a proactive character, for example, still attempt to replace many of the existing devices which can do their respective jobs more conveniently, and do not provide much opportunity to nurture them into more functional and/or fun devices that they could be. Pepper, while utilising some of its physically, is not particularly skilled with its appendages. This physicality has a lot of untapped potential to date. Acceptable social behaviour towards the owner, and towards others is another desired property of ideal companion robots, not currently implemented. Finally, a classification of “a friend” or a “companion” while should be made obvious is currently not concrete when being applied to a commercial digital device.

As technology develops, perhaps these gaps can be bridged, and humanity will finally have the companions it always wanted but couldn’t quite get.

Appendices

In the appendices I list materials which would otherwise impede the smooth presentation of the case, which are none the less important to the respective studies.

Appendix 1: Questions Asked During Interviews

1.1 Pre-Adoption – Adverts Study

1. What do you think about this one?
2. Do you think this robot adapts its behaviour to people? How so/Why not?
3. Do you think this robot can make decisions without human help? How so/Why not?
4. What do you think *you* can use this robot for?
5. How do you feel about a future where we have these robots at home?
6. How would you defend the adoption of social robots?
7. What argument would you put against adoption of social robots?
8. Do you have any concerns over privacy of having such machines at home?
9. Would you mind adopting these kinds of robots for a further study when they become available? Why/Why not?

1.2 Smart Speaker Deployment

1.2.1 Interview 1

Household Information

1. Who is related to whom and how?
2. Could you describe your typical day? Your typical weekend?
3. How often would you have friends or relatives in your house?
4. What kind of major events happened in your life (Any event that you consider significant)?
5. What kind of major events do you expect in the near future?
6. How do you deal with technology? Do you feel you are good with it? Do you struggle with it?
7. Could you show me your tech gadgets and explain how you use them?

8. What kind of hobbies do you have? How do you like to spend your spare time?
9. Do you work? What kind of timetable do you work to? What kind of lifestyle do you have? What is your occupation?

The Echo Dot-Specific

1. Have you looked up any information about the Echo Dot prior to this interview?
2. What do you expect from the Echo Dot? What kind of things do you think it could do? What kind of limitations do you think it might have?
3. How do you feel about using the Echo Dot?
4. How secure do you feel about the Echo Dot? Do you feel like the Echo Dot can be hacked?
5. What, if anything, do you feel is risky about the Echo Dot?
6. What kind of opportunities/utility do you envision in the Echo Dot?
7. How do you feel about the shape of the Echo Dot? Does it attune with what you think it should look like? What kind of shape would you have given to it?
8. What kind of uses could the Echo Dot have in your opinion? Could it do anything in your life better than what you have with the current arrangement of technology? What do you think you need help with most from technology like the Echo Dot?
9. Do you feel comfortable or uncomfortable about the Echo Dot? Why?

1.2.2 Interview 2

1. Are you still using the Echo Dot? If so – how? If not – why not?
2. Have you looked up any more information about the Echo Dot?
3. What do you expect from the Echo Dot? What kind of things do you think it could do? What kind of limitations do you think it might have?
4. How easy or difficult was it to be understood by the Echo Dot? Were there any particular difficulties with speech understanding?
5. Did you give it a name?
6. How do you feel about using the Echo Dot?
7. Did the Echo Dot fail on you at any time? What happened during that episode?
8. How secure do you feel about the Echo Dot? Do you feel like the Echo Dot can be hacked?

9. What, if anything, do you feel is risky about the Echo Dot?
10. What kind of opportunities/utility do you envision for the Echo Dot?
11. How do you feel about the shape of the Echo Dot? Does it attune with what you think it should look like? What kind of shape would you have given to it?
12. What kind of uses could the Echo Dot have in your opinion? Could it do anything in your life better than what you have with the current arrangement of technology? What do you think you need help with most from technology like the Echo Dot?
13. Do you feel comfortable or uncomfortable about the Echo Dot? Why?
14. What do you value most about the Echo Dot?
15. Which features are not helpful in the Echo Dot?
16. Could you show/tell me how you used the Echo Dot since the last time we met?
17. Does the Echo Dot help you with your daily life? What kind of helpful/unhelpful things does the Echo Dot do?
18. What kind of information do you think the Echo Dot stores? Who do you think should own that data?
19. Do you think the Echo Dot can think for itself? Why (not)?
20. Can the Echo Dot feel? What could you tell me about its feelings? Why can it not feel?
21. Did you have any interactions with the Echo Dot that were emotional on its part?
22. Did you have any interactions with the Echo Dot that were emotional on your part?
23. Do you wish you could erase something that you said to the Echo Dot? Have you erased something from the Echo Dot?

1.2.3 Interview 3

1. Could you describe me one of your past days, including as many interactions (typical or specific) with technology (paper-based, phone, laptop, the Dot, &c.) as you can remember?
2. Is the Echo Dot still in the same place?
3. Can I take a photo of where the Dot is?
4. Could you describe your experiences with the Dot in the past 2 weeks? What worked? What did not work? What was curious/unusual?

5. How much of what you want from it does the Dot understand? Do you feel it understands you more or less?
6. Can you demonstrate me some of the uses you had with it?
7. Have you connected/disconnected anything from the Dot?
8. Have you installed/uninstalled any more skills? Which skills are fun? Which skills are there for utility?
9. Have you asked Alexa any weird or unusual questions?
10. Whose account does Alexa use? Have you connected multiple accounts to it?
11. What do you wish the Dot could do for you?
12. Have you programmed anything of your own into Alexa?
13. Have you deleted anything you have said to Alexa?

1.2.4 Interview 4

1. How have you used the Dot over the past weeks?
2. Can you spell out for me all the skills and integrations installed in the Dot right now?
3. Have you received emails about what Alexa can do?
4. Have you moved the Dot at any point?
5. Did you have any visitors throughout the 2 months you had the Dot? When? What did you do? Have you introduced the Dot to any visitors that came in during the time?
6. Have you talked to anyone about having the Dot? What did you say? What did they say?
7. What kind of recommendation would you give to people who think about buying a smart speaker like the Echo Dot?
8. Can I download usage information from the Dot?
9. Have your ordered your own copy of a smart speaker? Why/why not?
10. Have you ordered a custom cover for your smart speaker?
11. Do you both still use it? If so, how?
12. Whose profile(s) does Alexa use?
13. Have you programmed anything for Alexa?

14. How do you find the voice of the Dot?
15. What can you tell me about the accuracy of the Dot's recognition? How well does it understand you? How well does it reply to you?
16. How easy or difficult is it to use the Dot?
17. Do you feel like things like the Dot or Google Home have changed any of your routines or thinking?

1.3 Pepper Interviews

Household Information

1. What kind of hobbies do you have? How do you like to spend your spare time?
2. Do you participate in any other kind activities like volunteering? If so, could you describe what you do?
3. What were the major milestones in your life so far (Any event that a participant considers to be significant)?
4. What kind of major events do you expect in the near future (Any event that a participant considers to be significant)?
5. Could you describe your typical day? Your typical weekend?
6. How often do you have friends or relatives visit your house?
7. Could you describe me one of your recent days that you remember well, and specifically point out as many interactions with technology (paper-based, phone, laptop, Pepper, &c.) as you can remember?
8. Could you show me your tech gadgets and explain how you use them?
9. Do you feel confident about using the technology that you have in your house?

Pepper-Specific

1. How long do you have Pepper for?
2. Could you tell me how you interact with Pepper?
3. What did you expect from Pepper when you first acquired it? Did it fulfil your expectations?
4. How much of your speech is understood by Pepper? Are there any particular difficulties with speech understanding?
5. Do you feel it understands you more or less over time?

6. Do you feel secure about Pepper? Do you feel like Pepper can be hacked?
7. Do you feel comfortable or uncomfortable about Pepper? Why?
8. Did Pepper fail you at any time? If so, what was the experience like?
9. How do you feel about the shape of Pepper? Does it attune with what you think it should look like? What kind of shape would you have given to it?
10. What kind of extra functionality do you feel Pepper needs?
11. Could it do anything in your life better than the other technologies you have?
12. What kind of smart devices (if any) are connected to Pepper?
13. What do you think you need help with most from Pepper?
14. Is there any functionality you avoid using in Pepper?
15. Have you modified Pepper in any way since you bought it? If you did, could you tell me a bit about the modifications? If not, why not?
16. Have you discovered new ways you could use Pepper since you have acquired it? If so, could you tell me about those discoveries?
17. Where do you keep Pepper when you are not interacting with it?
18. What are the benefits of living with Pepper?
19. What are the drawbacks of living with Pepper?
20. What kind of information do you think Pepper stores? Who do you think owns that data?
21. Do you think Pepper can think for itself? Why (not)?
22. Can Pepper feel? What could you tell about its feelings? Why can it not feel?
23. Did you have any interactions with Pepper that were emotional on its part?
24. Did you have any interactions with Pepper that were emotional on your part?
25. Is there anything you avoid saying to Pepper?
26. Do you wish you could erase something you said to Pepper? Have you erased anything?
27. Does your Pepper have a name you gave it?
28. How do you feel your relationships with Pepper develop over time?
29. Do you ever take Pepper outside the house?

30. What kind of fun experiences (if any) have you had with Pepper?
31. Are you the only person interacting with it? If not, how do other people interact with it?
32. Do you still discover surprising or new functionality with Pepper, or do you feel you know what Pepper is fully capable of?

Appendix 2: Thematic Analyses Codes

2.1 Pre-Adoption – Adverts Study

Table 3. Code names for the Pre-Adoption – Adverts Study, identified with at least half the participants. Ordered by the number of the participants.

Descriptive Code Name	# of Participants	% of Participants	# of Occurrences
Data collection worries	20	100%	67
Other devices can do it	20	100%	56
Other people interpreting your data	20	100%	42
Potentially adopting one of the robots	20	100%	20
Replacing people	19	95%	100
Presentation of robots in ads	19	95%	75
Design of companion robots	17	85%	87
Emotions in (and related to) robots	17	85%	52
Attitude in general	16	80%	55
Creepy, Terrifying companion robots	14	70%	61
companion robot Intelligence	14	70%	38
Autonomy-arbitrary comments	14	70%	33
Adaptability	14	70%	29
General uselessness	13	65%	72
Companion/Personnel-use case	13	65%	40
Automation/home-use case	13	65%	36
Are they real?	13	65%	23
Telepresence-use case	12	60%	22
Personal assistance-use case	11	55%	30
companion robots make mistakes (prone to)	11	55%	28
Etiquette for companion robots	11	55%	17
Toy/Play-use case	10	50%	29
Worries that companion robots' autonomy can be harmful & exercising control	10	50%	26
Films mentioned to help interpretation	10	50%	23
Robot mobility	10	50%	23
It will be hard for companion robots to do what they are advertised to do	10	50%	16
Camera-use case	10	50%	13

2.2 Smart Speaker Deployment

Table 4. Code names for the Smart Speaker Deployment, identified with at least half the sources. Ordered by the number of the sources.

Descriptive Code Name	# of Sources	% of Sources	# of References
Security, Trust, Control	12	100%	54
Use	12	100%	364
Emotional Attachment	11	92%	50
Comments on Functionality	11	92%	93
About the Dot with the Outsiders	10	83%	28
Device Ecosystem	10	83%	100
Comparison to Other Devices	10	83%	57
Shape & Design	10	83%	15
Misinterpretations of Alexa	10	83%	37
Re-Enacting Interactions with Alexa	10	83%	122
Personalization	9	75%	14
Emotionality	9	75%	36
Confidence in Use	9	75%	9
Desired Functionality	9	75%	102
Erasing Data from the Dot	8	67%	12
Smartphone	8	67%	17
Novelty	8	67%	15
Non-Use Comments	8	67%	77
Discovery of Functionality	8	67%	41
Promised Interactivity	8	67%	42
Security	7	58%	8
Google Home	7	58%	29
Expectations	7	58%	15
Summative Judgements	7	58%	15
Dot's Understanding of Language	7	58%	17
Desired Ecosystem Connections	7	58%	42
Google Devices/Services	6	50%	26
Control of Smart TV/Other Displays	6	50%	18
Mind of Alexa	6	50%	20

2.3 Pepper Interviews

Table 5. Code names for the Pepper Interviews, identified with at least half the participants. Ordered by the number of the participants.

Descriptive Code Name	# of Participants	% of Participants	# of Occurrences
Affection	4	100%	25
Community	4	100%	46
Software Development	4	100%	16
Utility	4	100%	36
Unexpected of Failed	4	100%	13
Expectations held	4	100%	9
Usefulness	4	100%	14
Sociality of Pepper	4	100%	12
Pepper's Shape	4	100%	7
Going Outside with Pepper	4	100%	2
Hacking/Privacy	4	100%	6
Connecting Pepper to Other Devices	3	75%	4
Naming Pepper	3	75%	4
When Pepper is on	3	75%	6

Appendix 3: Interrelation of Topics between Studies

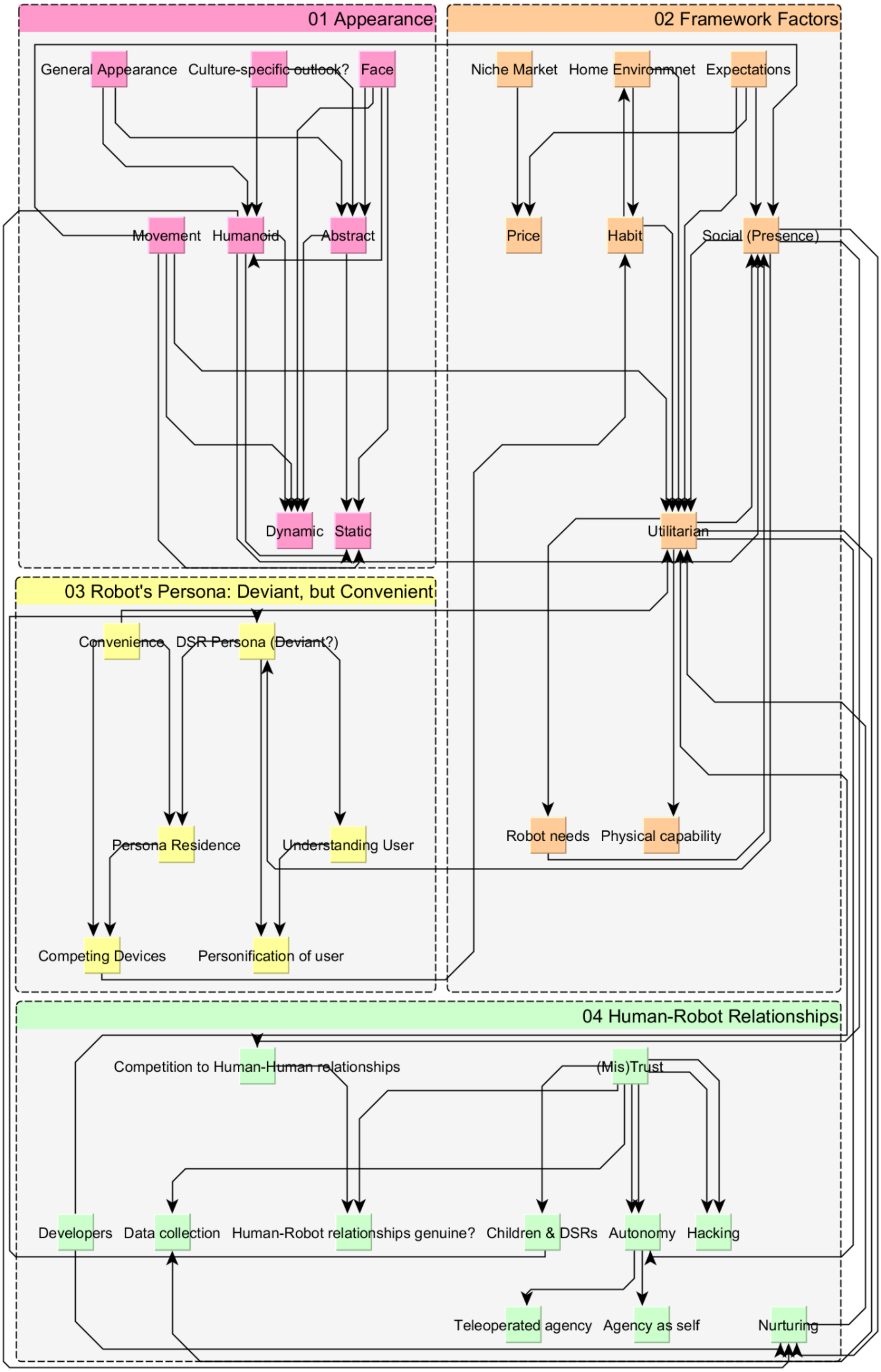

Figure 33. Interrelation of Topics between Studies.

Appendix 4: Smart Speaker Frequency of Use Table Data

Table 6. Frequency of smart speaker use by participant and day

Day #	H1 - Gavin & Jason	H2 - Tristan & Rebecca	H3 - Chris & Alice
0	47	7	31
1	50	1	2
2	24	1	0
3	11	24	11
4	7	8	4
5	0	7	1
6	0	17	1
7	6	7	2
8	5	2	1
9	4	0	1
10	0	9	1
11	5	3	0
12	0	3	0
13	1	19	0
14	5	4	5
15	7	4	2
16	1	1	1
17	4	15	1
18	2	3	2
19	0	0	1
20	0	3	0
21	1	2	0
22	3	1	0
23	4	2	0
24	23	7	0
25	6	0	0
26	1	2	0
27	3	7	0
28	2	3	0
29	1	2	0
30	1	3	0
31	0	7	5
32	0	3	1
33	0	7	0

34	0	2	0
35	2	4	0
36	0	3	1
37	1	1	9
38	8	3	0
39	1	3	5
40	0	3	2
41	0	0	1
42	0	3	2
43	0	3	3
44	0	3	1
45	0	3	0
46	0	12	0
47	0	2	1
48	0	3	1
49	3	4	0
50	0	6	0
51	0	8	0
52	0	6	0
53	0	10	0
54	0	9	0
55	0	2	0

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