Dynamics of Human-Robot Interaction in Domestic Environments

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PAR

Julia FINK

acceptée sur proposition du jury:

Prof. J. Paik, présidente du jury
Prof. P. Dillenbourg, Prof. F. Mondada, directeurs de thèse
Prof. A. Ijspeert, rapporteur
Dr L. Takayama, rapporteuse
Dr A. Weiss, rapporteuse

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“If you don’t get everything you want,
think of the things you don’t get that you don’t want.”
— Oscar Wilde

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Abstract

Domestic service robots are nowadays widely available on the consumer market. As such, robots have begun entering people's homes and daily lives. However, it seems that the dissemination of domestic robots has not happened as easily and widespread as it was anticipated in the first place. Little is known about the reasons why because long-term studies of ordinary people using real robots in their homes are rare. To better understand how people interact, use and accept domestic robots, studies of human-robot interaction require ecologically valid settings and the user and their needs have to come into the focus.

In this dissertation, we propose to investigate the dynamics of human-robot interaction in domestic environments. We first explore the field by means of a 6-month ethnographic study of nine households. We provided each of the households with a Roomba vacuum cleaning robot. Our motivation is to understand long-term acceptance and to identify factors that can promote and hinder the integration of a domestic service robot in different types of households. We would like to find out how people's perception of the robot, and the way they interact with it and use it, evolve over time. Furthermore, as social factors were highlighted in previous studies on technology adoption in homes, we shed light on to what extent people view Roomba and other types of domestic robots as a social entity and to what extent they anthropomorphize it. Findings of this research can be used to guide the design of user-oriented robots that have the potential to lastingly become a valuable part within the home ecology.

Then, we pursue the idea of developing our own domestic robot prototype that could be used in a household with children. We imagine a playful robot that aims to motivate young children to tidy up their toys. In a first evaluation of the robot in 14 family homes, we study the effect of a proactive and reactive robot behavior on children's interaction with the robot and their motivation to tidy up. A follow-up experiment explores the possibility to sustain children's engagement by manipulating the robot's behavior in such way that it appears unexpected. We further investigate how far this influences children's perception of the robot in terms of anthropomorphism.

Our findings emphasize the importance of research in ecologically valid settings in order to obtain a better understanding of human-robot interaction, advance further the design of user-oriented robots and foster the long-term acceptance of these devices.

Keywords: domestic robots, human-robot interaction, social robotics, technology acceptance, user experience.

Résumé

Les robots domestiques de service sont aujourd'hui largement disponibles sur le marché et sont entrés dans les foyers et le quotidien des gens. Il semble cependant que le déploiement effectif de ces robots ne se déroule ni aussi facilement, ni aussi massivement que ce qui était initialement espéré. Les raisons en sont encore mal comprises car rares sont les études longitudinales impliquant des utilisateurs lambda et leur utilisation de robots à leur domicile. Or, comprendre comment les gens interagissent, utilisent et acceptent les robots domestiques nécessite en effet une approche expérimentale écologiquement valide, qui donne toute son importance aux utilisateurs dans leur contexte quotidien.

Cette thèse de doctorat étudie la dynamique des interactions homme-robot dans l'environnement domestique. Nous explorons tout d'abord le domaine à travers une étude ethnographique de 6 mois impliquant neuf foyers auxquels est confié un robot aspirateur Roomba. Notre motivation est de comprendre les mécanismes d'acceptation d'un robot domestique sur le long-terme et d'identifier les facteurs qui peuvent accroître, ou au contraire freiner, l'intégration d'un robot de service dans différents foyers. L'étude vise à clarifier comment évoluent dans le temps la perception du robot par les sujets, la manière dont adultes et enfants interagissent avec lui et ses modalités effectives d'utilisation. En outre, et en nous basant sur des études précédemment publiées relatives à l'importance des facteurs sociaux dans le processus d'adoption des technologies au sein d'un environnement domestique, nous proposons un nouvel éclairage sur les phénomènes qui conduisent à percevoir les robots comme des entités sociales, sujettes à anthropomorphisme. Les résultats de cette première étude offrent un éclairage intéressant pour la conception de robots domestiques porteurs d'une valeur ajoutée sur le long-terme au sein de l'écosystème d'un foyer.

Cet éclairage nous permet ensuite la conception d'un prototype de robot domestique adapté à une utilisation domestique avec des enfants. Nous présentons le robot ludique Ranger dont le but initial est de motiver les jeunes enfants à ranger leurs jouets. Lors d'une première évaluation du robot dans 14 familles, nous étudions les effets du comportement du robot, proactif ou réactif, sur l'interaction et sur la motivation des enfants à ranger leur chambre. Une seconde expérience explore la possibilité de maintenir l'engagement des enfants à un haut niveau en manipulant le comportement du robot afin d'y introduire des éléments non-prévisibles. Les résultats de cette seconde expérience sont aussi interprétés en termes de comportements anthropomorphiques.

L'ensemble de nos résultats montrent l'importance d'une méthode privilégiant la validité écologique pour obtenir une meilleure compréhension de l'interaction homme-robot, et ceci afin de faire évoluer la conception de robots autour des besoins de l'utilisateur et d'encourager ainsi l'acceptation de ces machines sur le long-terme.

Mots-clés : robots domestiques, interaction homme-robot, robotique sociale, acceptation de la technologie, expérience utilisateur.

Zusammenfassung

Serviceroboter zur privaten Nutzung sind heutzutage weitgehend auf dem Markt verfügbar. Damit haben sie auch begonnen Einzug in die Haushalte und in das alltägliche Leben der Menschen zu halten. Die Verbreitung von Haushaltsrobotern scheint jedoch beschwerlicher und weniger intensiv von statten zu gehen als man zunächst angenommen wurde. Über die Gründe ist relativ wenig bekannt, denn Langzeitstudien mit Robotern, die von normalen Personen in ihren Haushalten genutzt werden sind selten. Um ein besseres Verständnis davon zu bekommen, wie Menschen mit Robotern interagieren, wie sie diese im Alltag nutzen und akzeptieren, sind Studien zur Mensch-Roboter-Interaktion unter ökologisch validen Bedingungen notwending. Zudem müssen der Nutzer und seine Bedürfnisse stärker in den Fokus gerückt werden.

Diese Dissertation beschäftigt sich mit den Dynamiken der Mensch-Roboter-Interaktion in häuslichen Umgebungen. Zuerst wird mittels einer 6-monatigen ethnographischen Studie in neun Haushalten der Forschungsgegenstand erkundet. Jeder der neun Haushalte erhielt einen Roomba Staubsaugerroboter. Das Ziel dieser Studie ist es die nachhaltige Akzeptanz dieses Roboters zu erforschen sowie konkrete Faktoren zu ermitteln, die die Akzeptanz und Integration eines Serviceroboters in verschiedenen Arten von Haushalten begünstigen oder behindern können. Es wird erforscht wie sich die Auffassung der Studienteilnehmer von dem Roboter und die Art und Weise wie sie mit ihm interagieren und ihn nutzen, mit der Zeit verändert. Nachdem soziale Faktoren in früheren Studien zur Annahme von Technologien in Haushalten betont wurden, wird diese Arbeit desweiteren erforschen, inwiefern die Studienteilnehmer Roomba und andere Serviceroboter als sozialen Agenten wahrnehmen und inwieweit sie ihn anthropomorphisieren. Die Ergebnisse dieser Forschungsarbeit können dazu dienen, das Design nutzerorientierter Robotern anzuleiten, welche das Potential haben, nachhaltig ein nützliches Teilstück innerhalb der Haushaltsökologie zu werden.

Dann wird die Idee verfolgt einen eigenen Prototyp eines Haushaltsroboters zu entwickeln, welcher in einem Haushalt mit Kindern eingesätzt werden könnte. Es wird ein spielerischer Robot angedacht, welcher versucht kleine Kinder dazu zu motivieren ihre Spielsachen aufzuräumen. In einer ersten Evaluierung in 14 Haushalten mit Kindern werden die Auswirkungen eines proaktiven sowie reaktiven Verhaltens des Roboters auf die Interaktionen der Kinder mit dem Roboter sowie auf ihre Motivation aufzuräumen untersucht. In einem Folgeexperiment wird erforscht, inwieweit das Interesse der Kinder für den Roboter aufrechterhalten werden kann, wenn der Roboter ein für die Kinder unerwartetes Verhalten zeigt. Weiterhin wird erfasst, inwieweit diese Manipulation des Roboterverhaltens die Wahrnehmung der Kinder bezüglich des Roboters und in Hinblick auf Anthropomorphismus beeinflusst.

Die Forschungsergebnisse dieser Arbeit unterstreichen, wie wichtig es ist, Studien in natürlichen Umgebungen durchzuführen, um ein besseres Verständnis über Mensch-Roboter-Interaktion zu erlangen, das Design von nutzerorientierten Robotern voranzutreiben und die nachhaltige Akzeptanz dieser Geräte zu begünstigen.

Schlagwörter: Haushaltsroboter, Mensch-Roboter-Interaktion, Soziale Robotik, Akzeptanz von Technologien, Nutzererfahrung.

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Introduction

Anecdote I

The first time I encountered a robot I was about 4 years old. Suddenly, this thing was there, right in front of me, and I had never seen such a thing before! It was huge, even taller than me. This happened in an aisle in the supermarket where we went with my mother to do the groceries. I was playing hide and seek with my twin-brother. But where was he now that this huge thing was blocking my way? I felt that this was a strange situation. What was this thing and where did it come from? After a couple of moments in which I did neither dare to move nor to breathe, I turned around but there was no one. I turned back and a tinny voice asked me *"Where is your mom?"*. This thing was talking to me! I was fascinated but scared at the same time. *"I don't know"* I spluttered back quietly. How did this thing know that I was with my mother? Had it been observing me? I watched it carefully. Then, it spoke to me again: *"Do you want me to help you find your mom? Jump on, I offer you a ride!"* and it turned and it had a small stair on its back. It was moving! My parents had told me I should not accept any offers made by any stranger. But this was fascinating! I had to bite my tongue. I worked up my courage, went over to the thing and stepped on its back stair. *"Now, hold tight, here we go!"* I held on to its shoulders and we started moving along the aisle in between shelves full of laundry detergent and fabric softener. We went quite slow but I felt that I was red all over my face because I was so exited. We reached the hallway, turned, and there was my mother on the lookout for me. We smoothly wheeled over

Figure 1: My first encounter with a robot was in an aisle in a supermarket. [source: gettyimages.ch]

to her, stopped, and I jumped off. The eyes of the thing were blinking in blue and it made some strange sounds as it went back to the aisle with the laundry detergent.

My mother told me later that the thing was a robot and that it was there to promote and make people buy a new type of laundry detergent. She also told me that she had seen a man who was remote-controlling the robot. I don't know. She was probably right. But the matter which counted for me and which I remember still today is my own experience I had on that day. This first encounter with a robot left a mark.

* * *

Opening

> *"From the human-robot interaction perspective, a very important characteristic [...] is that robots share physical spaces with people. In some applications, these people will be professionals that may be trained to operate robots. In others, they may be children, elderly, or people with disabilities whose ability to adapt to robotic technology may be limited. The design of the interface, although dependent on the specific target application, will require substantial consideration of the end user of the robotic device. Herein lies one of the great challenges that the field of robotics faces today."* Thrun (2004, p. 14)

It has been recognized that designing robots that can enhance people's daily lives at home is a multifaceted and interdisciplinary challenge. This challenge does not only concern technical aspects of Human-Robot Interaction (HRI) but also addresses human and social factors. Still, the development of robots is mainly inspired by technical challenges. However, the design of robots that can enable meaningful and effective interactions with humans, requires to go beyond this. On one hand, we need to understand social factors, such as people's perception, their expectations and their needs related to domestic robots. On the other hand, we need to study how people and robots interact with each other and within the space they are supposed to share. How do people use and incorporate a robot in their home? What impact does the robot have on the household itself, the established routines and roles? It is well known from the field of Human-Computer Interaction (HCI) that interaction studies can powerfully inspire technology design. Therefore, in HCI, concepts such as usability, user-experience, aesthetics, enjoyment, and play have already become common sense (Bannon, 2011). However, HRI is not yet at this stage, mainly because robots are not yet as commonly available and robust as computers and other technology which is used in the home. Finally, we also need to consider the long-term. How can we sustain interaction and people's engagement with a robot? What are the factors that promote and hinder a lasting adoption of a domestic robot? There are many open questions and there is a real need of long-term HRI studies in ecologically valid environments.

Motivation

For a couple of years now, various types of robots with applications in domestic settings are available on the consumer market. As robotic technologies not only become more advanced, robust and reliable, but also increasingly less expensive, the number of commercial products is growing, and a more widespread diffusion of robots in society has begun. However, we do not yet know much about the impacts and consequences that the distribution of robots and their integration in people's daily lives has – on the short as well as on the long-term. This makes research in the areas of Social Robotics and HRI progressively more important. Systematic investigations of HRI in domestic environments are still rare, especially concerning long-term studies. More research in ecologically valid settings needs to be done to be able to gain insights into how people perceive, accept, and interact with robots in the *real world*. Further, though we do not focus on this here, it needs to be mentioned that with autonomous robots being used by ordinary people in everyday life settings, almost anything can happen, and therefore legal aspects need to be considered. Another crucial point in terms of robots interacting with humans in private spaces and in social manners, is ethics. We ourselves are the ones that develop robots and therefore it is our responsibility to decide what we want robots to do, how we want to engage with them, and what roles we want them *not* to fulfill in our daily lives. We are aware of these two important topics but they are not in the focus of this thesis.

Recently, several projects in Europe have received funding to explore and advance the role of robots in everyday life settings (for example, LIREC[1] and ALIZ-E[2]). The main motivation behind these projects is to build robots (and other artificial companions) that support long-term relationships with humans and enable meaningful social interactions with users in real world settings. This kind of research is often motivated by the fact that, as the population continues to age, there will soon be a lack of human caregivers for elderly people. In turn, there is a trend toward developing social and assistive robots that can be deployed in elder care centers and homes of elderly people to assist them and improve their quality of life. The research presented in this thesis is not motivated by the aging population trend and does not especially focus on elderly people as users of domestic robots. We do not exclude the elderly (or other people that need assistance) in our research but we do not put their specific needs into focus.

In Switzerland, the National Center of Competence for Research on Robotics (NCCR robotics[3]) was launched, with the common objective of developing human-oriented robots for improving the quality of life. One of the projects in this research program analyzes human-robot-interactions, focusing on educational and domestic environments. The research work presented in this thesis is part of this project. Central questions are how to develop and effectively introduce robots in these settings, as well as how to foster the dissemination of robots and their acceptance by the public. A first step to address these questions is to gain a comprehensive understanding of the occurring long- and short-term interactions between humans and robots in educational scenarios and domestic settings. The work presented here focuses on latter one.

General Research Questions and Goals

In this thesis, we propose to investigate interactions between humans and robots in homes. Our aim is to study how people perceive, react to, accept, use, and interact with domestic robots. We are particularly interested in long-term factors. On one hand, we will explore how human-robot interaction changes over time, and we use the term *dynamics*, to refer to these changes. On the other hand, we will study how a robot which can be used in a family home, can be designed in such way that it is acceptable and engaging over an extended period of time. In this thesis, we

[1] http://lirec.eu
[2] http://www.aliz-e.org/
[3] http://www.nccr-robotics.ch

understand *acceptance* as embracing a variety of aspects that play a role in how far a robot is welcomed and approved in a daily life environment. We will come back to this in Chapter 1, when reviewing technology and robot acceptance models (Section 1.4).

By carrying out short- and long-term interaction studies and acceptance research with ordinary people in mostly natural settings, such as their homes, we expect to find answers to the following general **research questions**:

1. **People's perception of robots:** How do people perceive having and using a robot in their home? How does perception change over time and with growing experience with the robot? (related work on people's perception of robots is presented in Chapter 2, Section 2.1)

2. **Interaction analysis:** How do people, the robot, and the environment they are sharing interact with each other? How does the robot's impact on the home ecology and the general interaction change over time? (an overview of interaction studies and field studies with domestic robots is presented in Chapter 2, Section 2.2)

3. **Acceptance factors:** What are the factors that promote or hinder the acceptance (both short- and long-term) of a domestic robot in a household? How important are social factors? (relevant theoretical background to acceptance is presented in Chapter 1, Section 1.4)

4. **Adoption process:** How can the process of adoption (or rejection) of a domestic service robot be described? And how does usage and experience change during this process? (relevant theoretical background to the process of long-term adoption is presented in Chapter 1, Section 1.4)

5. **Social engagement:** Do people engage socially or in a human-like way with a service robot, such as a vacuum cleaning robot? How does people's engagement with the robot change over time? (relevant related work to engagement with robots and anthropomorphism is presented in Chapter 2, Section 2.3)

These five topics and the posed questions partly overlap and are related to each other. For instance, people's perception of a robot plays a role in how they interact with it. Ultimately, the goal based on our research questions is to understand how we can design a domestic robot that is acceptable and can become a valuable part of people's daily life at home. To achieve this, we carry out a *first research phase* in which we investigate the aforementioned aspects with commercially available products. This phase is mostly exploration driven. Then, based on the outcomes of this phase, there will be a *second research phase*, in which we aim to design, develop and evaluate our own domestic robot (in collaboration with other researchers in the project group). This phase can be considered as an interaction design phase, in which we aim to study and refine the interaction and user experience with our own domestic robot. The second phase is motivated by the following **research goals**:

1. **Design and services / functionality:** Design and development of a functional robot that is acceptable in a family home and can enhance their daily routine.

2. **Engagement:** Create a valid human-robot interaction scenario that is engaging and meaningful, also in terms of long-term interaction.

There is a research paradigm that we think is important in studying human-robot interaction, and that we would like to follow: **ecological validity**. Doing ecologically valid studies means that we aim using methods, materials, and settings that approximate the real-world as much as possible. More concretely, we aim to use real embodied robots in natural interaction scenarios with ordinary people in real-world settings. Ecological validity in research is not trivial. We will come back to the expected costs and challenges of this paradigm later, in the section about "Challenges of Research in the Wild" (Section 2.2.2).

Methodological Considerations

Domestic robots can be seen as a form of innovative technology for home use. How do we study this kind of technology? Brown (2008) notes that with the recent advancements of technology a change of study methods is likely. Rather than simply conducting **surveys** of households, she argues that we need to consider alternative methods, such as ethnography. For instance, Venkatesh and Brown (2001) conducted an **ethnographic study** of household technology use. Ethnography is a qualitative research method that attempts to generate a holistic account of cultures or groups of people, such as a household. In its origin, ethnography is a form of anthropological practice and both a methodology and perspective (Bell, 2001). Ethnography is considered a type of field work where the researcher spends time in and with the culture or peoples studied, participating in everyday life and attempting to make sense of the patterns of that culture (Bell, 2001). By using an ethnographic approach, Venkatesh and Brown (2001) were able to uncover important themes associated with household technology use, such as the causes of user frustration and the limited integration of technology into the household. In other projects that studied technology and Internet use at home, *e.g.* the HomeNet Project[4], households were given computers and asked to keep **diaries** of computer use and to participate in **interviews** with researchers. Ethnographic studies and other types of field research in domestic settings are often combined with the so-called **cultural probes** method (Gaver et al., 1999). A "probe package" is given to participants which usually consists of diaries, cameras, post cards, and sometimes maps, in order to gather as much information as possible of participants' life styles, use patterns, interactions, and behaviors. According to Bernhaupt et al. (2008), this methodology serves to enable the investigation of daily life without the participation of researchers in the field studies (which can have negative effects). For instance, Bernhaupt et al. (2008) carried out two ethnographic studies in homes using creative and playful probing to understand user media behavior and perceived trends of technology use in the living room (*e.g.* related to personalization, privacy, security, and communication).

[4]http://www.homenet.hcii.cs.cmu.edu

In general, ethnographic and other research that uses these more **descriptive and open-ended techniques of collecting data** has become increasingly important for understanding how households appropriate technology, and subsequently reshape it (Brown, 2008). For several years now, there has been a tendency towards using ethnography and similar more qualitative and in-depth methods also in HRI studies. Some long-term studies in daily life settings have applied these techniques (Forlizzi, 2007a; Sung et al., 2009a, 2010; Fernaeus et al., 2010) (see Chapter 2).[5]

We address the aforementioned research questions and goals by carrying out several studies of different types and using a variety of methods and techniques. We present the specific research questions and the according methodology in each chapter about the respective study. The following table gives an overview:

Table 1: **Overview of the studies presented in this thesis.** The first two studies on human-robot interaction involve commercial robots and technology, and belong to the *first research phase*. The last two studies focus on child-robot interaction and involve our own prototype. They belong to the *second research phase*.

Study	**Robots / Technology**	**Environment Duration**	**Methods**	**Participants**	**Focus**
Roomba Study	Roomba	domestic 6 months	ethnography, probes interviews	9 households 30 participants 1-71 years	long-term adoption, usage, perception, social impacts
Forum Study	Roomba, AIBO, iPad	virtual	content analysis	3 online forums 750 forum posts	anthropomorphism, usage, perception
Ranger Study	Ranger	domestic 30 min	observations, videos, interviews, questionnaire	14 families 31 children 2-10 years	interaction analysis, perception, prototype evaluation
Domino Study	Ranger	laboratory 30 min	observations, videos, interviews	13 groups 26 children 4-5 years	interaction analysis, engagement, anthropomorphism

Contributions

We expect our work to contribute to the field of HRI in several ways. On one hand, results contribute to a better understanding of what happens when domestic robots enter people's homes, especially in terms of long-term dynamics and human-social factors. Due to their unique characteristics (*e.g.* their physical presence and their ability to act autonomously), robots are expected to have an impact on and within a household, that is different to what can be observed with other household technologies or tools. Still little is know about how far people accept and continue using a domestic robot after novelty effects and initial fascination have worn off. A

[5]An overview of long-term interaction studies with robots used in various daily life applications is given in the PhD thesis of Iolanda Leite (Leite, 2013).

lot of research about the acceptance of robots in daily life contexts uses surveys or short-term observations but only few studies have investigated long-term interactions and other dynamics with real robots used by ordinary people in their homes. On the other hand, our findings can be used to guide the design of domestic robots, and we give an example by developing and testing our own robot prototype in several interaction studies. So far, the development of robots is mostly inspired by technical challenges. With our work, we shed light on the user point of view, and show how results from interaction studies can inspire robot design. Finally, we contribute to the challenge of how to study and evaluate HRI, from a methodological point of view. HRI is a field that integrates many disciplines; however, multi-disciplinary research is not trivial. We apply methods from social science and interaction design, which is not common in robotics research. By this, we give an example of how researchers from different disciplines can work together towards a common goal.[6]

Overview

This dissertation consists of three parts:

The **First Part** embraces Chapters 1 and 2. It is concerned with the theoretical background and the related work on HRI as well as the acceptance and long-term dynamics that have been investigated with home technologies and domestic robots.
Chapter 1 presents the relevant **theoretical background**. We first discuss what we understand by "robot" and by "Human-Robot Interaction" (HRI). Then, we report on design and human factors aspects of HRI, and investigate how HRI can be evaluated, focusing on a human-centered approach. After this, we present models of technology / robot acceptance that integrate factors which can promote or hinder acceptance. Then, we outline existing theories and frameworks about the long-term adoption of home technologies and about the dynamics in interaction / user experience with technology and robots over time. Finally, we give an overview of the domestication process and social shaping of technologies and present approaches of integrating robots into the domestic environment.
Chapter 2 reviews the **related work** in respect to our own research. We give a short overview of what is known about people's perception of robots, and their expectations of domestic robots, in particular. We present what field studies and long-term research has found on HRI in domestic environments and we highlight people's social activities and special types of engagement with robots, such as anthropomorphism. Finally, we review literature on child-robot interaction, as two of our studies focus on children.

The **Second Part** forms the main part of and is composed of Chapters 3 to 6. This part covers our practical research and empirical studies on the dynamics of HRI in domestic environments:

[6] The research presented in this thesis would not have been possible without exchanges and collaborations with social scientists, ethnographers, mechanical engineers, computer scientists, roboticists, interaction designers, pedagogical advisers and HCI researchers. I appreciate our teamwork and will acknowledge the involved research groups in the respective parts.

Chapter 3 presents our first study, the **“Roomba Study”**. This 6-months ethnographic field work was done in 9 households that were given a Roomba vacuum cleaning robot. The study is of explorative nature and focuses on the long-term adoption of Roomba in households. We present findings on how people’s perception and experience with the robot changed over time and what factors promoted and hindered the adoption of the robot.
Chapter 4 is about the so-called **“Forum Study”** which was conducted to better understand how people generally relate to Roomba, and compared to the robotic dog AIBO and the tablet computer iPad. This study is a content analysis of online discussion forums that investigates the amount and use of anthropomorphic language. We present findings on what topics are prominent related to the three devices and where they range on a hypothetical scale of being anthropomorphized.
Chapter 5 describes the **“Ranger Study”**, which is about the development and first evaluation of our own prototype, called “Ranger”. This robotic toy box aims to motivate young children to tidy up their toys. We brought the robot to 14 family homes and tested our approach using the Wizard-of-Oz technique. Two different types of robot behavior (a proactive and a reactive behavior) were used, in order to see which behavior can better motivate the children. We report findings on how children interact and play with Ranger in general, and show how the manipulation of the robot’s behavior led to a different interaction style.
Chapter 6 is about a child-robot interaction study, that we label **“Domino Study”** because children were assembling a domino together with the Ranger robot. Carried out in a controlled laboratory setting, a human Wizard manipulated the robot’s behavior in such way that it was unexpected to the 4-5 year old children. 13 groups played with the robot that either made a mistake, got lost, or disobeyed from time to time. The goal of this study is to explore possibilities of sustaining engagement and to investigate the effect of unexpected robot behavior on children’s attribution of human-likeness to the robot. We show that unexpected robot behavior can increase engagement in the interaction but that stronger variations of it can make a difference.

Finally, the **Third Part** consists of **Chapter 7**. This chapter first summarizes and highlights the important research findings and contributions of our work. Then, we synthesize our results into an initial conceptual model of the dynamics of human-robot interaction over time. More specifically, we propose an extended understanding of anthropomorophism in HRI, which takes into account person-related factors, robot-related factors, contextual factors, and the history of interactions between the user and the robot. This initial model is a first step towards conceptualizing how people’s tendency to anthropomorphize a robot may evolve over time, with growing user experience. We conclude by critically discussing alternatives of introducing service robots into households and propose topics for future research.

1 Theoretical Background

"... technology is not given. It's not like the sun or the moon or the stars. It was made by people like us. If it's not doing for us what we want, we have a right and a responsibility to change it."
Mike Cooley, Right Livelihood Award Speech, 1981;
[source: http://www.rightlivelihood.org/cooley_speech.html]

This chapter gives an overview of the theoretical background and relevant concepts related to human-robot interaction in domestic environments. First, we briefly sketch the history of robots, and discuss the unique characteristics of robots as artifacts and interaction subjects, compared to machines and computers. This is followed by an overview of Human-Robot Interaction (HRI) as a research field.[1] We outline how the matter is related but different from the close-by fields Human-Computer Interaction (HCI) and Human-Machine Interaction (HMI). Based on the unique interaction characteristics that robots offer, we present various classification schemes of HRI. Then, we outline concepts about the design and evaluation of human-robot interaction, taking a human-centered perspective, and provide a list of technology and robot acceptance models. This is supposed to give an overview of which factors impact on the acceptance and account for long-term adoption of technology, with a focus on household technology. Finally, the concept of technology domestication is presented, along with the trends and different approaches to integrate robotics into people's homes.

1.1 Robots

Since the ancient civilization, humans have been fascinated with building machines and character-like creatures that perform human-like and animalistic behaviors, and with computing cosmic phenomena with mechanical designs (Oh and Park, 2014). Originating in various ancient cultures around the world, there were two main ideas for mechanical creations: automating work with some self-operating apparatus / machine *(e.g. Automaton)*, and entertaining the public with a kind

[1] A detailed and fairly comprehensive survey of HRI can be found in Goodrich and Schultz (2007).

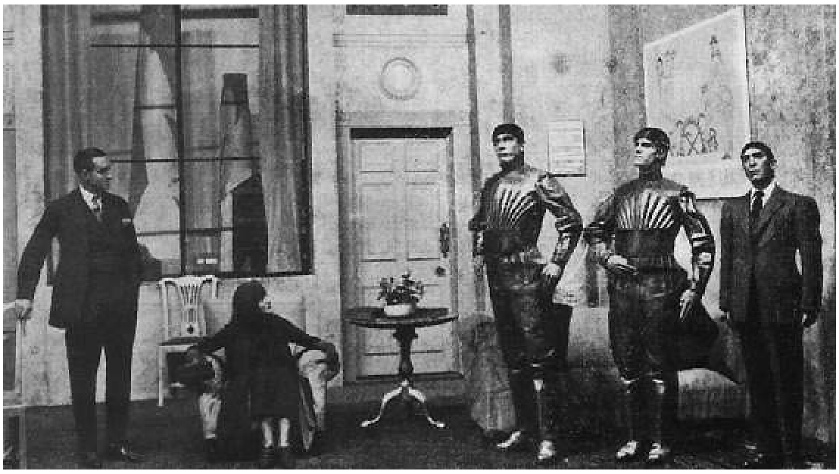


Figure 1.1: A scene from Karel Ĉapek's 1920 play R.U.R. (Rossum's Universal Robots), showing three robots; [source: http://www.umich.edu/~engb415/literature/pontee/RUR/RURsmry.html]

of self-performing mechanical spectacular *(e.g. Mechanical Theater)*. Sometimes, both ideas were realized in the same artifact, and sometimes these artifacts were resembling a human or an animal. The modern concept of robots began with the Industrial Revolution in the 18th century, as there was a transition from hand production methods to machines, more complex mechanics were used and also electricity was introduced.

The first application of the term "robot" however, occurred in a play written by Karel Ĉapek entitled R.U.R. (Rossum's Universal Robots) published in 1920 (see Figure 1.1). The term "robot" is derived from the Czech word *robota*, which means "compulsory labor" (or also "servitude"). In R.U.R., robots were created to work for people and, as in many fictional stories thereafter, they went on to rebel and destroy the human race. During this time, many robots were constructed that could perform some stunts, and they were mostly exhibited to the public and used for public relations purposes, for instance. Also, robot characters appeared in fictional scenarios in plays and films. In the early 1940s, the science fiction writer Isaac Asimov coined the term "robotics" to describe it as a field of study and he was among the first to examine the fundamental concepts of HRI, most prominently in his book *I, Robot* (1950). The original benchmarks for HRI were proposed as the now famous *Three Laws of Robotics*.
For long time, the history of robots was closely related to the advancements in building a programmable computer and creating artificial intelligence (AI). In his 1950 paper *Computing Machinery and Intelligence*, Alan Turing proposed to consider the question *Can machines think?*. His later elaborated *Turing Test* was created to evaluate whether a system was able to "fool" a human user into believing he or she was communicating with another human. Since this time, one of the benchmarks for success in AI and HRI has been how well the system can imitate human behavior (Feil-Seifer and Mataric, 2009). Later on, with the creation of artificial (programming) languages, it was possible to communicate instructions to a machine (computer) and to make robots programmable. The cornerstone for a new generation of industrial robots was set, and soon, during the 1960/70ies electro-mechanically driven industrial robots were developed and deployed

in manufacturing. Advancements in artificial intelligence, computer sciences and mechanical engineering were quickly moving forward the field of robotics.
Today, robotics is commonly grouped in three major categories: **industrial robotics**, **professional service robotics**, and **personal service robotics** (Thrun, 2004). These categories also represent different technologies and correspond to different historic phases of robotic development and commercialization. Today, robotics is still a rapidly growing field, as technological advances continue and inspire new purposes for robots. There are many applications for robots today, among the most prominent types are industrial robots, service robots, military robots, medical robots, telerobots, domestic robots, and entertainment & toy robots (these categories are neither absolute nor mutually exclusive, they may overlap).

In this thesis, we focus on the category of personal service robotics and mostly exclude the other two categories. More concretely, we are interested in studying personal service robots with applications in the domestic environment (homes).

What is a Robot?

There are as many different types of robots as there are tasks and other actions for them to perform. With so many different types existing, it is hard to give a definition that would embrace all robots. Also, it is not very clear where to set the boarders between robot, machine, and computer, and one strives hard to find a good answer to the question what a robot is. Consequently there is no single one definition of what a robot is (today). Back in 1979, the Robot Institute of America defined a robot as

> *"a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of task."* Robot Institute of America, 1979

It is accepted that this definition has limitations, especially as new types of interactive (sociable) robots emerged, but it is still one of the most widely used, definitions of robot. Commonly, a robot is viewed as a *tool*: a device (or machine) which performs tasks on command (Fong et al., 2003b). As such, all direction is given to the human and the robot has limited "freedom". This has changed. While initially, robots were mostly used to carry out repetitive tasks by showing high precision and efficiency, they are now becoming involved in increasingly more complex and less structured tasks and activities, including direct (social) interaction with humans. By this, robots do not only require to be more autonomous (we come back to this in the next paragraphs), but robots also start filling a growing number of *roles* in today's society (Feil-Seifer and Mataric, 2009). This raises ethical concerns. Nowadays, robots cannot only be found in factory automation and industrial applications but also in more service-oriented fields, such as, medical care and rehabilitation, search and rescue scenarios, as educational tools, to entertain people, and in daily life contexts such as public spaces, work environments and in homes.

What robots have in common with many other physical devices, such as household appliances or cars is the fact, that they *"inhabit the same physical spaces as people do in which they manipulate some of the very same objects"* (Thrun, 2004, p. 10). However, there is a difference between a vacuum cleaning robot and a *kitchen machine*.[2] Thrun (2004, p. 10) mentions that possibly the biggest difference between robots and other physical devices is **autonomy**, which refers to *"a robot's ability to accommodate variations in its environment"*. In other words, autonomy empowers robots with an ability to make their own decisions in broad ranges of situations (Thrun, 2004). Different levels of autonomy are required in different environments and tasks, due to the different complexity of both. Consequently, different types of robot require different levels of autonomy (depending on which environment the robot operates in, carrying out which kind of task). The aforementioned three major categories of robotics (industrial, professional service, and personal service robotics) are also based on different autonomy levels:

> *"It should come as little surprise that industrial robots operate at the lowest level of autonomy. In industrial settings, the environment is usually highly engineered to enable robots to perform their tasks in an almost mechanical way. For example, pick-and-place robots are usually informed of the physical properties of the parts to be manipulated, along with the locations at which to expect parts and where to place them. Driverless transportation vehicles in industrial settings often follow fixed paths defined by guide wires or special paint on the floor. As these examples suggest, careful environment engineering indeed minimizes the amount of autonomy required–a key ingredient of the commercial success of industrial robotics."*
> Thrun (2004, p. 14)

The picture is quite different for service robots, which are used in environments that *"mandate higher degrees of autonomy"*. Thrun (2004, p. 15). Service robots are deployed in highly unstructured, constantly changing environments, with humans moving around in an unpredictable manner, for instance. According to Thrun, *"the type and degree of autonomy in service robotics varies more with the specific tasks a robot is asked to perform and the environment in which it operates."* A domestic environment is among the most complex territories for service robots and in turn require a high level of robot autonomy. However, at the same time domestic service need to be targeted toward the consumer market, thus the robot needs to be fairly low-cost. Consequently, Thrun (2004, p. 15) asserts that *"endowing a personal robot with autonomy can be significantly more difficult than its more expensive professional relative."* The author elaborates further that autonomy of a robot opens the door to much richer interactions with people (*e.g.* when able to react socially to human interaction partners).

[2] There is something interesting when doing research of kitchen machines and domestic robots in a French-speaking region. It stems from the different terms which are used in different languages. In English there is the *kitchen machine* which is commonly not viewed as a robot because it is labeled as a machine. In French, however, a *kitchen machine* is translated as *robot ménager* which literally means *robot homemaker*. As such, the term suggests to francophone people to view a kitchen machine as a robot.

A more recent definition is offered by Fong et al. (2003b):

> *"[Robots are systems] which have complex, dynamic control systems, which exhibit autonomy and cognition, and which operate in changing, real-world environments."*
> Fong et al. (2003b, p. 257)

Also this definition considers autonomy as an essential characteristic of a robot. However, as industrial robots hardly exhibit autonomy and cognition, it is questionable to what extent this definition includes industrial robots (some of them may also be far from operating in a changing real-world environment). Again, this illustrates the vague borderline between machine and robot (in industrial settings).

When trying to find what the unique characteristics of a robot are, one can also look at how a robot is different from similar systems, namely machines and computers.[3] A machine is understood as a device that uses energy to perform some activity, and as such a robot can be considered a machine. However, not all machines are robots. Also a computer can be considered as a specific kind of machine, one that manipulates data according to a set of constructions. Thus, the concept of "machine" embraces both the concept of robot and computer. A computer (data processing machine) is usually part of a robot, it kind of guides the robot. However, a robot also has some electro-mechanical parts, which are moving, carrying out some action, or completing a task. A robot is able to do something on its own. Thus, a robot seems to be somehow both a machine and a computer but even more than that.

Struggling to define this specific *je ne sais quoi* of a robot, I read across people's personal definitions of robot in online forums, and discussed with researchers in the community. Several times I came across the idea to regard a robot as an **agent**, in order to make the difference between referring to something as a machine or a robot. Though this does not count for a formal definition, I would like to take up the concept of a robot being an agent that can have agency:

> *"I think that the reason the 'agency' definition works well is that it replaces the poorly defined and poorly understood concept of 'robot' [...] with the equally poorly defined, but much better understood concept of 'agency'. Even if we don't explicitly think of animals and robots as agents, we are wired to recognise agents, and categorise objects into things that are and aren't agents. We can easily tell the difference between animals and plants (well, for the types of animals and plants we usually encounter): animal $\rightarrow$ robot, plant $\rightarrow$ machine."*
> "Rocketmagnet" forum post Stackexchange - Robotics, on Aug 31 2013

[3] When discussing about what a robot is and what property it is that distinguishes it from a machine, one can easily find borderline examples such as highly automated or driverless cars, trains or unmanned airplanes but even more simple daily life things such as an electronic toothbrush or an automatic door. Can these things be considered a robot? Ultimately, the discussion of what a robot is, often leads to the questions of what a human is and what makes a human. For instance, what about robotic prosthesis? After how many body parts being replaced, enhanced or substituted by prostheses, exoskeletons, cardiac pacemakers, hearing aids, and so forth can a human still be seen as being a human? As long as it has (biological) parents? Can a robot have parents?

Note that **agency** has many subtle dimensions, but in its sociological meaning it is somehow related to the fact of being able to act autonomously, with a certain intention. Bandura states *"to be an agent is to intentionally make things happen by one's actions."* Bandura (2001, p. 2). Similarly, Nowak and Biocca (2003, p. 483) define the concept of agency as *"the state of being in action or of exerting power"*, and also propose that agency *"is central to the issue of the volitional or intentional force that drives the actions of an entity."* More concretely, Sullins (2006, p. 27) suggests that it is sufficient for an entity to have its own agency, *"if an agent's actions are interactive and adaptive with their surroundings through state changes or programming that is still somewhat independent from the environment the agent finds itself in."* Accordingly, Nowak and Biocca (2003) use the term *agent* to describe *"an entity whose actions are controlled by the computer itself"*. In contrast, other entities (*e.g.* avatars) *"are controlled by a human in real time."* It is possible to discuss in length about what entities can have agency and what agency means. Takayama (2012) suggests defining agency as something that is perceived, and as such agency describes a relation. Thus, it is not a property of a robot itself but emerges in an interaction (between a specific robot and a human, for instance). Some recent definitions of a robot include the agent notion but then often also refer to virtual or software agents as robots, which we do not include here because being virtual violates the "physical embodiment" property of the robot definition that we use in this thesis.

Summary

Overall, we have seen that "robot" is a very general term. It appears necessary to use more specific definitions, in order to refer to specific types of robots. The robots that we are interested in are domestic service robots (thus we exclude industrial and professional service robots). As such, the aforementioned definition by Fong et al. (2003b) is most appropriate, and we use their definition in this thesis. However, we would like to put an emphasis on the physical embodiment property of robots and consequently exclude virtual (non-physical) systems.

Moreover, in this thesis, we focus on a specifically challenging application field of robots: everyday environments, in which mostly non-expert users are interacting with robots. More concretely, we study robots with applications in homes. This means domestic (or household) service robots, and some types of entertainment & toy robots with a practical use or educational aspect in the domestic environment. However, we exclude assistance and health-care robots that target especially elderly people or other people that need assistance. Most interesting is not to study the robot itself as an artifact but to look at the interplay with its surroundings (including people) when the robot is deployed in its "natural" environment. In order words, we are interested in studying and analyzing the interactions that occur between people and robots (and other agents and parts of the domestic environment they are sharing). This kind of research is an own field of study: Human-Robot Interaction. The increase of robots that operate in close proximity to people (that interact with people) raise a number of research and design challenges. Some important challenges are outside the scope of this dissertation.

1.2 Human-Robot Interaction

The growing complexity with which robots are used has prompted an entirely new endeavor of research. Human-Robot Interaction (HRI) can be defined as *"the study of the humans, robots, and the ways they influence each other"* (Fong et al., 2003b). In its core, the study of HRI deals with the question how best to design and implement robot systems capable of accomplishing interactive tasks in human environments.

By default, HRI is multidisciplinary, incorporating contributions from communications, computer science (human-computer interaction, artificial intelligence, robotics, natural language understanding, and computer vision), engineering (electrical, mechanical, industrial), design, social sciences (psychology, cognitive science, communications, anthropology, human factors), and humanities (ethics and philosophy), as well as theater. The fundamental goal of HRI is to develop the principles and algorithms for robot systems that make them capable of direct, safe and effective interaction with humans. (Feil-Seifer and Mataric, 2009; Murphy et al., 2010)

As a research field, HRI is diverse and broad. It regards the analysis, design, modeling, implementation, and evaluation of robots for human use. As such, HRI is closely related to Human-Computer Interaction (HCI) and Human-Machine Interaction (HMI). It is not clear whether HRI should be regarded as a subset of HCI or as a subset of computer-supported collaborative work (CSCW) (Yanco and Drury, 2002). It depends how far the robot is regarded as an (unequal) interaction partner in the human-robot team. When accepting the aforementioned definition of a robot by Fong et al. (2003b) it is clear however, that HRI differs from both HCI and HMI because it concerns different kinds of systems which have unique properties. In addition, Scholtz (2003) mentions that differences occur in the types of interactions (interaction roles), the physical nature of robots, the number of systems a user may be called to interaction with simultaneously, and the environment in which the interactions occur. In short, the main aspects that make HRI unique seem to be robots' ability to **encourage in social interaction** and create a sense of **agency**, on one hand, and the **embodied interaction experience** that users can have with robots (Young et al., 2011). These and other differences lead to different possible classifications of HRI, and will be shortly outlined in the following section.

Classifications of Human-Robot Interaction

There exists several HRI classification schemes. An overview of related taxonomies and suggestions for classifying HRI can be found in Yanco and Drury (2002, 2004).

On one hand, HRI classifications can draw on existing taxonomies from HCI or CSCW. For instance, one can apply the *time-space taxonomy* (Ellis et al., 1991) to HRI (Yanco and Drury, 2004). This taxonomy divides interactions into four categories based on whether collaborators (here: human and robot) are using computing systems at the same time (synchronous) or different times (asynchronous), while in the same place (collocated) or in different places (non-collocated).

On the other hand, there exist other classifications which are based on the particularities of HRI, and consider different types of interactions between human(s) and robot(s), as well as different roles that they take in an interaction. For instance, one particularity of HRI is that robots show some degree of autonomy which balances the human-robot interaction in a specific direction.[4] As such, HRI can be classified according to the robot's level of autonomy, or in other words the amount of human intervention needed. Another particularity of HRI is that robots are not fixed, but can move around (mobile robots), and as such distances (and *proxemics*) become a factor as well as the environment, which becomes part of the interaction scenario (the robot interacts within its environment). The robot's surrounding and specific parts (and agents) in it are considered as additional (passive) interaction partners. One would speak of a multi-agent interaction (Takeda et al., 1997), a term which is also used to refer to an interaction in which one human interacts simultaneously with multiple robots (multi-robot systems) but this will not be treated here.

In the following, we present some HRI classification schemes (this list is not comprehensive).

An early taxonomy of different types of HRI is proposed by Takeda et al. (1997). The authors classify four different interaction types between humans and robots, according to how "natural", "rich" and in turn "acceptable" the interactions are expected to be for people:

1. **Primitive interaction** is communication through special instruments, such as a computer-based interface. The drawback of primitive interaction is that people are bound to computer terminals and cannot interact directly with a robot.

2. **Intimate interaction** is direct, one-to-one interaction (*e.g.* gesture). This type of interaction enables multimodal direct interaction which is expected to be more acceptable. The drawback, however, is that people and robots need to be close to each other to establish such an interaction.

3. **Loose interaction** is needed to enable interaction at a distance.

4. **Cooperative interaction** involves automatically introducing additional robots and people as needed by the interaction. This could solve the problem of limitations of functions of a single robot.

As the optimal solution to the human-robot interaction problem Takeda et al. (1997) suggest a so-called **ubiquitous human-robot interaction**.[5] By this, the authors understand *"natural ways for people to communicate and cooperate with robots just as same as they do with other people [...] anywhere at anytime"*. Besides these different interaction types, the authors also propose

[4]Sheridan et al. (1983) describe several levels of autonomy (regarding computer systems) to describe to what extent a system can act on its own accord, which has been applied also in HRI (or variations / extensions of it).

[5]This term seems to be loosely based on what we understand by **ubiquitous computing**, which describes the approach of embedding technology in an everyday environment, such that it kind of disappears for the user, and becomes unremarkable (Weiser, 1991).

an architecture for **multi-agent interaction** in which the environment, which includes multiple agents (people, robots, automated instruments, and computers), is modeled.

Another basic categorization of HRI is proposed by Thrun (2004). He distinguishes two categories: **(1) direct interaction**, in which the robot acts on its own, the robot acts and the person responds or *vice versa*, thus bidirectional flow of information; and **(2) indirect interaction**, the interaction that takes place when a person operates a robot. According to Thrun, the main differences arise in the flow of information and control.

Similarly, Fong et al. (2003b) divide HRI according to different interaction types. The authors list three categories: **(1) direct / proximal interaction** (*e.g.* physical contact); **(2) mediated** by a user interface ("operator interface" or "control station"), where human input is transformed to robot commands and feedback is provided via a display, for instance; or through **(3) teleoperation**, when the human and robot are separated by a barrier (distance, time, etc.) and information is exchanged via a communication link.

Dealing with a similar challenge of how humans and robots can communicate and cooperate with each other in an efficient way, Scholtz (2002a,b, 2003) look at different *roles* occurring in HRI. The starting point here is to view the human(s) and robot(s) as a team in which dialogue and collaboration is required. The different interaction roles balance the interaction according to the degree of *human intervention*, respectively *robot autonomy*. First, three main interaction roles were defined: supervisor, operator, peer. Later, a mechanic role was added and the peer role was divided into a bystander and teammate role:

1. **Supervisor interaction**, which could be characterized as (a human) monitoring and controlling the overall situation, from a remote location. For example, a number of robots could be monitored and the supervisor would be evaluating the given situation with respects to a goal that needs to be carried out.

2. **Operator interaction**, describes that a (human) operator is called upon to modify internal software or models when the robot behavior is not acceptable. This could possibly be in a remote interaction, and the operator would have an external device to use as an interface to the robot. In contrast to the supervisor, the operator cannot formally change the intentions of longer term plans.

3. **Mechanic interaction** deals with physical interventions, thus the human and robot are co-located. However, it is still necessary for the (human) mechanic to determine if the interaction has the desired effect on the behavior. The difference to the operator interaction is that the modifications have been made on the hardware.

4. **Peer interaction** is face-to-face interaction and can be divided into a **teammate role** and a **bystander role**. Teammates' commands are within the larger goal/intentions scope, on a higher level (*e.g.* follow me). Contrary, bystanders, who are co-existing in the same

environment as the robot, are able to cause the robot to stop by walking in front of it. They are, however, not able to interact with the robot at the goal or intention level.

From these roles, Scholtz (2002b) derives different models of HRI, based on Norman's seven stages of interaction (in HCI). Ultimately, five stages (including feedback) are taken into account: goals, intentions, actions, perception, and evaluation. It needs to be stressed that to truly develop a synergistic human-robot team, Scholtz reports that it needs more than a clever interface for the user. It is necessary to consider the skills of both humans and robots and to develop an overall system that allows all parties to fully utilize their skills.[6]

1.3 Design and Evaluation of Human-Robot Interaction

The experience of interacting with a robot has been shown to be very different in comparison to people's interaction experience with other technologies and artifacts, and often has a strong social or emotional component – a difference that poses potential challenges related to the design and evaluation of HRI (Young et al., 2011).

Both, design and evaluation of HRI, are fundamental aspects. Goodrich and Schultz (2007) see it as one of the core problems in HRI to *"understand and shape the interactions between one or more humans and one or more robots."* Evaluating the capabilities of humans and robots, and designing the technologies and training that produce desirable interactions are essential components of HRI. Such work is inherently interdisciplinary, and there is a lot of research going on. One could have an extensive discussion about how to design HRI and how to evaluate it. However, our research focuses on specific types of robots used in a specific environment, the home. As in the domestic environment, non-expert users and human factors play a central role, we focus here on the human-centered perspective in designing HRI.

1.3.1 Human-Centered Robotics

Already in 1992, Kidd argued that robotic systems always require some human skill (Kidd, 1992). Though he applied this more to industrial robots, the author maintains that designers should use robot technology to support and enhance skills of the human as opposed to substituting skills of the robots for skills of the human. He states that

> *"there is, therefore, no logic in developing and using technologies such as robotic systems in a way that attempts to replicate the skills of the people who will have to use the system, if this leads to unsatisfactory work. Moreover, the human-centered*

[6] When the human and the robot are viewed as partners in an interaction, they somehow must engage in a dialogue, and jointly solve problems. To achieve this, systems for **collaborative control** are suggested. In such systems, the human gives advice but the robot can decide how to use this human advice (Fong et al., 2003b).

> *philosophy offers the potential of a better way in which to introduce new technologies. It can also avoid creating the need for skills that do not exist."* Kidd (1992, p. 237)

Kidd argues for developing and using robotic technology such that human skills and abilities become more productive and effective, such as freeing humans from routine or dangerous tasks (Scholtz, 2003). He points out that robotic researchers tend to focus on issues that are governed by legislative requirements such as safety, and that human-centered design issues have been mostly ignored.[7]

Whereas traditional HCI takes a user-centered (human-centered) approach, others in the automation / robotics field have taken a system-centric approach (Scholtz, 2002a). During the first years of HRI, research was mostly driven by technical challenges, and a system-centric approach was advancing the technical development but not necessarily the human-robot interaction. Nevertheless, for a couple of years now, robots have become accessible also to people outside the domain and as such, the field has started to integrate more a user-centered perspective. It is advocated that the human-centered approach to HRI is needed as a compliment to the system-centric approach. According to Kidd (1992), **human-centered robotics** is characterized by four key factors:

1. The technology is designed to be skill supporting and skill enhancing.
2. Social science knowledge is applied in the design in a prospective manner to generate initial design proposals.
3. Social science knowledge is used to shape the technology.
4. The design process focuses attention on issues which lie between disciplines (*i.e.* between technology and the social sciences).

With human-centered design of HRI it is suggested to look beyond technology issues and to consider issues such as task allocations[8] between people and robots, safety, group structure. These aspects need to be considered already in the early stages of the technology design, otherwise the issues become secondary and have little impact on design considerations (Kidd, 1992).

What are the main attributes of human-robot interaction that designers can consider? To adopt a designer's perspective Goodrich and Schultz (2007) break down the human-robot interaction into its constituent parts, and list five attributes that affect the interactions between humans and robots:

[7] However, in his article Kidd also suggests that *"for safety purposes it is desirable to keep human and robot apart as much as possible"* which is kind of the opposite of for what HRI aims today. Note that Kidd was mainly referring to manufacturing robotics (industrial robots), and that his article was published in 1992, long before commercial robots such as the AIBO, Roomba, Paro or Pleo encouraged users to engage in direct (and social) interaction.

[8] Similar, in HCI one speaks of the *division of labor* what does not exactly match task allocation but may also be related to the structure of the human-robot team, which will also be mentioned later.

1. The level and behavior of **autonomy**. This refers on one hand to the amount of time that a robot can be neglected by the user; and on the other hand to describe to what degree the robot can act *"on its own accord"* Goodrich and Schultz (2007, p. 217) (without human intervention).

2. The nature of **information exchange** between the human and the robot. The two primary dimensions are communication medium (delineated by the senses seeing, hearing, touch) and format of the communications (*e.g.* language based, haptic icons, auditory alerts, social gestures, *etc.*).

3. Structure of the **team**. This considers, for instance, the ratio of humans and robots in the team, but also how the team is organized.

4. The **adaptation**, **learning**, and **training** of people and the robot. Thus, how far can, do or should both human and robot adapt to each other and in which ways? (*e.g.* learning by demonstration)

5. The shape of the **task**. This takes into account the fact that the introduction of the robotic technology into a task changes the way that humans do this task. Either, the robot allows a human to do a task that they could not do before, or to make the task easier or more pleasant for the human.

Goodrich and Schultz (2007) argue that from the confluence of these factors, an interaction emerges, whereby they understand the *"process of working together to accomplish a goal"*. In designing human-robot interaction, one attempts to understand and shape the interaction itself, with the objective of making the exchange between humans and robots beneficial in some sense.

The first step in the design of a human-centered robotic system should be to define the major design decisions. The next step should be to identify the relevant social science considerations before any concrete design work starts. Kidd (1992) lists ten main factors (not comprehensive list) that need to be considered in the design process: (1) the underlying reasons for using robots and the role of the robots; (2) task allocation between people and robots; (3) safety; (4) stress control; (5) opportunities for colleague support; (6) opportunities for socialization; (7) group structure; (8) robot noise levels; (9) training; and (10) the nature of the devices used to program and control the robots.
Kidd suggests further that the final step should be to generate feasible design options using the identified criteria in a prospective way. More detailed design work should then be undertaken to evaluate the feasible options. In this later phase of the design process further decisions can be made and more design detail will gradually begin to emerge. Towards the end of his article, Kidd stresses again the importance of integrating a social science perspective:

> *"The main point is this. If social science design criteria are not used in a prospective manner, in the same way that technical and financial judgment criteria are used,*

> *then new ideas, unforeseen possibilities, and new original ways forward will not be forthcoming. This last point is an extremely important one with implications for human-robot interaction. If robots are just perceived as reliable and faster replacements for people, then the vision of human-robot interaction is that of people serving the needs of robots and compensating for the inadequacies of these devices. If robots are seen as tools to support [...], then human-robot interaction becomes potentially much richer and deeper."* Kidd (1992, p. 239)

In particular, when introducing robotics into people's homes – a private setting in which the main users are ordinary people – it becomes evident that the human user point of view needs to be considered from the very beginning. Human-centered design places the understanding of people, their concerns, and their activities in the forefront (Bannon, 2011). For the design of domestic robots, the challenge is to combine the practical aspects learned from engineering, the human concerns that guide design, and social science perspectives on our world (Terry Winograd, cited after Bannon (2011)). Besides putting so much focus on the human user, one may not forget about the physical context of the human-robot interaction. Consequently, the human-centered robotics approach may be extended to also take into account the physical environment of the home. Kawamura et al. (1998) brings these three factors - robot, user, environment to a point:

> *"[...] our responsibility is to find the right mix of robot intelligence, environmental modification and user interaction to create robust and useful service robots that can be widely used to improve the quality of life for all of us."*
> Kawamura et al. (1998, p. 115)

Summing it up, one of the main research challenges in HRI concerns **design and human factors** and, related to this, **social robotics** (Feil-Seifer and Mataric, 2009). For instance, prominent research topics concern long-term interaction and acceptability of robots in daily life environments. Regarding the human-centered design of robots and HRI, in general, there needs to be a balance between the human user, the robot, and the environment in respect to several aspects, that contribute to a "good" and purposeful interaction (for all counterparts).

What we can keep in mind here is that research in HRI related to design and human factors can draw from similar research in HCI (as some of the considerations are similar), however it features a number of significant differences related to the robot's physical real-world embodiment (Feil-Seifer and Mataric, 2009) and human's tendency to perceive robots more than other products as having some sense of agency (Takayama, 2012). We can situate parts of our research in the just mentioned sub-regions of HRI: design and human factors, social robotics. More concretely, we analyze HRI from a human-centered perspective, taking into account social aspects such as user experience[9] and the acceptance of robots and of the resulting interaction.

[9] User experience refers to how a product (in our case, a robot) is perceived, used, and learned Norman (1998).

1.3.2 Evaluation of Human-Robot Interaction

To have an idea about how appropriate and effective a specific human-robot interaction is, one needs to evaluate it. However, due to the general complexity of robots' overall context of interaction, related to their dynamic presence in the real world, and their tendency to invoke a sense of agency, it is challenging to evaluate HRI (Young et al., 2011). Two main aspects that still seem to be unclear are (1) how to evaluate HRI, so in which kinds of **scenarios** using which **methodologies**; and (2) what exactly should be evaluated and assessed (**metrics** and **measurements**).

Evaluation Scenarios

Regarding evaluation scenarios, Goodrich and Schultz (2007) report on several practices that they observed when reviewing HRI research. For instance, for a couple of years now, there is a tendency toward creating real systems and then evaluating these systems using experiments with human subjects (**user studies**). It is often difficult to conduct a carefully controlled experiment with a physical robot, so sometimes studies use a mix of simulated and physical robots. Also, even when a physical robot is available, studies involving human subjects are not easy to setup because it is hard to account for all details that might happen in a free human-robot interaction. Consequently, some research uses a **Wizard of Oz study**, in which a human "Wizard" is controlling the robot from the background (what is unknown to the human subject) (Weiss et al., 2009b).[10]
Moreover, it is agreed that **longitudinal studies** are an important scenario to evaluate HRI. Such studies, which can last from several weeks to several months, require a considerable investment, both in terms of time and financial resources. Long-term studies shift research methodologies from carefully controlled small-scale experiments to other methodologies such as surveys and ethnography.

Only recently, robots have also become reliable enough to be actually deployed in the **"real world"** (outside the controlled laboratory environment), which is about to become another practice in evaluating HRI. Any model or law cannot substitute real-world observation. Especially with respect to domestic robots, an evaluation "in the wild" (Sung et al., 2009a) is preferred, as more natural interactions and human reactions can be expected. Further, the robot itself can be tested within its intended environment, the home, which is unpredictable and dynamic, unstructured and full of obstacles – attributes that could never be simulated or modeled in the laboratory. This offers unique insight into HRI, however, research in ecologically valid settings is not trivial, for instance, in regard of controllability of variables. In the spirit of real-world observation, the field of ethnography has developed a set of methodologies for recording observations in real-world settings, and efforts have been made to translate these observations and summarization methods into tools for designing interventions (Goodrich and Schultz, 2007).

[10]Steinfeld et al. (2009) explored different possibilities of applying a Wizard of Oz approach in HRI. The authors also propose the opposite, an Oz of Wizard technique.

Evaluation Metrics

The HRI community tries to establish **common metrics** and standards for evaluating the interaction between humans and robots. Overviews can be found in Steinfeld et al. (2006); Young et al. (2011). We fill focus here mainly on the human-perspective.

As Steinfeld et al. describe it:

> *"The primary difficulty in defining common metrics is the incredibly diverse range of human-robot applications. Thus, although metrics from outer fields (HCI, human factors, etc.) can be applied to satisfy specific needs, identifying metrics that can accommodate the entire application space may not be feasible. As such, it may be necessary to rely on measures that, while not ensuring comparability across applications, provide the benefits afforded by familiar methods and scoring. A good example of this would be the use of subjective ratings scales (e.g., Likert)."*
> Steinfeld et al. (2006, p. 33)

In HCI typical evaluations of a user interface use efficiency, effectiveness, and user satisfaction as measures when evaluating user interfaces (Scholtz and Bahrami, 2003). **Effectiveness** is a measure of the amount of a task that a user can perform via the interface. **Efficiency** is a measure of the time that it takes a user to complete a task. This is sometimes also referred to as *time-to-completion*. **Satisfaction** ratings are used to assess how the user feels about using the interface. These three measures seem appropriate for evaluation of a number of HRI roles. Additionally, because robots interact with the physical world and may at times be remote from the user, the user will also need some awareness of the robot's current situation. According to Drury et al. (2003) and Scholtz and Bahrami (2003), this involves both an understanding of the external environment as well as the internal status of the robot.

The difficulty with robots being used in a social context like the domestic environment, is to determine which metrics (engineering, psychological, sociological) are most appropriate for evaluating the effectiveness and **performance** (focusing not on the task but on the user's perspective, and the human-robot interaction). Of course, as mentioned in the quote, specific contexts and task(s) require different metrics, and there is no general solution. It needs to be kept in mind that, according to the robot's purpose and application scenario, different types of metrics need to be applied to achieve an overall evaluation. Steinfeld et al. (2006) mention five different robot tasks: (1) navigation, (2) perception, (3) management, (4) manipulation, and (5) social. In terms of robots performing a social task (5), the authors suggest the following five metrics to evaluate the overall human-robot interaction:

1. **Interaction characteristics** refers to an analysis of the interaction, *e.g.* according to interaction style and social context. This can be assessed via observation or conversational analysis.

2. **Persuasiveness** applies to scenarios in which the robot is used to change the behavior, feelings or attitudes of humans (*e.g.* robot as mediator in human-human interaction, robot in autism therapy).

3. **Trust** is an important measure in HRI evaluation, as it is likely to influence reliance on complex, imperfect automation in dynamics environments that require the human to adapt to unanticipated circumstances.

4. **Engagement** is a key metric in social HRI. The efficacy of various social characteristics (emotion, dialogue, personality *etc.*) can be measured for capturing attention (acquisition time) and holding interest (duration).

5. **Compliance** refers to the amount of cooperation that a human gives to a robot. Social characteristics (appearance, adherence to norms, *etc.*) can have an impact on this.

Steinfeld et al. (2006) suggest to use both *qualitative* and *quantitative measures* to assess the effectiveness and efficiency of the interaction. For instance, quantitative performance measures include (1) the percentage of the mission that was accomplished, or (2) the time required to complete a task. Qualitative measures can be subjective ratings, for example.

More design-centered evaluation metrics for social HRI are proposed by Bartneck and Forlizzi (2004a). The authors propose to classify social robots according to five properties: **form, modality, social norms, autonomy**, and **interactivity**. Further, several broad guidelines for social robot design are presented.

As mentioned before, as robots show some autonomy, the user's **awareness** of the robot's status is an important metric in HRI (Scholtz and Bahrami, 2003). There are many definitions of awareness, and for HRI, different perspectives need to be taken, to account for all combinations of single and multiple humans and robots in a team (Drury et al., 2003). Based on these perspectives, four metrics are proposed: (Scholtz and Bahrami, 2003)

1. **Predictability of behavior**. This refers to the degree of match between the user's model of behavior and the actual behavior of the robot. Given a particular interaction with the robot, is the user able to predict the response?

2. **Capability awareness**. This refers to how far the user is aware of the robot's functionality. Does the user have a model of all the possible behaviors that the robot is capable of?

3. **Interaction awareness**. Does the user understand all the ways to interact with the robot?

4. **User satisfaction**. How satisfied is the user with the interaction? This can be assessed via rating scales or responses to questions about interactions.

An evaluation of these factors can give insights into how "well" and appropriate the human-robot interaction is, and in turn, which aspects of the robot's design could need improvement. Such evaluations are in their idea similar to a user interface evaluation or usability evaluation in HCI.

Along with the identification of common metrics to evaluate HRI, several "toolkits" (measurement instruments) have been proposed to assess the aforementioned criteria (amongst others) in a systematic way. For HRI studies with human subjects, various questionnaires and other tools have been developed to allow for evaluation of the user experience and participant's social acceptance of robots (overviews can be found *e.g.* in Fong et al. (2003a); Weiss et al. (2008); Young et al. (2011)). For instance, to assess people's perception of robots, Bartneck et al. (2008) propose the so-called *Godspeed* questionnaire. It uses semantic differential scales and consists of different parts that evaluate specific aspects of a robot and the human-robot interaction, such as likeability, perceived intelligence, or human-likeness. The use of questionnaires with rating scales allows to quantify people's perception. This can be useful to get an overview of a larger sample, and to identify factors that may influence the perception (*e.g.* gender or cultural background). In a longitudinal study, rating scales may be used recursively, to highlight how perception evolves over time. For qualitative evaluations with a smaller sample, using questionnaires is not sufficient, however. Rating scales may still be used but could be integrated into a semi-structured interview that uses open-ended questions to allow people to justify and explain their ratings.

Based on evaluations of human-robot interaction, it is an ongoing effort to integrate the evaluated metrics (factors of the interaction) into something like a "robot acceptance model". This will be treated in the following section.

1.4 Technology / Robot Acceptance Models

A key question is not only what *"acceptance"* means in HRI both in short- and long-term but also what aspects it includes. First of all, we need to keep in mind that it is not only the system (the robot) which needs to be acceptable but also the interaction with it, and the result that it produces. Traditional technology acceptance models usually look at which factors play a role for the acceptance of the system, for using it. With respect to robots and human-robot interaction, we also need to take into account the specific context and task for which the robot is used. Due to the many application scenarios and different types of robots, there is not a single master model for robot acceptance. In the following sections, we present not only relevant acceptance models but also look at evaluation frameworks and at models that focus on long-term acceptance.

1.4.1 Acceptance Models

Over the last 20 years many technology acceptance models were developed, empirically tested, refined and extended. This overview is not comprehensive and the reader may refer to the original work for more details.

Technology Acceptance Model (TAM, TAM2, TAM3)

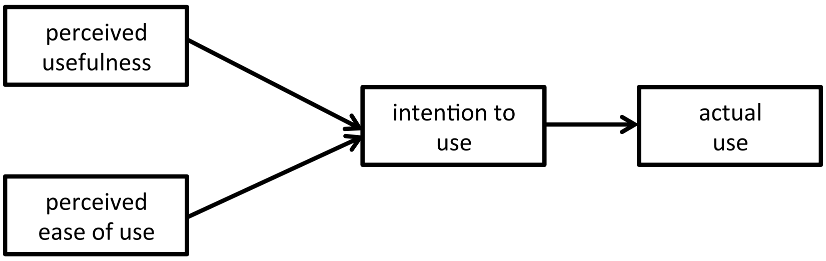


Figure 1.2: **Technology Acceptance Model (TAM)** (simplified version). This figure illustrates only the basic assumptions of the TAM, in the original version, a user's *intention to use* is preceded by his or her *attitude toward using* (and individual's positive or negative feeling about using a system). Further, both *perceived usefulness* and *perceived ease of use* are impacted by some *external variables*; [adapted by Davis et al. (1989)].

Author(s): Davis (1986); Davis et al. (1989); Venkatesh (2000); Venkatesh and Davis (2000); Venkatesh and Bala (2008) [11]

Overview: The Technology Acceptance Model (TAM) originates in the idea of providing a model that allows for empirical testing of the acceptance of *"new end-user information systems"*. The model considers how users accept and use technology according to several determinants. The basic assumption is that acceptance, which is understood as actual usage of a technology, is based on two main factors (see Figure 1.2). The chain is the following: The two main factors, namely **perceived ease of use (PEOU)** (the degree of ease associated with the use of the system) and **perceived usefulness (PU)** (the degree to which an individual believes that using the system will help him or her to attain gains in job performance) influence a user's intention to use a system which in turn is the main predictor of the actual use of the system. There are two extensions of TAM. The TAM2 integrates several external factors (*e.g. job relevance*, the individuals perception regarding the degree to which the target system is relevant to his or her job) and social factors (*e.g. subjective norm*, a person's perception that most of the important others think he or she should (not) use the system). The TAM3 further also accounts for so-called *anchors* (*e.g.* computer anxiety) and *adjustments* (*e.g.* perceived enjoyment).

Background: The model is based on the *Theory of Reasoned Action* (Fishbein and Ajzen, 1975), updated versions integrate constructs of the *Theory of Planned Behavior* (Ajzen, 1991).

Limitations: This model is very broad and did first not account for change processes (long-term). It focuses on the individual user, and as such does not really take the social aspects of an *interaction* and the environmental context into account.

[11] A comprehensive overview of the theoretical backgrounds and an extension of the TAM can be found in Mathieson et al. (2001)

Unified Theory of Acceptance and Use of Technology (UTAUT)

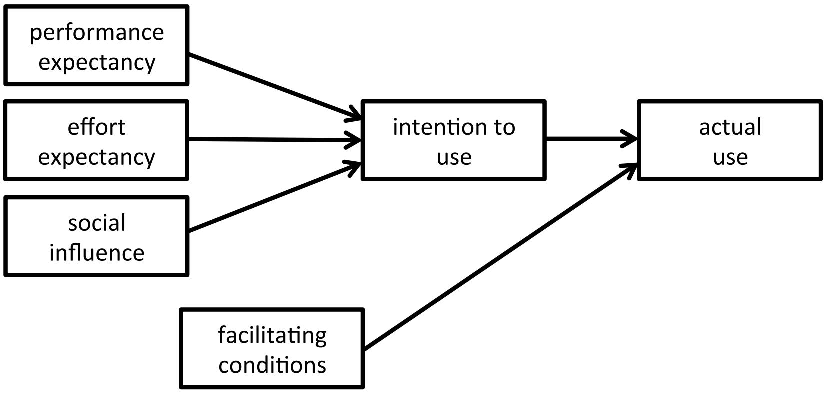


Figure 1.3: **Unified Theory of Acceptance and Use of Technology (UTAUT)** (simplified version). This figure illustrates the main influences on a user's *intention to use* and *actual use* of a system. The original version further includes four moderating influences: *gender*, *age*, *experience*, and *voluntariness of use*; [adapted by Venkatesh et al. (2003b)].

Author(s): Venkatesh et al. (2003b)

Overview: The UTAUT focuses on explaining user intentions and usage behavior. Four key constructs determine the intention to use and usage (see Figure 1.3): three of them impact on the intention to use: **performance expectancy** (equivalent to PU), **effort expectancy** (equivalent to PEOU), **social influence** (the degree to which an individual perceives that important others believe he or she should use the system), and one more construct directly links to the usage behavior, namely the **facilitating conditions** (the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system). As main moderating influences *gender*, *age*, *experience*, and *voluntariness of use* (the extent to which potential users/adopters perceive the usage/adoption decision to be non-mandatory) are identified. *Self efficacy* (the degree to which an individual believes that he or she has the ability to use the system), *attitude*, and *anxiety* were not found to have a direct influence.

Background: The UTAUT is an extension and adaption of the TAM, and synthesizes several other models of information system usage behavior, such as the *Theory of Reasoned Action* (Fishbein and Ajzen, 1975), *Theory of Planned Behavior* (Ajzen, 1991), *Diffusion of Innovations* (Rogers, 1995). It also integrates theories from cognitive psychology.

Limitations: The full theory is quite complex, including many variables and links between them.

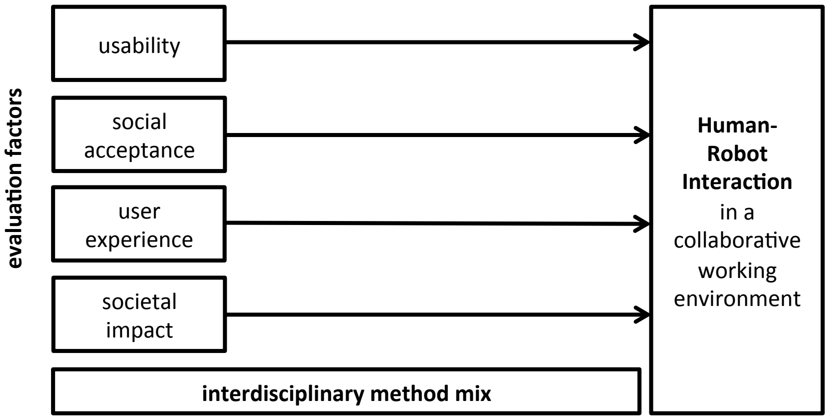


Figure 1.4: **Usability, Social Acceptance, User Experience and Societal Impact Evaluation Framework (USUS)** (simplified version). The framework combines theoretical and methodological foundations; [adapted by Weiss et al. (2009a)].

The Usability, Social Acceptance, User Experience and Societal Impact Evaluation Framework (USUS)

Author(s): Weiss et al. (2009a)

Overview: The USUS evaluation framework focuses on the evaluation of HRI (human-robot collaboration) with humanoid robots. The four main factors addressed in the framework are **usability**, **social acceptance**, **user experience**, and **societal impact**. The theoretical framework also proposes how to operationalize these factors, and also suggests a mix of methods derived from related disciplines.

Background: The USUS framework takes a human-centered perspective, and builds on all the previous models, by integrating several of their constructs as so-called *indicators*. For instance, *effectiveness* and *efficiency* are seen as two of the indicators for the main factor **usability**.

Limitations: The framework does a good job in providing a holistic view on evaluating HRI, it is not primarily an acceptance model. Due to the integration of a wide range of theories and methodologies, the framework as a whole appears complex, however one can decide to focus on a specific part (factor) of it.

Almere Model

Author(s): Heerink et al. (2010)

Overview: The Almere Model is a model of technology acceptance that is specifically developed to test the acceptance of assistive social agents by elderly adults. The takes into account a variety of constructs that impact on the acceptance: **anxiety (ANX)**, **attitude (ATT)**, **facilitating conditions (FC)**, **intention to use (ITU)**, **perceived adaptability**

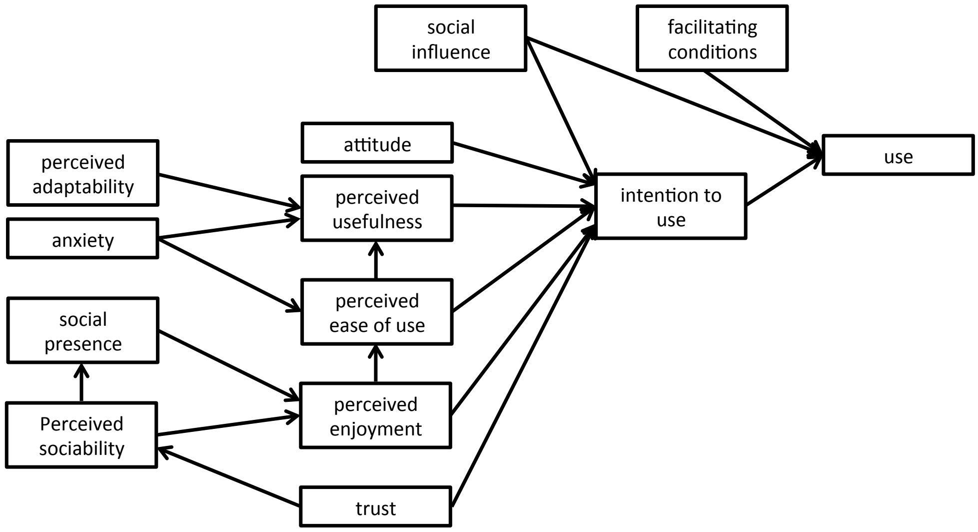


Figure 1.5: **Almere Model**, visualization of hypothetical construct interrelations; [adapted by Heerink et al. (2010)].

(PAD), **perceived enjoyment (PENJ)**, **perceived ease of use (PEOU)**, **perceived sociability (PS)**, **perceived usefulness (PU)**, **social influence (SI)**, **social presence (SP)**, **trust**, and **use/usage**[12]. Along with these 13 model constructs, a questionnaire consisting of 41 questions using a Likert type scale is proposed. The questionnaire can be adapted to other types of robots and application scenarios.

Background: The Almere Model is an adaption and extension of the UTAUT model, and as such also based on the TAM. It has been repeatedly refined, tested and validated through various experiments and evaluations with physical robots in natural environments.

Limitations: The authors mention that to become more robust, their model would require testing in long-term user studies, and with different types of robots. Further, the model does not consider moderating factors (*e.g.* age, gender, expertise) which have been found to play a role.

Summary

Reviewing the various models and frameworks on technology / robot acceptance, several similarities can be found, and we extract and highlight the following key factors:

- **perceived usefulness** (similar / equivalent to performance expectancy, utility),
- **perceived ease of use** (similar / equivalent to usability, effort expectancy),

[12]For definitions of these constructs please refer to the original work (Heerink et al., 2010).

- **social influence** (similar / equivalent to social acceptance, social norm),
- **user experience**, composed of, and influenced by
  - individual factors, *e.g.* perceived enjoyment, emotion, attitude, expertise *etc.*
  - external factors, *e.g.* the embodiment of the robot, and the context of use.

Overall, the factors that impact and mediate acceptance seem to concern three main points and their respective interplay: **(1)** related to the product in questions (here: the robot); **(2)** related to the human user, and **(3)** related to the context / environment in which the robot is deployed and used. The *user experience* is a good example of one of the acceptance factors that arises in the interplay of other robot-, person-, and context-related factors.

Most of the models and frameworks presented in the previous paragraphs have been applied and empirically tested in user studies and experiments. Adaptions and extensions have made some of these models robust tools to understand and evaluate the acceptability of human-robot interactions. However, HRI and the acceptance of a technology are both not static. Things evolve over time. There are several models and theories that focus specifically on long-term acceptance and adoption of technology. Overall, these models suggest that people's acceptance and use of technology / robots change over time, on an individual level, as well as when considering different adopter groups. This will be important for this PhD.

1.4.2 Long-term Acceptance and Adoption

In this section we give a brief overview of models and related theories that focus on the long-term acceptance and adoption of technology and robots, as well as on how the interaction experience changes over time. Also this list is not comprehensive, and the reader may look at the original work for more details.

Diffusion of Innovations (Technology Adoption Lifecycle)

Author(s): Rogers (1995)

Overview: The Diffusion of Innovations Theory was first published in the 1960ies. It aims at explaining variables that influence how and why members of a social system adopt an innovation at what rate. At the core of the theory is the *innovation-decision process* which consists of all the decisions, activities, and their impacts that occur from recognition of a need or problem, through research, development, and commercialization of an innovation, through diffusion and adoption of the innovation by users, to its consequences. The particularity of this theory is that it focuses on the macro-level (society), *i.e.* it describes the rate with which new ideas and technology spread through cultures (*"diffusion"*). Diffusion is understood as a special type of communication, and defined as *"the process in which*

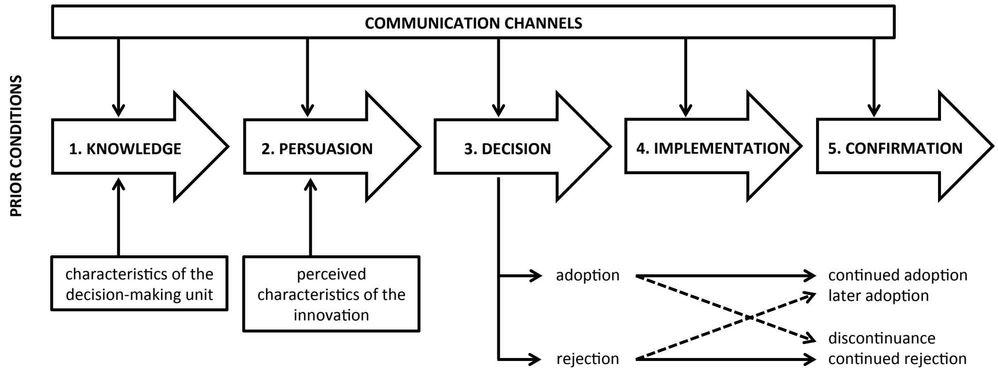


Figure 1.6: **Innovation-Decision Process**, in five stages. The *decision-making unit* (*e.g.* an individual) passes from first *knowledge* of an innovation, to forming an attitude toward the innovation (*persuasion*), to a *decision* to adopt or reject, to *implementation* of the new idea, and to *confirmation* of this decision; [adapted by Rogers (1995)].

an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 1995, p. 5). The emphasis on the social system is one of the particular aspects of Roger's theory. The author understands diffusion as a *"kind of social change"*, thus an innovation always comes along with an alteration that occurs in the structure and function of a social system.
The innovation is characterized through four stages: invention, diffusion (or communication) through the social system, time, and consequences (on the social system). At some point within the rate of adoption, the innovation reaches critical mass, and sustains itself. Rogers classifies the members of a social system into five adopter categories, based on their *"innovativeness"*: **innovators**, **early adopters**, **early majority**, **late majority**, and **laggards**.

In the *innovation-decision process*, prior conditions, the characteristics of the decision-making unit, and the perceived characteristics of the innovation, as well as the communication channels are influencing factors at different stages of the process (see Figure 1.6). More concretely, there are five characteristics of a technology (an innovation) which determine its diffusion and thus its acceptance: **relative advantage**, the degree to which an innovation is perceived as better than the idea it supersedes, (or a product offers improvements over available tools); **compatibility**, the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters (consistency with social practices and norms among users); **complexity**, the degree to which an innovation is perceived as difficult to understand and use (ease of use or learning); **trialability**, the degree to which an innovation may be experimented with on a limited basis (opportunity to try an innovation before committing to use it); **observability**, the degree to which the results of an innovation are visible to other (the technology gains are clear to see).[13]

[13] As Rogers' theory can be applied to nearly any kind of innovation, including new technologies, I reason that the theory can be applied to the acceptance / adoption process of robots. The reader may keep the five factors in mind, we

Background: The origins of the Diffusion of Innovations Theory are varied and span multiple disciplines. Rogers based the theory on evidences mostly taken from research of agricultural methods and medical practice.

Limitations: This theory is very broad, and can be applied to almost any context, it gives a holistic view and takes into account the whole social system; however, it considers the innovation (technology) as something static (that does not adapt to the user), which is probably due to the fact that the flow of communication is only considered in one direction. Consequently, the proposed adoption rate curve might look different.

Interaction and User Experience over Time

In terms of analysis of how the interaction and user experience evolve over time, an existing framework in HCI which can be (and has already been) applied to HRI (Weiss et al., 2009c; Young et al., 2011) is Norman's three-level framework. It analyzes how people interact with and understand everyday objects, with an explicit concern for emotion (Norman, 1988). The framework highlights three stages that a person may go through when dealing with a product over time: **(1)** the **visceral level**, which is the first initial impression of a product that people form without thinking about the product but by making spontaneous judgments; **(2)** the **behavioral level**, in which people use and experience the product, appraise its functions, and consider aspects such as usefulness and usability; and **(3)** the **reflective level**, in which consciousness takes part in the process, and past experiences are taken into account.

Similar to this, Takayama (2012) takes two perspectives to distinguish between different user responses to agentic objects, taking into account the time factor. Accordingly, an immediate (sometimes visceral) sense in a situation is called **in-the-moment** in contrast to the user's more distanced cogitation and consideration after some time, which is called **reflective**. This distinction implies different cognitive processes.

Model of Acceptance of Technology in Households (MATH)

Author(s): Venkatesh and Brown (2001); Brown and Venkatesh (2005)

Overview: The Model of Acceptance of Technology in Households (MATH) is a domestication of technology framework that focuses on the home (compared to adoption / acceptance by an individual). Three main drivers of adoption and non-adoption are identified: **attitudinal beliefs** (comprising behavioral beliefs), formed by the underlying utilitarian, hedonic, and social outcomes; **normative beliefs**, comprised of social influence and secondary sources; and **control beliefs**, such as lack of knowledge, difficulty of use, and high cost. However, the decisions driving adoption and non-adoption are different. The model shows that whereas adoption is driven by utilitarian, hedonic, and social outcomes;

will come back to them later on, namely in the long-term study of the Roomba vacuum cleaning robot, Chapter 3.

non-adoption is primarily influenced by the fact that technology changes rapidly, and the consequent fear of obsolescence.

Background: As the MATH focuses on intention and behavior and how both evolve over time, it is mainly based on the *Theory of Planned Behavior*, the TAM and the *Diffusion of Innovations*, but also takes into account other previous works. There exists an extension of the model which incorporates the household life cycle; it shows that the influence of attitudinal beliefs varies by life cycle stage. The MATH was developed around an extensive longitudinal study of the adoption of PCs into over seven hundred households across the U.S., primarily concerning the factors that people cited for or against adoption (Venkatesh and Brown, 2001).

Limitations: The study on which the MATH is based showed an interesting asymmetric relationship between people's intention and behavior to adopt a product. Nearly all non-intenders followed up with their intention not to adopt the product; however, less than half of the intenders followed with their intent to adopt the product. However, as the model originates from this empirical study (mostly telephone interviews), there are limitations, regarding the response bias.

User Experience over Time Framework

Author(s): Karapanos et al. (2009)

Overview: The User Experience over Time Framework looks at how the quality of users' experience develops over time. After the user's anticipation of expectations related to the

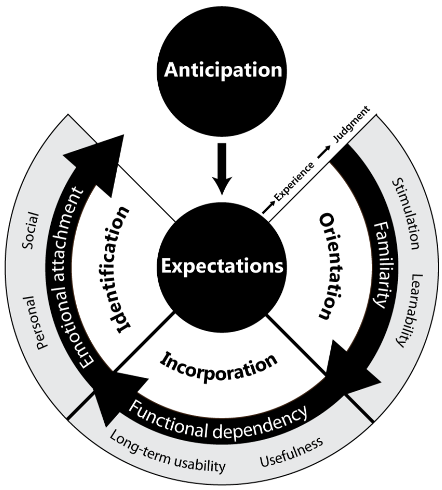


Figure 1.7: **User Experience over Time**, consisting of three main forces, an increasing *familiarity*, *functional dependency*, and *emotional attachment*, all responsible for shifting users' experience across three phases: *orientation*, *incorporation*, and *identification*. In each phase, different product qualities are appreciated; [taken from Karapanos et al. (2009)].

product, there are three driving forces that evoke a change in the user's experience with the product: **familiarity** (based on stimulation and learnability), **functional dependency** (judged by usability and usefulness), and **emotional attachment** (composed of personal and social attachment). With these aspects evolving over time, the user experience shifts along three phases: **orientation**, which describes the user's initial experiences that are pervaded by a feeling of excitement as as frustration as novel features and learnability flaws are encountered; **incorporation**, describes how the product becomes meaningful in the user's daily life, and usefulness becomes the major factors impacting the overall evaluative judgment; and **identification**, a phase in which the product is accepted in the user's life, and participates in social interactions. In each phase different product qualities are appreciated. For instance, first hedonic aspects and novelty are likely to play a role, while later usefulness might be a more important factor to motivate the use of the system.

Background: The framework is based on the perspective of the so-called *Social Shaping of Technology*[14] (MacKenzie and Wajcman, 1985; Williams and Edge, 1996), as well as on Silverstone and Haddon's framework on the dimensions of adoption (Silverstone and Haddon, 1996). It also integrates views from pragmatist philosophy and social psychology, that aim to describe how experience is formed and adapted, and explain how user's form preferences.
An empirical 5-week ethnographic study following 6 individuals, who were given an iPhone, was used to validate the framework. The key idea is that user's experience with a novel product changes over time, as users become more familiar with it.

Limitations: The framework carefully looks at how user experience changes over time and what the driving forces behind these changes are. The framework is validated by an empirical study. There are no major limitations.

Domestic Robot Ecology (DRE)

Author(s): Sung et al. (2010)

Overview: The Domestic Robot Ecology (DRE) is an initial framework of domestic robot adoption. It applies a holistic view to the relationships that robots shape in the home and takes into account long-term effects. The DRE is a first step towards a comprehensive understanding of HRI in domestic environments. As shown in Figure 1.8, a domestic robot can form relationships with three key attributes: the **environmental context** of the home [A.1], which includes both the physical and social space of a household; the **social actors** in the household [A.2], which are the living member in the home, such as householders, guests, and pets; and the **tasks** related to the robot [A.3], including the task that the robot is designed to serve (however, since domestic tasks are closely inter-related, automating one task by using a robot may also bring changes to the connected tasks). The formed

[14] This perspective is based on the assumption that technology is affected at a fundamental level by the social context in which it develops.

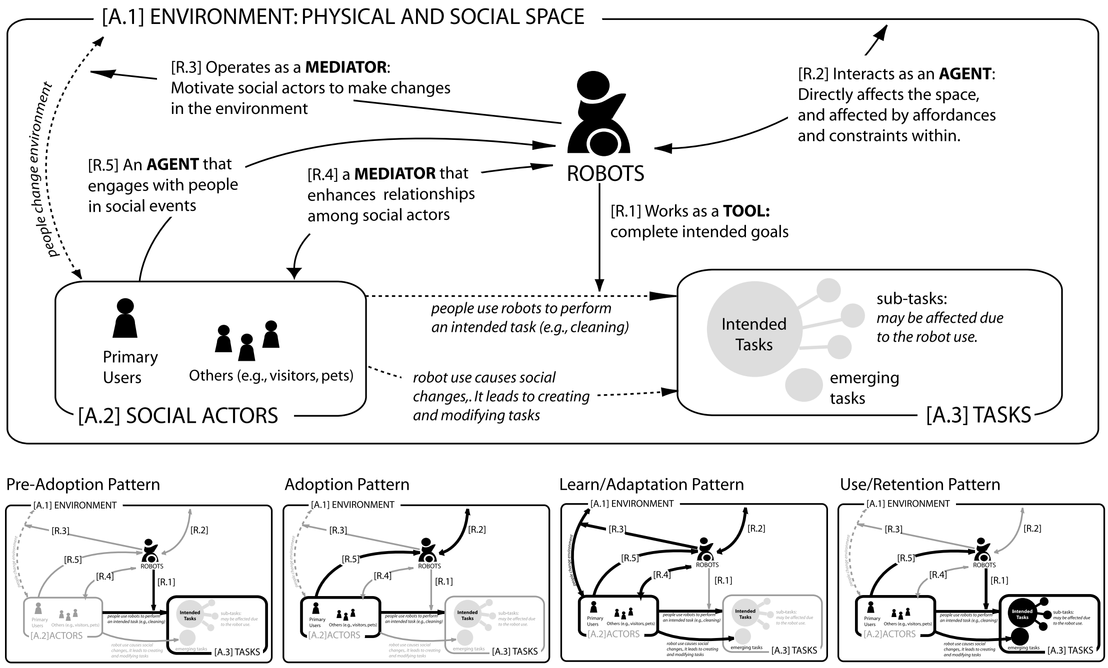


Figure 1.8: **The Domestic Robot Ecology** is an initial framework of domestic robot adoption; [taken from Sung et al. (2010)].

relationships can be of different nature. The robot can serve as a *tool* to perform tasks [R.1], as an *agent* that impacts the *environment* [R.2], as a *mediating factor* that motivates people to make changes in the environment [R.3], as a *mediator* that enhances social relationships within the household [R.4], and as an *agent* that engages with people in *social events* [R.5].

Regarding the process of adoption, the DRE framework also gives a holistic view of how the different relationships that the robot shapes change over time. Accordingly, the DRE framework identifies four temporal stages (or patterns) of how households adopt a domestic robot (see bottom of Figure 1.8): (1) **pre-adoption**, a stage in which people learn about the technology and form expectations and attitudes toward it; (2) **adoption**, a stage that refers to the first (initial) impression that people gain of a technology, when purchasing it and when interacting / using with it for the first time; (3) **adaptation**, a stage during which people learn more about the technology (*e.g.* by experimenting with it), and adapt the environment to better incorporate the technology; and (4) **use and retention**, a stage in which people begin to show a routine with the technology.

Background: The framework is based on a 6-month field study of 30 households that were given a vacuum cleaning robot. It takes traditional acceptance models (TAM) into account. The concept of ecology is based on the "product ecology" Forlizzi (2007b), which was also applied to analyzing the impact of a domestic robot on the home, seen as an ecology (Forlizzi and DiSalvo, 2006; Forlizzi, 2007a).

Limitations: The framework would need to be refined as domestic robots (and other technology) advance. For instance, the DRE does not take into account a robot's ability to communicate and coordinate with other technology and robots in the home. The framework does not make statements about concrete adoption factors in terms of characteristics of the robot or the household, including the household members.

Summary

Models and theories that focus on long-term adoption of technologies show that how users experience and use a system changes over time. Consequently, it is important to investigate acceptance in a longitudinal way. Empirical findings show the change in user experience and suggest that there are different phases / stages of adopting a technology / robot (Sung et al., 2010). However, it is not agreed upon how many phases this process takes, and how long these phases last. At least three phases seem to be characteristic of the adoption process:

- **pre-adoption** phase, (similar / equivalent to anticipation), a phase before the actual usage of the product, in which *knowledge* about the product is gained, *expectations* are built, and an *intention* to purchase the product is formed.
- **orientation and incorporation** phase(s), (similar / equivalent to initial adoption and adaptation, implementation), a phase that last from the initial experiences with a product, to trying out and learning how to use the device, making sense of it. (this phase may consist of several sub-phases)
- **identification** phase, (similar / equivalent to confirmation), a phase in which the adoption is continued, and the task in which the product functions cannot be imagined without the product.

Several aspects have been investigated in the dynamics of user experience over time, for instance people's **attitude**, **intention**, and their actual **usage behavior**. Growing user **familiarity** and, related to domestic environments, the **household life cycle** may account for changes in how a technology is adopted.

1.5 Technology and Robots in Domestic Environments

Domestic environments are receiving increasingly more attention as an application field for robots and also for HRI research. Even though domestic robots were envisioned many years ago, only recently have robots become robust enough to allow the execution of short- and long-term evaluations in domestic settings. Consequently, only few studies of robots in homes have been conducted so far, and rather little is known about what happens (in this broad sense) when robots enter into the home. In contrast, the so-called **domestication** of information and communication technology (ICT), such as the telephone, PC and Internet use is fairly well studied. In the following, we will give a brief overview of the domestication of technology and trends that may apply also to robots. Then we present related work on HRI in domestic environments, and outline the unique design challenges that people's homes bring along to robots and the research carried out in these settings.

1.5.1 Domestication and Social Shaping of Technology

There are three main themes in research of technology in the household: adoption, use, and impacts Brown (2008). As presented before, research on **technology adoption** has examined the factors associated with why households do and do not acquire a technology for home use. Research on **technology use** has examined the various tasks and activities that people engage in with household technology. Research in the area of **technology impacts** has examined the potential outcomes of using household technologies, both intended and unintended.

There is a recognition that the household is a rather complex social system, and standard theories of diffusion and adoption may not fully explain household adoption behaviors (Venkatesh, 2006). While the standard questions in diffusion theory refer to adoption patterns and the profiles of adopters, for instance, they say very little about usage patterns and user experiences. The concept of domestication emerged in the early 1990s from an empirical and theoretical project organized by Roger Silverstone in the U.K., and was influenced by the *Social Shaping of Technology* perspective (MacKenzie and Wajcman, 1985; Williams and Edge, 1996), which highlights that technology is affected at a fundamental level by the social context in which it develops. Concretely, users of a technology (*e.g.* household members) are perceived as having a dominant role in defining the nature, scope and functions of the technology. In its traditional sense **domestication** refers to the taming of a wild animal. Using the same metaphor, domestication of technology refers to the process in which users bring an artifact from the public realm to the private and 'tame' it, gain control, and shape or ascribe meaning to the artifact in the context of their daily lives. In other words, domestication is the process of the technology finding its place in the rest of the domestic life. This process of domestication of technology consists of four dimensions (see Haddon (2011)):

1. **Appropriation**, which means the negotiations and considerations that lead to the acquisition of the technology;
2. **Objectification**, which describes how the use of the technology is scheduled in people's routines and time structures;
3. **Incorporation**, which refers to how the technology is located spatially within the home;
4. **Conversion**, which deals with how the technology is mobilized as part of the user's identity and how he or she presents himself or herself to others (*e.g.* how one talks about and displays the technology).

The process of domestication comes along with a so-called **innovation by the user / consumer**, which implies, for instance *re-purposing*. The user may be creative in using and domesticating a technology in ways that were not intended by the designers (we come back to this in one of the following paragraphs). As Venkatesh (1996, p. 53) formulates it: *"Don't assume that what the technology can do in the household is the same as what the households wants to do with the technology."* Consequently, the technological innovation is not only a matter of engineering because the technology is also symbolic and aesthetic for the user and is a material and functional object (Silverstone and Haddon, 1996).

Studying the domestication / adoption of technology is characterized by mostly qualitative methods, such as observations, in-depth interviews, and long-term studies of households. Consequently, one of the strengths in the domestication approach lies in providing the context to people's technology decisions. However, there are also drawbacks. In general, domestication research is quite resource-consuming, as homes are a challenging terrain for research, and studies are time-consuming in terms of conduction but also concerning the analysis of the information gathered (Haddon, 2011; Williams and Edge, 1996). Further, Haddon mentions that another "problem" is that you can always add more context. These are probably some of the reasons why only a fairly limited number of domestication studies have taken place.

Why does the domestication perspective matter when studying the acceptance and adoption of domestic robots? Essentially, the domestication approach can provide contextual information about households and individuals to better appreciate why they use a technology in the way they do (Haddon, 2011). Information about people's wider values and aspirations, their general circumstances (*e.g.* their organization of time, the spaces in which they live, their financial situation) and their relationships with others (*e.g.* parents making rules about how their children can use technologies, social network commitments), can help formulate a broader understanding of people's different forms of engagement with technology. In other words, while the ultimate research interest is in technology, the domestication approach also relates the technology to the non-technological aspects of people's lives (Haddon, 2011). So far, most of the domestication studies included ICTs, and domestic robots are somewhat different to an ICT. However, theoretically and methodologically, the domestication perspective makes sense to the study of adoption of domestic robots – although differences due to the unique characteristics of robots and HRI may be expected.

1.5.2 Domesticated Technologies and Innovation by the User

Domestic technology, which may be seen as the pre-stage of domestic robotics, has developed quickly over the past 100 years. Hamill (2006) reviews that today, many of the duties of servants have been taken over by domestic appliances, which have reduced the need for human labor in the home.[15] The introduction and growing availability of electricity to households made the use of

[15] This is true, however, I have the impression that first domestic appliances replaced the household servants but now, other mobile technologies have made us that busy with work that we spend less time just being home, and are

domestic machines and appliances possible, and households could save their servants' wages.[16] As new technologies were adopted and adapted in the home (besides kitchen tools, mostly ICTs and entertainment technologies), they both changed and were changed by the social relations that they mediate (Bell et al., 2005). Bell et al. note that in the evolution of domestic technologies, there has been a strong emphasis on efficiency over quality: microwaves, for example, make food faster but not better. Also from the user-side, there seems to be a greater priority on entertainment technologies than on task-based technologies: In 2003, more people had a video recorder than a dishwasher (see Hamill (2006)).

Williams and Edge (1996) point out that there is a paucity of links between designers and potential users, which in turn leads to a lack of understanding of 'the housewife' as a possible user, and of 'her' needs. This means that domestic technologies may reflect technology-push rather than user-need; they do not really address the realities of domestic labor and have little appeal to many customers. According to the authors, this may be one of the reasons why the adoption of domestic IT has often fallen far short of expectations. Where products are embraced by households, research has stressed the active nature of consumption, involving decisions to purchase the technology and incorporate it within family routines (Williams and Edge, 1996). This domestication, as outlined above, often involves **innovation by the consumer** – using technology in ways not anticipated by the designer.

Taking the case of the home computer, the authors provide an illustration of how technology gets appropriated by domestic users. Though initially promoted as a means of carrying out various 'useful' activities (*e.g.* word processing, educational programs), this was largely subverted by boys, whose enormous interest in computer games has shaped the evolution of home computers, leading to the creation of a specialized market for these products. Similarly, also the Internet evolved during domestication, a process that Venkatesh (2006) describes as a reciprocal effect of household and technology, labeled as **co-evolution**. The author illustrates the evolution of the Internet itself along with the readiness and evolution of the three different living spaces of a household (physical, technological, social). Venkatesh concludes that the co-evolution of the artifacts and the users is a very important condition for the diffusion of technologies.

Domestication, including innovation by the user, is an interesting process as there is no one single user or household but many different ones that use a technology in many different ways: *"However, domestic users (and refusers) are not homogeneous; their responses are differentiated by gender, generation and class, and shaped in the complex social dynamics [...] of the family"* (Silverstone (1991), cited after Williams and Edge (1996)). Also Venkatesh (2006) underlines that specific household factors (*e.g.* life-cycle stage, presence of children, female household manager), as well as long-term changes in the use of the technology influence the process of domestication, and need to be considered.

hiring cleaning services and household helpers to actually use our domestic appliances for us ...

[16] An interesting article about how domestic appliances replaced much of the human labor in the home, is written by Hamill (2006). She also deals with the topics trust and control, as well as (non-)presence with respect to human servants and technologies. Also, Hamill discusses the question of how human and autonomous these technologies should be, to which we will come back later in this section.

Overall, domestication advocates to regard the home as an intelligent environment that shapes and is shaped by technology. As such, a household's "intelligence" presents opportunities for introducing new technologies in the home (Venkatesh, 2006). There seems to a shift from single domestic technological devices and home automation toward connected distributed or remote controlled systems. These developments may pave the way for domestic robots.

Home Automation, Smart Homes, Ecology of Technological Systems

Today, homes are full of domestic appliances that are, or could potentially become smart. There is growing interest in studying how these and other domestic technologies might be usefully linked to each other and to external agents, machines or humans.

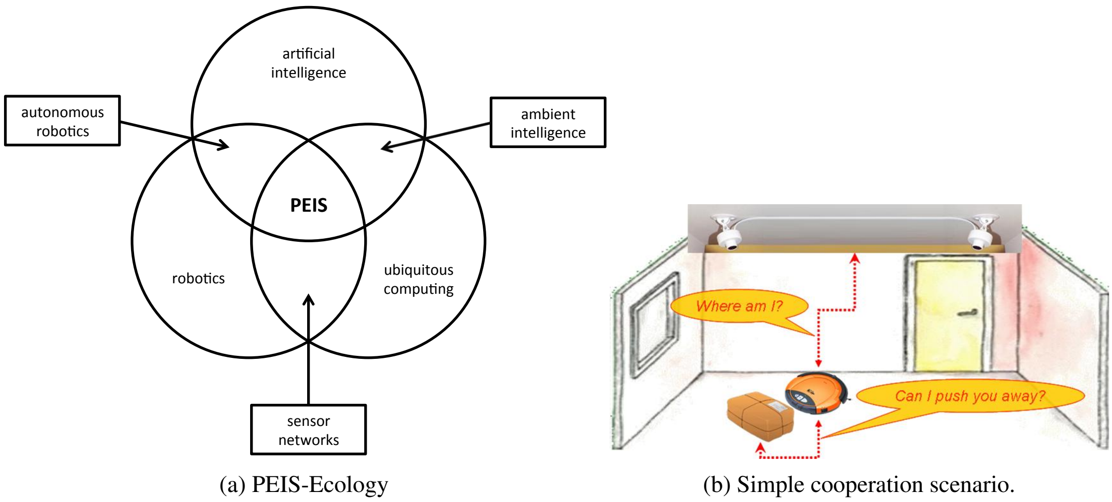
Home automation basically means automation of the home, housework or household activity. The **home automation** concept is based on the (electro-mechanical) automation of household tasks and controllable electrical appliances in the home (which has both developed a lot over the last 80 years). The main idea is to connect home appliances and features such as lighting or heating to a network (**networked home** (Venkatesh et al., 2003a)) and control it using computer and information technology. One of the advantages is a centralized control (often done remotely through a smartphone or tablet) of the network of systems.

One step further, when integrating technologies with the home environment, is putting some "intelligence" into the home automation, such that one could speak of a **smart home**, in which things are not only automated but show some sort of cognition. This progression from computers to smart homes appears to be logical (Venkatesh, 2006). The general trend seems to be that smart homes are the emerging intelligent environments and if only the home can behave with some level of intelligence, life can be easier and simpler. A smart home or house can be defined as *"a residence equipped with information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security, and entertainment through the management of technology within the home and connections to the world beyond"* (Aldrich, 2003, p. 17; in: Hamill (2006)). In other words, it is a home that is equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the needs of its inhabitants (Balta-Ozkan et al., 2013). Recent systems of home automation and appliances are able to communicate, and "sense" relevant happenings in the environment in order to "react" as desired. By this, home automation becomes "smart", and can provide improved convenience, comfort, energy efficiency, and security. Especially elderly and disabled people may benefit from smart home automation, as it can provide an increased quality of life; however, there is also the question of cost, usability, and acceptance. Balta-Ozkan et al. (2013) explored social barriers to the adoption of smart homes. Their research highlights the importance of barriers such as control, security, and cost. Further, participants mentioned concerns related to loss of control and apathy; reliability; the view of smart home technology being divisive, exclusive or irrelevant; privacy and data security; cost; and trust.[17] These may also be relevant aspects in regard of domestic robots.

A term that is often used similar to intelligent home automation is **domotics**, which on one hand stands for the combination of domestic and informatics, and on the other hand can be seen as a contraction of domestic robotics.

A concept which is similar to the smart home and which is relevant for the integration of domestic service robots in homes, is the so-called **PEIS-Ecology** (Saffiotti and Broxvall, 2005; Saffiotti et al., 2008). The authors imagine a concept in which physically embedded intelligent systems (PEIS) are connected to form an ecology. In their concept of an ecology of physically embedded intelligent systems (PEIS), they combine artificial intelligence, ubiquitous computing and robotics (see Figure 1.9). Research on PEIS is situated at the intersection of the sub-fields autonomous robotics, ambient intelligence, and sensor networks. In developing such a PEIS ecology, there are two main starting points. First, any system (or robot) in the environment is abstracted as a PEIS, a physical device which includes a number of functional components. A PEIS can be as simple as a toaster and as complex as a humanoid robot. Second, all individual PEIS can be connected by a uniform cooperation model, based on the notion of linking functional components. More precisely, each participating PEIS can use functionalities from other PEIS in the ecology in order to compensate or to complement its own. The power of a PEIS ecology does not come from the power of its constituent PEIS, but it emerges from their ability to interact and cooperate. As such, the PEIS-Ecology approach redefines the very notion of a robot to encompass the entire environment. Perception and manipulation of objects are thus replaced by direct communication

[17]The authors provide a comprehensive summary of the social barriers to the deployment and adoption of smart home technology. This list is interesting as it is combines aspects that were highlighted in the literature (both smart home and demand-side), articulated by experts, and mentioned by the public.



(a) PEIS-Ecology (b) Simple cooperation scenario.

Figure 1.9: **Ecology of Physically Embedded Intelligent Systems (PEIS-Ecology)** lays at the intersection of artificial intelligence, ubiquitous computing and robotics. Robots and other domestic appliances are individual PEIS. The concept's main idea is to form an ecology of several individual PEIS by connecting all systems; [adapted by and taken from Saffiotti and Broxvall (2005)].

between sub-systems in the environment. In the PEIS-Ecology vision, the robot would disappear in the environment quite in the same way as computers should disappear according to the well known vision of ubiquitous computing (Weiser, 1991).

Overall, regarding domestic technologies, one can observe that not only households have become more open to let ICTs and other technological devices enter into their home, but that also household technology has become more adapted. This trend is characterized by two visions: bringing more technology into the home, and making the home a more technological space. Venkatesh (2006) describes a tension between these two visions:

> *"[There is] a tension between two visions, the domestication of the virtual and the virtualization of the domestic. Both perspectives are legitimate, and as we move forward to explore the issues further, our task is not to choose between the two visions but to combine them both and produce a unified vision."*
> Venkatesh (2006, p. 194)

Maybe nowadays, this tension does not only concern the virtual but can be extend to the domestication of the robotic and the robotization of the domestic. However, robots itself present several unique dynamics that differ substantially from previous domesticated advanced technologies, and robot designers and producers must consider these differences systematically in ways that go beyond many existing ideas about technology acceptance (Young et al., 2008).

1.6 Introducing Robots into Household Routines

Domestic robots are fundamentally different from other common domestic applications of advanced technology such as the ubiquitous PC. Robots have an invasive physical presence and a unique interface paradigm: they actively and physically share spaces with people and display a level of autonomy and intelligence. Young et al. (2008) define a domestic robot to be

> *"a machine that (a) is designed to work with individuals and groups in their personal and public spaces, (b) has a dynamic spatial presence in those spaces, and (c) can "intelligently" interpret its environment and interact physically with it."*
> Young et al. (2008, p. 99)

Further, the authors note that a robot can alter its presence and influence its surroundings by moving itself or altering its morphology (such as turning its head or moving its arms). Often, the term *personal robot* is used synonymous to *domestic robot*. The addition *service* describes that the robot is primarily meant to carry out a task (a service), and is practical or, in other words, functional (*e.g.* in contrast to robotic toys).

Household routines are a promising application field for domestic service robots, with the goal of automating certain tasks or providing help to the user in carrying out the task. Routines are the very glue of everyday life (Tolmie et al., 2002), and nobody denies that machines are invented and put to use because they can possibly save us from drudgery, menial and repetitive tasks. But what are domestic routines and how should robots fit in there at all?

Tolmie et al. (2002) define routines as sequences of action that are simultaneously unremarkable and yet central to the realization of domestic life. The routine character of events is fundamentally undermined when to pay manifest attention to them prompts out some kind of special account for that attention. To mark something out is in many ways then the exact opposite of something having a routine character and to mark out something that is normally a routine has the consequence of generating a requirement to produce and account, explanation or rationale (Tolmie et al., 2002, p. 402). In one of our studies, namely the Roomba study (presented in Chapter 3), we studied peoples' routines of vacuum cleaning. One participant was using a monthly cell phone alert that reminded him of doing the vacuum cleaning. We can note that by marking out this activity in his agenda, he does not view vacuum cleaning as a routine. We can keep this in mind for later.
Research of routines is a challenge. It requires to recognize the subtle character of the often complex, yet unremarkable, details that surround our everyday routines (Tolmie et al., 2002). This in turn, places powerful requirements on any technology that might become embedded in such activities. The question is what it will really mean for technology and robots to fit comfortably within everyday routines and augment them without losing or disrupting the qualities that make them what they are. Similarly, the authors ask what it would mean for systems to utilize knowledge of peoples' routines themselves in order to deliver calm and context-sensitive support.

Rodney Brooks, director of MIT's Computer Science and Artificial Intelligence Laboratory (1997-2007), and co-founder and chief technology officer of iRobot Inc., has devoted a large portion of his career toward domesticating, quite literally, the potentials of artificial life (Anderson, 2009). The (self-proclaimed) fantasy Brooks offers – a fantasy that seems to be coming true as iRobot launches each new product – is that of a household *ecology of robots*, in which, similar to the before-mentioned PEIS-Ecology, numerous machines and the relations between them create a network of interactions that, in turn, produce a comprehensive environment in a continual state of modulating behavior (Anderson, 2009). Soon this fantasy might include domestic robots that clean the kitchen and dining room tables, scrub windowsills, pick up the laundry, get the groceries, do the dishes, and so on. Accordingly, Brooks writes: *"It is not a top-down engineered solution where all contingencies are accounted for an planned around. Rather, the house gets cleaned by an emergent set of behaviors, driven by robots that have no explicit understanding of what is going on"* (Brooks, 2002, p. 120; in: Anderson (2009)).

As robots start to enter homes, a key question for roboticists is: What are the key dynamics and factors that influence how people perceive, understand, and ultimately accept robots?

Factors that Impact how People Perceive (Using) Domestic Robots

The context of the home is a particular one when it comes to decide whether to purchase and adopt a technology. To understand people's perception and acceptance of (using) domestic robots, one has to keep in mind the particularities of robots and of the domestic environment. In comparison to other contexts (*e.g.* the workplace), household decisions have a more normative structure and are highly affected by social pressure, views of relevant others, and media (Venkatesh and Brown, 2001). These secondary sources (*e.g.* TV and newspapers) have a particularly strong impact on the decision making of *early adopters* because there are fewer informed friends and families to exert pressure, and the media often provides the first impressions (Rogers, 1995). Also, both Venkatesh and Brown (2001) and Rogers (1995) agree that the perception of **hedonic gains / value** (*i.e.* entertainment, fun, pleasure), as well as **social gains** derived form a product (through both possession and use) play a strong role. These social gains can be related to family life, friends and social network influence, for instance, including public recognition or being a knowledge reference within a social group (Venkatesh and Davis, 2000). Moreover, from an attitudinal perspective, the home has a strong focus on factors on perceived barriers or rules surrounding adoption, such as lack of knowledge (*e.g.* inability to properly use a product), prohibitive cost, depreciation, maintenance, space requirements, or regulations requiring / restricting adoption of technology. Venkatesh and Brown (2001) found that non-adopters primarily cited fears of technology obsolescence.

It has been accepted that innovation in consumer environments is highly dependent upon factors of socialization that merge utility with symbolic and cultural factors, and that this involves subtle transfers of knowledge from consumers to producers about emerging social trends and preferences (Young et al., 2008). Young et al. argue that one of the most important and unique barriers to the widespread domestic adoption of robotics is an especially complex socialization process (Young et al., 2008). The problems of technology acceptance are far more significant in a domestic environment than in an industrial one.

> *"By design, it is intended that domestic robots will enter into our personal spaces, where their mere physical presence will have an effect on the space they occupy [...]. Thus, the socialization of robots in the domestic context is far more than a conventional "human factors" design problem, in which barriers are overcome through the design of interfaces, infrastructures and routines. Neither is it merely a conventional "diffusion" problem whereby mass markets are created through positive feedback as more consumers experience and adopt a technology [...]. Instead, [...] the domestic socialization of robots is largely dependent upon subjective consumer perceptions of what robots are, how they work and what exactly they are and are not capable of doing in a domestic environment."* Young et al. (2008, p. 96)

Young et al. (2008) present several factors that are likely to influence how users perceive domestic robots:

1. **Safety**: taking into account that robots have an autonomous physical presence and as such provide a level of potential danger.
2. **Accessibility and usability**: the capabilities and complexity of robots raises serious accessibility concerns. Fears such as lack of knowledge and usability on one hand, and space requirements within the home and affordability, maintenance and obsolescence, as well as legal barriers and regulations play a crucial role.
3. **Practical benefits**: highlighting that utility gains really matter to people. Robots must not only be useful, but need to fit properly into the social structures of a given particular lifestyle.
4. **Fun**: recognizing that domestic robots may not only bring direct fun but also secondary fun (more free time). Further, companionship and comfort are basic human needs that robots may be able to meet. Perhaps, similar to the way games help drive PC technology, entertainment and toy robots may serve as a catalyst for the entire domain.
5. **Social pressures**: twofold social pressures can be expected with domestic service robots. On one hand, social pressures might motivate adoption, *e.g.* for a family to appear to be "modern", on the other hand, negative pressures such as appearing lazy or wasteful can be expected.
6. **Status gains**: with a domestic robot one may be perceived as a cutting-edge person or household. This is a factor that has been found important for adoption of technologies in the past.
7. **Social intelligence**: considering people's tendency to anthropomorphize robots. An expectation of social intelligence may inherently result from a robot's design, which on one hand can leverage robots as being easy to communicate with, but on the other hand can lead to disappointment when expectations are not met.

Most of these factors are well known from the previously mentioned technology acceptance models (see Section 1.4). Another factor that is not specifically mentioned here, but appears important, is the **sustainability** of the domestic robot. Sustainability comes even more into focus when extended periods of time are considered, and the robot or parts of it need maintenance or being replaced. The sustainability of the domestic robot may influence how users perceive the robot.

Young et al. (2008) outlines further that besides the aforementioned factors that directly affect acceptance, also the perception of these factors is meaningful to domestic users. How people shape their understandings and perceptions of the aforementioned factors is likely to be affected by:

1. **Previous experience**, including personally-experienced lifetime actions, personally inferred beliefs, education, and probably also previous experience with animals and children;

2. **Media**, as important source of information (especially when previous experience is limited), including science-fiction-like literature, movies, and television, as well as more fact-oriented news sources;

3. **Personal social network**: opinions and perspectives of friends, neighbors, family;

4. **Robot design methodology**: including physical appearance, actions, interface, and all other aspects of design.

Also these influencing or mediating factors are known from traditional models of technology acceptance, however, the social aspect and expected impacts of introducing robots in the home environment need to be highlighted. Accordingly, the factors related to social acceptance and influence of robots in homes particularly challenge the design of robots.

Summary

The domestication of robots seems to be overall similar to how other technologies were (and are) domesticated. However, there are several influencing or mediating factors that go beyond traditional models of technology acceptance in households. Again, this differences are related to the unique characteristics of robots, and the resulting particularities of the interaction with the human(s) and the shared environment. For instance, social aspects, previous experience, and the manifold impacts that the user expects of purchasing and using a domestic robot are special. There is a need to study these aspects in more detail, and especially over extended periods of time.

Yet, despite ongoing industrial interest to introduce robots in homes, we do not have the expected robotic servants or other kinds of multi-purpose robots in our homes. There is to mention the current success of vacuum cleaning robots, which have been introduced to the consumer market several years ago. However, at this point of time, we cannot say whether these appliances got lastingly adopted and integrated in the home. However, since some robots are commercially available for fairly low cost, this offers a new possibility for HRI studies, including ordinary people being studied using real robots in their ordinary homes.

2 Related Work

"The general population, arguably, has a practical understanding of what a robot is, but most people would have difficulty coming up with a clear definition. [...] It is yet not clear, how domestic users on a large scale respond to robots that enter their personal spaces and how this interpretation will relate to human perception of other kinds of robots (e.g., military robots). Will domestic robots be seen as just another electronic appliance along with the microwave and home theater system? Will people relate more strongly to science-fiction-inspired concepts of domestic robots? Or will domestic robots trigger a new and unique response?"
Young et al. (2008, p. 98f)

This chapter covers the related work on people's attitudes towards robots in daily life and on HRI in domestic environments. More specifically, we first summarize survey studies on people's perception and expectations of (domestic) robots (Section 2.1). Then we present findings of interaction studies and long-term field studies of robots in homes (Section 2.2). Related to this, we discuss the challenges that research in the wild, and long-term studies, in particular, bring along and how research can tackle these challenges. This is followed by a section about anthropomorphism, which we see as a special kind of social (human-like) engagement with robots (Section 2.3). Finally, we give a brief overview of child-robot interaction (Section 2.4) and highlight the particularities when doing research with children.

2.1 People's Perception, Attitudes, and Expectations of Robots

Several survey studies have been carried out to broadly assess people's perception of robots and to understand their attitudes and expectations towards deploying and using a robot in their home. Some research specifically addressed negative attitudes and anxiety towards robots (Nomura et al., 2004; de Graaf and Allouch, 2013), cultural differences (Kaplan, 2004; Bartneck et al., 2005; MacDorman et al., 2009), or variations between gender, age, and expertise with technology (Scopelliti et al., 2005). Most of the studies involving a human-centered approach with questionnaires or interviews are focused on a specific project, specific robot(s)[1], or a limited user group in a particular context (*e.g.* elderly people in care-centers (Heerink, 2011)). This research is often exploratory in nature, with small sample size and a specific scope and context. In our literature review, we are less specific but would like provide a general overview on people's perception of domestic robots. We focus on research in Europe (for an overview of the main studies reported here, see Table 2.1) but highlight also relevant findings from other regions.

People's general attitudes and expectations of robots

Various surveys across Europe revealed that people's general view of robots is positive or at least neutral (Arras and Cerqui, 2005; Scopelliti et al., 2005; Ray et al., 2008; European Commission, 2012). This is despite the fact that people's view of robots was found to be strongly influenced by media and science fiction (Khan, 1998).[2] This may explain why the two most reported fears related to robots are "humans being replaced by robots" and "loss of control or dysfunction of the robot" (Ray et al., 2008). In their view of robots, people with less experience with technology (often elderly people) tend to be more skeptical not being able to use a domestic robot (Scopelliti et al., 2005). At the same time, elderly people are most positive toward the idea of receiving help from a robot and they believe that a robot could contribute to their daily life (Arras and Cerqui, 2005).

In terms of expectations of domestic robots, it has been found that within their concept of robots, people distinguish between "domestic robots" and the great mass of "other robots" (Forlizzi and DiSalvo, 2006). This is important. People tend to have fairly clear and high expectations of robots in general but not when it comes to a specific domestic robot (*i.e.* Roomba) and its practical functionality. Dautenhahn et al. (2005) described that people tend to have difficulties in imagining the precise functions of a robot in the home. Generally, participants expect a domestic robot to be useful, to provide help, and to be intelligent and able to learn (Ray et al., 2008; Sung et al., 2009b).

It is important that the researcher assesses and understands people's specific expectations and attitudes towards a robot, to be able to make sense of their reaction during an HRI study. Therefore, people's perception of robots should be assessed beforehand. Forlizzi and DiSalvo (2006) argue that expectations can powerfully shape people's initial experience with a robot, which in turn is important for long-term adoption.

[1] An interesting study about what task people imagine for a domestic robot is presented in Lohse et al. (2008). Using an online survey, the authors compare four robots, namely AIBO, iCat, BIRON, and BARTHOC, and investigate the influence of the appearance and capabilities of the robots, on what type of domestic applications people ascribe to those robots.

[2] A compact overview of robots appearing in literature and science fiction is provided in Khan (1998).

Authors (year) (Place)	Research goal, focus, purpose	Methodology & sample	Overview main results
Khan (1998) (Sweden)	Investigate people's attitudes toward intelligent service robots.	Interviews (n = 6), pre-study Survey questionnaire (n = 134)	• Attitudes are based on media and science fiction • Robot design preferences: machine-like, serious, round shape • Interaction preferences: verbal communication (human-like voice)
Dautenhahn et al. (2005) (UK)	Explore people's perception and attitudes toward the idea of a future robot companion for the home.	Questionnaires and interaction trials (n = 28)	• Robot design preferences: machine-like, as assistant but not a friend • Tasks: household tasks preferred to social tasks • Interaction preferences: human-like communication (speech)
Arras & Cerqui (2005) (Switzerland)	Study people's attitudes toward the idea of sharing their life and body with robots.	Survey questionnaire (n = 2042) (conducted at a trade fair)	• General population has neutral or positive image of robots, robots are associated with classical machine qualities • Robot design preferences: human-like is not desired
Scopelliti et al. (2005) (Italy)	Study acceptability of robotic devices in home settings, with a focus on age differences.	Interviews (n = 23), pre-study Survey questionnaire (n = 120)	• In general positive toward home technologies and robots; women slightly more skeptical, elderly express more mistrust • Robot design preferences: different age groups prefer different design; young people view robot as lively, amusing and humanoid; older people view robot as cold, serious, with slow movements • Interaction preferences: age differences; young people prefer human-like communication (speech); older people prefer text-based communication (keyboard)
Ray et al. (2008) (Switzerland)	Explore people's perception of robots, with a focus on domestic use.	Interviews (n = 11), pre-study Questionnaires (n = 240)	• In general positive attitude towards robots • Robot design preferences: machine-like, small • Interaction preferences: human-like communication (speech)
"Special Euro-barometer 382" (2012) (27 countries within European Union)	Survey into public attitudes towards robots. Gauge public opinions towards robots by measuring public perceptions, acceptance levels, worries and reservations.	Interviews (n = 26751)	• Interest in scientific and technological developments has decreased since 2010 • The image of a robot is more likely to be that of an autonomous machine used in the workplace than a human-like machine that helps in the home • In general positive attitude towards robots; robots are necessary and good but also require careful management • Tasks: Robots should be used as a priority for tasks that are too difficult or too dangerous for humans; Robots should not be used to care for people

Table 2.1: **Overview of survey studies on people's perception of and attitudes towards robots (in Europe).**

Attitudes towards robot assistance in different tasks

In terms of what tasks robots should do in the home, the results of the surveys of Khan (1998); Dautenhahn et al. (2005); Ray et al. (2008) are similar. They suggest that people can imagine being assisted by a robot in typical routine tasks, such as vacuum cleaning, window cleaning, floor cleaning, moving heavy things, ironing, dust cleaning, or dish washing. In contrast, people do not want assistance from a robot in the following tasks: baby sitting, watching cat / dog, reading aloud, cooking. (Data suggests that for some tasks, men are more likely to accept help from a robot than women (Khan, 1998).) Similar results concerning occupations for robots are reported in a study carried out in the U.S. (Takayama et al., 2008). The authors found that public opinion favored robots for jobs that require memorization, keen perceptual skills, and service-orientation. Contrary, people were preferred for occupations that require artistry, evaluation, judgment and diplomacy. In general, the survey revealed that people felt more positively toward robots doing occupations *with* people rather than *in place of* people. Overall, the various surveys suggest that tasks typically involving some kind of social relationship or care are much less desired as being carried out by a robot, than "simple" routine household tasks.[3] A large-scale survey across Europe, carried out on behalf of the European Commission, confirmed this finding (European Commission, 2012).

Domestic robot design: appearance and autonomy

In general (not specifically related to domestic robots), people imagine a robot as either strongly anthropomorphic (*e.g.* with a human-like embodiment, arms, legs, and a head), or very mechanistic (Khan, 1998). To what degree a robot should look (and act) like a human has been extensively discussed in the design of robots and in terms of human-robot interaction. We do not discuss about the different effects of anthropomorphic form here. In short, anthropomorphic design (human-like embodiment but also social cues emitted by the robot, for instance) can on one hand have a positive effect on people's acceptance, and facilitate interaction with the robot. On the other hand, anthropomorphic design can also have strong negative effects, and lead people to reject the robot or even feel revulsion toward it. Commonly, a human-like design increases people's expectations of the robot, what in turn often has a negative consequence if the robot does not meet these expectations. *"It seems that if a robot cannot comply with the user's expectations, they will be disappointed and unengaged with the robot. If a robot closely resembles a human in appearance but then does not behave like one, there is the danger of the human-robot interaction breaking down."* Dautenhahn et al. (2005, p. 1192) But what kind of design do people prefer for domestic robots?[4] Findings were mainly consistent on this aspect: a machine-like design is preferred over a human-like design. In the survey by Khan (1998) participants favored a robot with machine-like appearance but personally designed, somewhat colorful and round-shaped.

[3] Tasks that are simple for humans, are not necessarily simple for robots.

[4] In terms of human-like robot design, it is possible that people's preferences depend on factors like culture, age, gender, expertise, profession as well as on the task of the robot. For instance, Scopelliti et al. (2005) highlighted different preferences for different age groups.

Similarly, also Dautenhahn et al. (2005); Arras and Cerqui (2005); Ray et al. (2008) as well as the Eurobarometer survey (European Commission, 2012) described that people do not want robotic household devices to be very human-like.

The degree of autonomy is another central question in the design of domestic robots: How much should the robot do on its own without any intervention by the human user? This, of course, depends on the task. In general, it is argued that the focus should not be on full robot autonomy, by replacing human labor with machines, but rather on supporting people through technology (Bannon, 2011). People do not want to give much autonomy to a domestic robot (Hamill, 2006) but favor a robot that is predictable, controllable and that supports the user rather than fully replacing them in household tasks. In a survey, Takayama et al. (2008) found that people would feel more positively toward robots doing occupations with people rather than in place of people. A possible explanation for this is that people prefer having the feeling of control over themselves and their environment (the home), and consequently, also over their household devices (Hamill, 2006). This holds implications for the design of domestic technologies and robots: *"The robot should allow people [...] to feel like they have control ..."* Pantofaru et al. (2012). For instance, despite the wish to have a household robot that is "intelligent", participants in the study of Sung et al. (2009b) did not want a robot to have the power of decision-making, such as being able to buy and sell assets. Also, most people want to be able to understand the logic behind technological devices, and therefore it is not a surprise that a predictable and controllable robot is desired (Dautenhahn et al., 2005). In terms of robot personality, people imagine a serious robot (Khan, 1998), which is considerable and polite (Dautenhahn et al., 2005).

Communication with a robot

In terms of how people want to communicate with a robot, studies reported consistently people's preference for a human-like and natural mode, namely speech (Dautenhahn et al., 2005; Scopelliti et al., 2005; Ray et al., 2008). In the survey by Khan (1998) participants preferred direct speech over written commands, or interacting with the robot via a touchscreen or using gestures. In terms of characteristics of the robot's voice, respondents favored a human-like voice that is neutral with respect to gender and age. To get a robot's attention, participants could imagine calling the robot by its name, as well as using a remote control or a specific verbal command.

Summary General surveys have been conducted to determine people's expectations and attitudes towards robots and domestic robots, in particular. It was consistently found that people of all ages and genders are generally positive toward the idea of domestic robots. Those being less familiar and savvy in using technologies express more distrust towards using a domestic robot (Scopelliti et al., 2005). (In the next paragraph, we see that this relates to the demographic profile of domestic robot owners). People can imagine support and help from a domestic robot in some basic household or other mundane tasks, but not with tasks that require care or social skills. The majority prefers a service robot with a rather machine-like appearance but a somewhat personal design. Interestingly, although people do not necessarily want a domestic robot to look very human-like, they would like to communicate with the robot in a human-like way; speech was the preferred mode of communication. Most people want a robot to be fully controllable and predictable. Dautenhahn et al. (2005, p. 1196) concludes that:

> *"On one level, any technology for the home should be controllable, in that the user should be able to instruct the device to perform requested actions. However, at the same time, any device should not necessarily require constant supervision, or it ceases to be an aid and instead becomes at best an interface to a task, and at worst something which slows the user down."*

We have to keep in mind that people perceive *domestic robots* not the same as *robots in general*. Also their expectations of both are different (Forlizzi and DiSalvo, 2006). Young et al. (2008) suggest that domestic robots are perceived as as a new kind of entity, *i.e.* a vacuum cleaning robot is not perceived as a usual vacuum cleaner and also not as a robot in general – it may be somehow both but still more than that. This makes it important to study people's perception of and reaction to domestic robots in more detail, for instance, by means of interaction studies.

2.2 Human-Robot Interaction Studies in Domestic Environments

In the previous section, we have outlined results from survey studies about people's perception and their expectations of domestic robots. We highlighted their specific preferences of a household robot. This understanding gives us the context for interpreting findings of research that investigates how humans and robots interact in real. Before we give an overview of interaction studies with domestic robots in people's homes, we first report on research that investigated the demographic profile of users of vacuum cleaning robots and the respective ways in which this robot is used. These results are of particular relevance for the "Roomba Study" presented in Chapter 3.

2.2.1 Domestic Service Robot User Profiles and Usage Patterns

Who is the typical owner of a domestic service robot and what are the demographic characteristics of this user group? Sung et al. assessed the user profiles and usage patterns of vacuum cleaning robots in an online survey among 379 Roomba owners (from the U.S., mainly). Data suggests that Roomba users are equally likely men and women, and tend to be younger (more than half of the respondents were between 18-29 years) with higher levels of education or technical backgrounds (Sung et al., 2008). These findings relate to the aforementioned main results of surveys on people's perception of robots: mostly, no significant gender differences were found but elder people and those less experienced with technology expressed more skepticism; consequently, they may not be equally well presented as users of a domestic robot. Half of the Roomba owners who took part in Sung *et. al*'s survey lived with one or more pets and those with children at home expressed greater satisfaction with the robot's performance. This suggests that the composition of a household influences how people use and experience a domestic robot (Forlizzi, 2007a).

Concerning the usage of vacuum cleaning robots, (Sung et al., 2008) found that a huge proportion of people cleans weekly and that the frequency tends to increase with using Roomba. This seems to be due to the fact that with Roomba people clean more regularly, also during the week, when they are not at home. The authors reported that the majority of survey respondents (64 %) still vacuumed manually, in addition to using Roomba, thus the robot did not replace the manual vacuum cleaner. Sung *et al.*'s survey data further suggested that the more people have to follow up with manual vacuuming, the less satisfied they are with Roomba. To help Roomba clean, householders made physical modifications to their homes (referred to as *roombarization*), such as clearing up wires, changing furniture layout, and tucking in rug tassel. Kim et al. found a discrepancy between the cleaning path participants in Korea used when manually vacuuming, and the paths chosen by vacuum cleaning robots (Kim et al., 2007). Specifically, the actual user cleans with methods unique to specific areas of the house, rather than by following a technically optimal path. Based on this, the authors suggest that a robot's path-planning method should use not only a layered map but also a cleaning area designation method reflecting each area's characteristics (personalized for each home or user). This goes along with people's expectation to have an intelligent domestic robot that is able to learn and adapt to its environment (Forlizzi and DiSalvo, 2006). Consequently, it is suggested to adapt the robot's path planning to the specific area of the home and according to user needs, as the user tends to use area specific methods for vacuuming (Kim et al., 2007). Sung et al. (2008) further investigated how common non-cleaning activities associated with Roomba are. For instance, it has been reported that people name their Roomba and ascribe personality and gender to it. The survey showed that most of the Roomba owners are watching Roomba running for fun or give a demonstration to others. However, results indicated relatively low rates of users treating Roomba as a living entity. Giving Roomba gender was most common, but only few people reported naming their Roomba (among them, most had multiple Roombas). Interestingly, Sung et al. found that those who engaged in such social activities had significantly higher rates of satisfaction with the robot. This important finding is in line with acceptance theories that highlight the facilitation influence of social factors during the adoption process (*e.g.* social gains). A similar relationship between social factors and acceptance was also described by Klamer et al. (2011). We come back to social engagement with robots later. A fact that we need to keep in mind about the identified Roomba user profile is, that half of the survey respondents owned Roomba for less than 6 months, and only 21 % have been using it for longer than a year. This means that the profile and usage patterns may reflect somewhat short-term usage and satisfaction rather than real long-term usage (relative to the time span that we would consider as long-term usage of other domestic service machines and technologies, such as the dishwasher, washing machine, or manual vacuum cleaner).[5]

[5] In HRI, there exists no definition of when long-term usage starts. It probably depends on whether we view the robot as "a robot", then already 10 days or 2 months may be considered as long-term, or if we view the robot as "a household device", then a longer time span may be considered.

2.2.2 Long-term Interaction Studies in Homes

The following paragraphs give an overview of studies that investigated how humans and robots interact with each other in the domestic environment. Most of this research openly explored how people accept, use, and integrate a robot in their home. Related to our research questions, we focus on long-term studies about robots being used in a variety of households, including families. Table 2.2 (page 59) gives an overview of the main studies on which we report here.[6] We do not specifically address social robots but are more interested in exploring the social dynamics elicited by domestic robots that are *not* particularly made to act socially, such as cleaning robots.
Only few long-term studies of robots in people's homes exists. This may be due to the fact that robots have only recently become robust enough to be deployed in homes. Further, there are challenges when doing research "in the wild", especially in terms of longitudinal research. We present the main challenges in the following paragraph, before reporting on the findings of these studies.

Challenges of (Longitudinal) Research "in the Wild"

Long-term studies with robots in homes ("in the wild") are rare. There are three main reasons for this: First, robots have only recently become robust enough to allow for studies in uncontrolled settings, involving naïve users. Second, studies in domestic settings pose many challenges to the researcher and the experimental setup due to privacy issues and consequent lack of control of external variables. There is a gap between the researcher's wish to measure as many things as possible and being constrained by the private nature of the home, as well as the time the researcher can effectively spend in the home to do observations and capture data. Third, studies on the usage of service robots, like a vacuuming robot, often try to measure changes in an activity that can be considered a "routine" (cleaning). Generally, routines and changes of routines are hard to study and to measure (as described in Section 1.6). The researcher is required to uncover information that may not be very conscious to the participants. Further, the way how household routines are done may be very personal and deeply rooted in the participant's personal convictions behind housekeeping.

Thus, evaluating users' subjective experiences with a robot in their home requires more original data collection methods than in any other environment and researchers have to come up with novel ways to gather interaction information while keeping user's privacy. (Leite, 2013). How can researchers master these challenges? Sung et al. (2009a) reported on the methods and techniques that they used during their 6-months field study of 30 households that were using Roombas. We can take this as a good example of how to set up and carry out a long-term study in a domestic environment. In terms of methodology used, the authors proposed a combination of several data collection methods in order to capture people's routines and interaction with the robot. Each

[6] We do not present studies that have been conducted in other settings, such as schools or elder care centers. A good overview of long-term HRI studies in a variety of application domains is provided by Leite et al. (2013a); Leite (2013).

household was visited five times during the 6-month period, and at each visit, semi-structured interviews were conducted and enhanced with various qualitative methods. For instance, the authors asked participants to make drawings, and used probing techniques, as well as activity cards, on which they checked the activities that they carried our related to the robot. These techniques helped people to talk about their cleaning routine and their experience with the robot. The authors also discuss that researchers need to carefully think about any kind of intervention that they do in the participants' homes, in order to not create unnaturalness. For this reason, Sung et al. (2009a) decided not to use logging data, not to do remote video/audio recordings, and not to make modifications to the Roomba. Researchers need to spend a considerable amount of time to carefully design a long-term study in homes. The authors further suggest that such a study should span over 2 months at least, in order to be able to observe adoption and natural human-robot interaction beyond the novelty effects have worn off. There were fewer changes in how the robot was used and experienced from two to six months than from two weeks to two months. This suggests that participants' relationship with the robot whether positive of negative had stabilized.

Also Leite (2013) conducted a series of longitudinal field studies with an interactive robot that was playing chess with children. The study took place in a school where children had their chess playing classes. Focusing on long-term engagement with the robot, Leite makes several suggestions for conducting long-term interaction studies:

- Sample size and number of interaction sessions should be reasonable to allow complete data analysis. The time and effort required to analyze large amounts of data needs to be taken into account. Qualitative methods are more valuable, yet more time consuming.
- Use control conditions carefully. Most of the existing long-term studies do not have a control condition. This is not only because most of them were exploratory, but also because user experience over time can already be considered a strong independent variable.
- Data collection methods should take into account the environment and types of users of the study. While video recordings may be appropriate for studies in public spaces, they are not very suitable for domestic settings.

The last item that Leite mentions, says that it is important to adapt the data collection methods to the study participants. An adaptation to the participants is also required in terms of the techniques that are used, for instance, different data collection techniques may be suited for adults than for children. We come back to the particularities of doing research with children, later.

Summing it up, HRI researchers agreed that research "in the wild", or in other words, research in ecologically valid settings, brings along a trade-off *"between the structures imposed by experimental design and the desire for removal of such constraints that inhibit interaction depth, and hence engagement"* (Ros et al., 2011, p. 335). This requires a careful balance. Similarly, Dautenhahn et al. (2005) conclude that

> *"[...] one has to be aware that in any HRI study it is practically and methodologically impossible to control for all possibly relevant factors that might influence an experiment, as well as providing a large and balanced sample size and rigorous analysis. Thus, exploratory studies [...] while they often raise more questions they are able to answer conclusively [...], serve an important role in HRI research: they can provide a starting point for identifying relevant future research directions that then need to be investigated in more depth in focussed* [sic!] *studies."* Dautenhahn et al. (2005, p. 1197)

Overview of the Long-term Studies with Robots in People's Homes

The Roomba vacuum cleaning robot is one of the most widely deployed domestic robots and has been subject to a series of field studies and ethnographic research in the home (mostly in the U.S.). This research was done by two groups at Carnegie Mellon University and Georgia Institute of Technology, respectively.

In 2006, Forlizzi and DiSalvo (2006) conducted two ethnographic studies involving 14 households that were using Roombas during several weeks. They applied an ecological approach to broadly explore the use of domestic service robots and to determine how autonomous mobile robots might "fit" into homes. By "home ecology", the authors understand the domestic environment formed by people, practices and products, as well as their interactions (which are characterized by a specific social and cultural context of use). The ethnographic research should shed light on how the different parts of the home ecology influenced the use of the robot and were impacted by it in turn. Findings revealed that the expectations which people had formed beforehand, shaped their initial experience with the robot and determined in what matters they evaluated it (*e.g.* in terms of intelligence). Concerning the usage, the authors found that Roomba influenced people's cleaning practices: the robot supported opportunistic cleaning and multitasking, as well as planned cleaning. Similarly, also Sung et al. (2008) later reported that Roomba increased people's cleaning frequency. In terms of the home environment, Forlizzi and DiSalvo (2006) found that the physical space of the home influences how the robot is used. More concretely, the physical space impacted the functioning of the Roomba which often led to the issue of intervention from the user by, most commonly, creating or removing obstacles (*e.g.* to keep Roomba in one spot and away from another spot). The authors discussed that a vacuum cleaning robot is perceived differently than other cleaning products: it holds not only a functional value to people but also an aesthetic and symbolic one. By using the robot, people tend to create social relationships with the robot. Forlizzi and DiSalvo propose that the introduction of a robot into a household is critical, and that homes and service robots must adapt to each other.

Focusing on the social aspects of robot use, which she discovered in the aforementioned study, Forlizzi conducted another ethnographic study comparing the Roomba to a manual vacuum cleaner (Forlizzi, 2007a). Each three families received one of the two vacuum cleaners. Usage was studied by home visits and interviews (enhanced with qualitative techniques similar to

Authors (year) (Place)	Robot Environment	Time frame	Research goal, focus, purpose	Methodology & sample	Overview main results
Forlizzi & DiSalvo (2006) (U.S.)	Roomba People's homes	3-6 weeks	Apply an ecological approach to broadly explore the use of domestic service robots in the home ecology (people, practices, products).	Sample: n = 14 households Measures: exploratory study, expectations, ecological view Methods: home visits, interviews	• Expectations shape initial experience • Roomba affected the activity of cleaning (supporting opportunistic cleaning, multi-tasking and planned cleaning) • Physical environment influences how robot is used • How robot is introduced is critical • Use of robots becomes social • Homes and robots must adapt to each other
Forlizzi (2007) (U.S.)	Roomba Hoover Flair stick vacuum cleaner People's homes	1 month (follow ups during 12 months)	Understand the social impact of robotic technologies in homes.	Sample: n = 6 families Measures: ecological view Methods: home visits, interviews	• While the Flair had little impact, the Roomba changed people, cleaning activities, and other product use. • Roomba but not the Flair encouraged long-term usage. • People described the robot in aesthetic and social terms.
Sung *et al.* (2009, 2010) (U.S.)	Roomba People's homes	6 months	Study adoption patterns, usage, and impact of domestic service robot on household, people, and related tasks (cleaning).	Sample: n= 30 households Measures: adoption process, ecological view Methods: home visits, interviews, observations, probing techniques	• After 2 months stable interactions can be observed • Several techniques should be complemented to capture people's routines at home • Domestic Robot Ecology framework (user experience and robot's impact on household at different stages of adoption)
Fernaeus *et al*. (2010) (Sweden)	Pleo People's homes	2-10 months	Explore discrepancy between expectations and long-term adoption of robot (novelty effect).	Sample: n = 6 families Measures: exploratory study, willingness to use robot (time) Methods: interviews, video recordings and photos	• Initial expectations about Pleo were not met (for both assumptions robot as pet, robot as toy) • After novelty effect, participants played with the robot only occasionally

Table 2.2: **Overview of HRI long-term studies in domestic environments.** [adapted and extended by Leite (2013)].

probing) during one month and follow ups were done until 12 months after the introduction of the new vacuum cleaner (either Roomba or Flair). An analysis of participants' home ecologies (before the introduction of the new vacuum cleaner) suggested that people's cleaning routine and their perception of cleaning activities is based on gender, age, and household composition. Overall, with the usage of the new vacuum cleaner, findings showed that the Roomba *"had substantial and lasting impact on people, activities, and the use of other cleaning products within an existing product ecology"* (Forlizzi, 2007a). This was not the case for the Flair vacuum cleaner. For instance, with the Roomba, men and children (who were not involved in the cleaning task before) took an active role in cleaning, and continued to do so beyond the end of the study. Interestingly, Roomba also encouraged some participants to undertake some pre-cleaning up, so that floors were clutter-free and Roomba was able to navigate around without getting stuck. All of the families in Forlizzi's study who received the Roomba were still using it one year later, which was not the case with the Flair. Further, in two of the three families that were using the Roomba, the robot replaced the other floor cleaning tools. The author interpreted that the observed differences between the robot and the manual vacuum cleaner are explainable by considering five dimensions of the respective product: function, aesthetics, symbolism, emotion, and social attributions. The differences are then mainly due to the social dynamics, that only the robot was able to create. Forlizzi (2007a) concluded that when simple social attributes are part of the design of robotic products and systems, people may adopt them more readily.

Also Sung and her colleagues conducted a long-term field study to explore how people use and accept a domestic robot in their home. They gave Roombas to 30 households and studied their usage of the robot and its impact on the home ecology during a 6-month period. The methods and techniques that they used during the study are presented in Sung et al. (2009a) whereas the findings of the study are reported in Sung et al. (2010). During the 6-month period, each household was visited five times. The first visit happened one week before the robot was introduced and served to assess the existing cleaning routine against which Roomba usage could be compared later. At the second visit, households received the robot and unpacked and used it for the first time (in front of the researcher). The other three visits took place respectively, two weeks, two months, and six month after Roomba was introduced. During these household visits, several qualitative methods besides traditional interviews were used to better capture people's routines and acceptance of the robot. For instance, the authors used drawings and probing techniques, as well as cards with checklists of activities in which one could engage with the robot. Participants were also encouraged to report their experiences with the robot by e-mail to the researchers. Based on this study, Sung et al. (2009a) argue that two months are the minimum time period required to observe stable interactions between robots and households, and ordinary use of the robot beyond the "novelty effect". Based on this long-term study with Roomba, the first steps towards the development of a long-term framework were taken, namely the *"Domestic Robot Ecology"* (Sung et al., 2010). This framework differentiates four temporal phases that contain key interaction patterns experienced while households go through the process of adopting the robot: *pre-adoption, adoption, adaptation,* and *use and retention* (as presented in Chapter 1, page 37).

Fernaeus et al. (2010) conducted a long-term interaction study with the dinosaur-shaped toy robot Pleo. Six families received a Pleo for home use, which they kept for 2 to 10 months, depending on how long the family wanted to continue using the robot (one possibility to measure willingness to engage with the robot). Participants were interviewed several times, and they were also given video cameras to record their interaction with the robot. The study focused on the discrepancy between previous expectations that participants had of the Pleo and how the robot actually met (or failed to meet) their respective expectations. In most cases, the families had high expectations of the robot. Interestingly, this was not related to the robot's shape but due to the usual fairly high market price of the robot, its sophistication, and how the robot was advertised in the booklet that came with it and on the internet. This shows, that the *pre-adoption phase* (as identified by Sung et al. (2010)), which is before the purchase of the robot, is an important stage that needs to be considered in the adoption phase. With these high expectations of Pleo however, participants were commonly disappointed when they started using the robot. The robot's interaction abilities were not attractive enough to keep children engaged in the robot. The authors reported that after the initial novelty effect of the robot had worn off, participants did not interact with Pleo in a regular manner (Fernaeus et al., 2010). After a while, Pleo was only switched on in special occasions, for instance, when friends were visiting. Even though at first, the dinosaur robot was treated in a similar way to a real animal, with activities such as petting and choosing a name for it, over time, the robot failed to encourage regular interactions and started being treated as a regular toy. One of the main reasons behind this was that the robot was not able to develop more skills and be able to learn, as it was expected by the participants.

Social dynamics with functional robots Some special social dynamics related to functional robots being used in homes have already been mentioned in the previous paragraphs (see mostly Forlizzi (2007a)). Sung *et al.* further investigated how people develop "intimacy" to their domestic robot (Sung et al., 2007), and customize their Roomba to better express the robot's personality that they ascribed to it or to align the robot better to the participant's lifestyle (Sung et al., 2009c). The authors argue that by developing a personal relationship to the robot, participants derived increased pleasure from using the robot, and expended their effort to fit the robot into their homes (Sung et al., 2007). These social dynamics, in turn promoted not only the acceptance of the robot, but also positively affected the perceived satisfaction with the robot, and the willingness to continue using it (Forlizzi and DiSalvo, 2006; Forlizzi, 2007a; Kidd and Breazeal, 2008; Sung et al., 2008; Klamer et al., 2011). A personal engagement with the robot, *e.g.* by giving it a name, was found to facilitate forming a relationship to the robot (Klamer et al., 2011) but was not very common among Roomba users (Sung et al., 2008). The importance of social factors for long-term acceptance has not only been mentioned related to robots but also earlier in studies about the usage of household technology (Venkatesh, 1996). More specifically, intimacy and positive emotional attachment, such as assigning an identity to the robot, is expected to lead to greater acceptance of the product in general and of the perceived usability of it (Venkatesh, 2000).

Various terms have been used to describe close personal relationships with technology, including intimacy, affective quality, and emotional attachment (Sung et al., 2007). An intimate relationship to a technology may consist of a cognitive and emotional closeness with a technology, or a physical closeness with the technology, or feelings of intimacy through the technology (between people mediated by technology) (Bell et al., 2003). These special kinds of social and emotional relationships between humans and a non-human artifacts are of special interest in the HRI domain, especially with regard to social / sociable robots (Breazeal, 2000). Robots that mimic human behavior to elicit social engagement from the human user offer both opportunities and pitfalls, however (Thrun, 2004, p. 10f):

> *"It offers the opportunity for the design of much improved interfaces by exploiting rules and conventions familiar to people in different social contexts. However, sociable interaction does so at the danger of people reflecting capabilities that do not exists into robotic technology. For these and other reasons it remains unclear if we ever want to interact with robots the same way we interact with our next-door neighbor, our colleagues, or with the people who work in our homes."*

What we broadly label as "social engagement" in this thesis, seems to be more distinct in people's interaction with robots than with any other technology. People commonly tend to engage socially with robots and, as a special form of this, attribute human characteristics to robots. However, we are skeptical of the frequently reported social relationship between people and *functional robots*, especially what concerns the long-term because literature suggests that interaction and engagement change over time. We treat this in more detail in the next section about anthropomorphism – people's tendency to perceive human-like characteristics in robots.

Summary Summing it up, field studies in people's homes indicate that domestic robots can create some unique dynamics within the "home ecology", by affecting routines, people, other product use, and the physical space. For instance, in contrast to a manual vacuum cleaner, the robot encouraged people to make adjustments to their home and to engage in pre-cleaning up activities. Further, it was found that the robot impacted on the established cleaning routines and led people to clean more regularly. Social dynamics seem to play a central role in the use of a domestic robot. Studies have commonly highlighted the importance of the **social impact** that the robot can have on one hand and the **social benefits** that people can derive from using the robot on the other hand. Moreover, findings of long-term interaction studies confirm what theoretical models suggested: interaction, usage and experience change over time. A phenomenon that has commonly been highlighted is the so-called **novelty effect**. Novelty effects have been described with interactive technologies in general (Rogers, 1995) and also in several long-term HRI studies in domestic (Sung et al., 2009a; Fernaeus et al., 2010) but also non-domestic environments (*e.g.* in studies about robots being used in workplaces (Hüttenrauch and Severinson-Eklundh, 2003; Mutlu and Forlizzi, 2008), in schools and public places (Kanda et al., 2004; Kanda and Ishiguro, 2005; Gockley et al., 2005), and in elder care centers (Sabelli et al., 2011)). In general, these long-term studies found that people's interest, engagement, and fascination with the robot decreased over time, which may be partly due to novelty effects. Efforts have been made to sustain long-term engagement with robots, for instance by letting the robot respond to its user in a social way, *e.g.* by showing empathy (Leite, 2013).

2.3 Anthropomorphism and Human-like Engagement with Robots

"Robots not only suggest,
what is human in the machine,
but what is machine in the human ..."
— Nicholas Anderson (2009, p. 43)

This section gives an overview on people's tendency to engage in a human-like way with robots that are not especially made to encourage such a relationship. Hence, we focus on functional service robots like the Roomba. The topic of anthropomorphism is relevant for several of the studies presented in this thesis.

What do we mean by "to engage in a human-like way with a robot"? Generally, the phenomenon of establishing a meaningful contact or connection in a human-like way with a non-human agent (*e.g.* a robot) is labeled as **anthropomorphism**. Broadly speaking, this refers to people's tendency to attribute human characteristics to robots. However, there exist various definitions of anthropomorphism, not only across but also within disciplines (Duffy, 2002). Note that the term anthropomorphism is used in a variety of disciplines. Also within robotics and HRI, there is no common agreement on how to define anthropomorphism. Bartneck et al. (2008, p. 74) refer to it as *"the attribution of a human form, human characteristics, or human behavior to nonhuman things such as robots, computers, and animals."* Contrary, Waytz et al. (2010) apply a more psychological-cognitive view and define anthropomorphism as *"a process of inductive inference whereby people imbue the real or imagined behavior of other agents with humanlike characteristics, motivations, intentions, or underlying mental states"*. The authors propose that this *"may occur by attributing humanlike physical features to another agents [...] but more commonly by attributing mental states perceived to be uniquely human to other agents."*

Originally, the term anthropomorphism comes from the Greek *anthropos* for "man" (or "human") and *morphe* for "from / structure" (or "shape"). However, despite the fact that "anthropomorphism" literally stands for "human form", we propose that the term should *not* be used to refer to the *form / design* of a non-human agent. To refer to an imitation of human-like form / design of a robot, we propose to use the term **anthropomorphic design**.[7] Bartneck and Forlizzi (2004b) suggest that *form* refers not only to the physical shape of a robot but to all ascertainable parts / aspects of it. As such, "form" can be understood as the total expression of the robot, including physical shape, materials, and behavioral qualities. Several categories of anthropomorphic form can be classified, but there is no common agreement on the boarders and transitions between these categories: anthropomorphic, zoomorphic, caricatured, functional (Fong et al., 2003a).
In contrast to anthropomorphic design, the term **anthropomorphism** should only be used to

[7] We may use "design" interchangeably with "form", and "anthropomorphic" interchangeably with "human-like".

refer to the psychological phenomenon of perceiving or attributing human-like characteristics to a robot. Throughout this thesis, we include both the perception of typical and unique human characteristics in anthropomorphism (*e.g.* attributing life or perceptual cognitive skills like the ability to see, are not unique human characteristics, as they apply to all living beings). We would further like to stress that as such, anthropomorphism can been seen as something that arises in a (real or imagined) interaction between a human and a non-human.[8] This understanding does not violate the aforementioned definitions of anthropomorphism. On the contrary, also Persson et al. (2000) propose that *"anthropomorphism emerges in the interaction between technology and user"* and further suggest that anthropomorphism is a multi-layered phenomenon.[9]

It has been described in several previous studies that Roomba users tend to engage in a variety of human-social activities associated with the robot, including but not limited to, personalizing the robot, choosing a name for it, or ascribing personality and gender to it (Forlizzi and DiSalvo, 2006; Forlizzi, 2007a; Sung et al., 2007, 2010). However, there seems to be a discrepancy. On one hand, in interviews with Roomba owners and in online discussion forums about Roomba, people frequently report their anecdotes about their personal relationship to the robot (Sung et al., 2007). On the other hand, the same group of researchers found in an online survey among Roomba owners, that overall, there were relatively low rates of treating the robot as a living entity (Sung et al., 2008). The question raises how frequent anthropomorphic perceptions of the Roomba are, regarding 1) whether there is only a specific group of people that anthropomorphizes and 2) concerning the long-term. As people's perception of robots changes over time, also their tendency to anthropomorphize the robot may change. A similar gap related to the perceived agency of the robot was described by Takayama (2012). She found that while some Roomba owners perceive their robot as an agentic object, others perceive it as just a plain machine. To make sense of both these observations at the same time, and improve the understanding of the perception of **agency** in robots, Takayama suggested to differentiate between what she calls an *in-the-moment* and a *reflective* perspective on agency. Accordingly, an *in-the-moment* perspective refers to one's most immediate (sometimes visceral) sense in a situation. In contrast, a *reflective* perspective refers to one's sense of a situation upon more distanced cogitation and consideration (Takayama, 2012). For instance, we reflectively (after some consideration) might not perceive agency in a social robot, however it can feel quite differently in the very moment of interacting with the robot. A critical dimension of agency is the perspective from which *something has* agency (this perception might be treated as anthropomorphism). Takayama (2012) argued that neglecting to separate an in-the-moment from a reflective perception of agency is one of the major sources of confusion

[8]Based on this notion, one can take two main perspectives of explaining why humans anthropomorphize: an *artifact-centered* perspective and a *human-centered* perspective. First one explains anthropomorphism from the ascertainable parts of the robot, namely the anthropomorphic features of its design (similar to an "extrinsic motivation" to anthropomorphize). The second perspective puts the human into focus and arguments that humans are self-motivated to anthropomorphize (similar to an "intrinsic motivation") (for a review see Epley et al. (2007). Both these perspectives go hand in hand and apply at the same time.

[9]When agreeing to understand anthropomorphism as a social phenomenon that is based on an interaction, it is not valid to speak of *"the robot's level of anthropomorphism"* (Bartneck et al., 2007; Feil-Seifer and Mataric, 2009) because the artifact itself does not "contain" anthropomorphism. In other words, a system *"is not anthropomorphic per se, but only in so far as it gives rise to anthropomorphic processes in a given user and situation"*.

when people talk and write about anthropomorphism. There seems to be a disconnection between what people consciously perceive and how they respond to stimuli that they may not consciously perceive. Often, these two aspects are not considered separately, which leads to a conflict. In other words, during an initial phase of interacting with a novel device people might not respond consciously but rather "mindlessly" (Nass and Moon, 2000). Only after some time of, what we refer to as "familiarization" with the robot, they may respond in a more reflective manner. This can be illustrated by the fact that when participants who had interacted with a technology are asked about whether they had just interacted with the technology in a human-like way, they tend to deny this (reflective perspective). However, in the moment of the interaction they had actually responded to the system in many ways that were remarkably similar to how they would respond to people (Reeves and Nass, 1996).

A theory that is often discussed alongside anthropomorphism and the anthropomorphic design of robots, is the *Uncanny Valley* (Mori, 1970). This hypothesis proposes that human-like designs of non-human agents can evoke both positive or negative feelings and cognitions (referred to as valence or affinity), depending on the object's degree of physical similarity to human appearance. Importantly, the relationship between valence and human-likeness is suggested to be non-linear: The Uncanny Valley theory predicts that when gradually increasing the human-likeness of a system, the human observer first experiences an increasing positive valence (emotional engagement, feelings of empathy for the human-like object) up to a first positive peak. However, with greater degrees of realism (at a certain not well defined point), the observer encounters difficulty in distinguishing an object from its natural human counterpart and experiences personal discomfort. Mori (1970) characterizes this discomfort as an uncanny feeling marked by a sense of strangeness, eeriness, and disquiet that can extend to feelings of disgust and revulsion. This shift from positive to negative experience can be very abrupt, and thus described as a "valley". When further increasing the human-likeness of the object, such that its appearance is so realistic that it cannot be distinguished from a real human, the valence of associated affect is thought to reach a second positive peak. Despite the fact that Mori's theory was more a working hypothesis and not meant to be subjected to empirical examinations, a lot of research has been carried out. However, findings of research on the Uncanny Valley are inconsistent (Cheetham et al., 2011) and the theory itself is controversially discussed. We do not enter this discussion here, as the Uncanny Valley will not become a central part of this dissertation.

Overall, it becomes clear that anthropomorphism, though commonly observed and sometimes even subtle, is a manifold and complex phenomenon. When studying anthropomorphism, one will at some point always come across the question of what human-likeness means and what it is that makes us human. The discussion appears to be similar to the one related to the question of *"What is a robot?"* (see Section 1.1). An interesting reflection on the complexity of anthropomorphism is offered by Waytz et al. (2010, p. 411):

> *"A moment's reflection, however, makes it clear that some agents are anthropomorphized more than others [...], some cultures seem more prone to anthropomorphism*

than others [...], children are generally more likely to anthropomorphize than adults [...], and some situations increase the tendency to anthropomorphize compared to others [...]. Anthropomorphism is not an invariant feature of everyday life to be taken for granted but rather a wide-ranging and variable psychological process to be explained.

2.4 Child-Robot Interaction

As some of our interaction studies involve children as participants, we provide a short review of the related work on child-robot interaction. The reported findings are of particular relevance for the “Ranger Study” and the “Domino Study” presented in Chapters 5 and 6.

Children are not just small adults. Their conception of the world is different and depending on the age and developmental stage in which they are, they conceive and experience things differently (Piaget et al., 1929). This also influences how children perceive robots. Hence, child-robot interaction might be fundamentally different from interaction between adults and robots (Belpaeme et al., 2013).

Children’s percpetion of robots

Children typically do not see a robot as a mechatronic device running a computer program, but are likely to attribute characteristics to the robot which are typically expected to be attributed to living entities (Belpaeme et al., 2013).

In a study with 38 school children, aged from 7 to 11 years, Bumby and Dautenhahn (1999) found that children tend to conceive of robots as geometric forms with human features. The authors analyzed the robot pictures that children were asked to draw. Children also wrote a story about the robot they had drawn, and the researchers found that in their stories, children tended to attribute free will to the robots and to place them in familiar, social contexts. Finally, most of the children attributed preferences, emotion, and male gender to the robots, even without explicit cues to prompt this response. These findings suggest that children tend to anthropomorphize robots, which has also been described earlier in psychological research.[10]

Leite et al. carried out a series of studies with children between 5 and 15 years old who were playing chess exercises with the iCat robot (Leite et al., 2009, 2010, 2012). The authors found that children’s perception of the robot changed over time. While in the beginning of their 5-week long-term study, most children considered the robot as an opponent when playing chess against it, they considered it as a friend toward the end of the study. This change in perception was

[10]It is however not clear whether children really anthropomorphize or if they not rather use anthropomorphic statements in a metaphoric sense (because their conceptions of the world are not fully formed and they are not able to describe things using more abstract words and concepts). For instance, children are likely to argue that *“the sun is hot because it wants to make people warm”* (Leeds, 1992).

influenced by the implementation of emphatic responses in the robot's behavior. By doing so, the robot was able to sustain children's engagement over an extended period of time.

In most child-robot interaction studies, researchers reported that children showed very positive reactions to the robot. For instance, in an interaction study with 19 children (ages 7-12 years) that was set up in a hospital environment, children described themselves as feeling "happy" in the company of the robot and found the interaction entertaining (Belpaeme et al., 2012). Also, the majority of children viewed the robot as a "friend" or as a "brother or sister".

How children interact with Robots

It has been found that children are generally more engaged with robots than adults (Scheeff et al., 2002; Weiss et al., 2009c), and for reasons not fully understood, they respond much more readily and strongly to social robots (Ros et al., 2011). However, the age of the children has a strong impact on how they interact with robots. Generally, it is suggested that human-robot engagement is significantly more easily attained with younger children than with adolescents (Ros et al., 2011).

That even very young children can interact effectively with a robot, was demonstrated in a study by Tanaka et al. (2007). Toddlers (1.5 to 2 years old) interacted with a small humanoid robot that was placed in a day care center. Children perceived the robot as a social agent and the quality of interaction improved over time. The robot had a wide repertoire of behaviors but it appeared that simple reactive routines (for example, touching the head resulted in the robot playing a pre-recorded giggle) were surprisingly effective at engaging the young children. The researchers concluded that for this particular age-group, haptic interaction is highly salient (*e.g.* children often touched and hugged the robot) whereas higher-level behavior, such as linguistic interaction does not seem to be necessary to engage children in this age range. Similar results are described by Michaud et al. (2005).

Kahn et al. (2004, 2006) studied children's perception of and interaction with the robotic dog AIBO compared to a stuffed dog. 80 children from two age groups (2.5-4 years and 5-6 years) played with each one of the two artifacts. The authors found similarities in children's reasoning about the stuffed dog and the robotic dog. More concretely, children attributed to a similar extent animacy, biological properties, mental states, social rapport, and moral standing to both artifacts. However, the researchers observed differences in how children interacted with the robotic and the stuffed dog. Children more often showed explorative behavior with AIBO than with the stuffed dog, more often engaged in apprehensive behavior with the robot, and more often engaged in attempts at reciprocity with the robot. In contrast, they less often mistreated AIBO than the stuffed dog, and less often engaged in endowing animation with the robot. Kahn et al. interpret that children may have engaged in imaginary play with AIBO in the same way and to the same degree that they engaged in imaginary play with the stuffed dog. However, the differences in children's behavior show that they distinguished between the two artifacts.

In another study the almost same group of researchers investigated children's reasoning about and behavioral interactions with the robotic dog AIBO compared to a live dog (an Australian Shepherd) Melson et al. (2009). 72 children from three age groups (7-9 years, 10-12 years, and 13-15 years) participated in the study. Results showed that more children conceptualized the live dog, as compared to AIBO, as having physical essences, mental states, sociality, and moral standing. Children also spent more time touching and within arms distance of the live dog, as compared to AIBO. However, a surprising majority of children conceptualized and interacted with AIBO in ways that were like a live dog. For example, over 60 % of the children affirmed that AIBO had mental states, sociality, and moral standing; and children were as likely to give AIBO commands as a living dog.

Kanda et al. (2007) introduced a humanoid robot in a primary school setting, with children aged between 10 and 11 years. The robot was able to identify children by the RFID tags they were wearing. The more a child interacted with the robot, the more the robot shared some "secrets" with the child and showed new behaviors. This manipulation was used to maintain children's long-term interest in the robot. However, only some of the children stayed engaged over the full duration of the experiment (2 months), whereas about 2/3 of the children gradually lost interest. It was unclear if this was due to the robot's behavior, or due to other external factors.

Ros et al. (2011) concluded two issues in the design an implementation of robots that intend to engage socially with children: As a first issue, the authors mentioned that *age plays a role*. Young children are very willing to endow the behavior of artificial agents with social meaning and interact accordingly. In contrast, older children appear to be less likely to view a robot as a social actor and maintaining their engagement is more challenging. Based on this, the second issue that Ros et al. mentioned, concerns the *interactive complexity* of the system. On one hand, Tanaka et al. (2007) found that a simple, reactive giggle behavior can be effective in engaging young children. However, it is reasonable to expect that in order to engage older users, a robot would require more complex behaviors and a richer repertoire of social responses. There is, however, a drawback that is a commonly observed phenomenon in HRI: the more sophisticated the robot, the greater a user's expectations of it; hence the greater is the risk that children disengage with the robot as they discover its limitations (Ros et al., 2011). Both the findings presented in Kanda et al. (2007) and in Fernaeus et al. (2010) have illustrated this relation between the robot's sophistication, the children's high expectations and their disengagement with it after some interaction.

Challenges of Child-Robot Interaction Research

There are a series of challenges when conducting studies that involve children, in general, and in doing child-robot interaction studies, in particular. Belpaeme et al. (2013) discussed three main challenges: technical aspects, evaluation, and expectations. Regarding the technical challenges, Belpaeme et al. suggest Wizard of Oz control as one possibility to enable open-ended interaction in real-world environments. In terms of evaluation, the authors discuss the problematic that children have the tendency to try to please the experimenter rather than answer truthfully to survey questions. This issue is also mentioned by Leite (2013). Suggestibility may not only be influenced by factors related to the interviewer (*i.e.* age and gender) but it also depends on the content and format of the questions. Therefore, questionnaires and interview scripts used with children need to be designed with special care. Concerning the last main challenge, expectations, Belpaeme et al. argue that it is important to set the right expectations. For this, not only the specific children as a user group need to be considered but also parents and teachers or who else is involved in the use of the robot. The authors suggest focus groups and regular meetings with the adult users, in order to adapt the robot also to them.

In terms of setting up a child-robot interaction study and choosing an appropriate scenario, Ros et al. (2011) share their practices. The authors carried out a series of child-robot interaction experiments (focusing on social aspects) in a hospital pediatric department and report on their experimental design and lessons learned about the implementation of systems for social HRI with child users towards application in "the wild". Mostly playful scenarios with an educational or rehabilitation aspect were chosen, as they are engaging for the children and meaningful at the same time. Ros et al. further mention that in conducting research with children, legal and administrative issues need to be considered. Also, researchers need to assure that the interaction study takes place in an environmental context that allows children to feel comfortable. *"The appearance of the room, of the robot and even of the experimenters needs careful control in order to avoid biasing the child's initial impressions and expectations of the interaction"* (Ros et al., 2011, p. 339).

In general, research with children and robots requires careful thought. One of the trade-offs of doing research involving children lies between the efforts to foster a naturalistic interaction on one hand, and the need for robust experimental paradigms on the other hand. These two sides need to be carefully balanced.

3 Exploring Long-term HRI in the Wild – The Roomba Study

As a first step in exploring interactions between human users and robots in daily life environments we carried out a 6-months lasting ethnographic study in nine households to which we gave a commercially available vacuum cleaning robot (iRobot's Roomba). Hereafter, we will refer to this study as the **"Roomba study"**.[1]

The remainder of this chapter is organized as follows: First, in Section 3.1 we present our motivations, the expected contributions, and the specific research questions that guided this study. Then we outline the methods used, present the study design, field tools, how the data was processed and describe the sample (participating households) of the Roomba study (Section 3.2). This will be followed by the findings part (Sections 3.3-3.7) which consists of five sections, related to the research questions. Section 3.3 sheds light on how people used the vacuum cleaning robot compared to the traditional vacuum cleaner, and how the usage of the robot impacted the cleaning routine. Section 3.4 focuses on how the layout of the home and the household's lifestyle had an impact on the performance of the Roomba. Then, Section 3.5 is about how participants perceived and treated the robot, and how these two aspects evolved over time. We present various specific social dynamics that the robot evoked in the households in Section 3.6 of the findings section. This is followed by an analysis of the process of adoption (Section 3.7). In the end, we summarize and synthesize the findings of the Roomba study and present several factors that we found play a role for the acceptance of domestic service robots, as well as during the process of adoption (Section 3.8). These factors might be seen as implications for the design of domestic service robots.

[1]This study is published in the International Journal of Social Robotics, vol. 5, no. 3, pp 389–408, Springer, 2013 (Fink et al., 2013). Further publications that include results of this study are: Fink et al. (2011); Bauwens and Fink (2012); Vaussard et al. (2014).

3.1 Scope and Research Goals

3.1.1 Motivation

With domestic service robots entering people's homes, it becomes increasingly important to understand both people's initial responses to robots and the process of long-term adoption. A holistic approach is needed to study the user experience with these devices, taking into account user needs, characteristics of the home, and the (social) impact that these devices can have on the home ecosystem (Forlizzi and DiSalvo, 2006). Yet little is known about these aspects, despite the fact that several million units of domestic robots have already been sold (mostly vacuum cleaning robots such as iRobot's Roomba). To date, only few studies are available that investigated HRI in domestic spaces over a longer period of time. This is due to several reasons: First, only few types of robots have only recently become robust and affordable enough to enter the consumer market. Second, long-term studies are methodologically demanding, and require specific training from the researcher side. And third, the home itself is a challenging environment for doing research, since homes are private spaces and no home is like the other. However, real-world studies can provide interesting insights into usage and experience from a user point of view, and help identifying factors promoting and hindering lasting adoption.

Moreover, long-term studies are crucial because it has been recognized that novelty plays a role in HRI and that interactions with technologies and people's perception change over time and with the user's growing experience (Kanda et al., 2004; Forlizzi and DiSalvo, 2006; Karapanos et al., 2009; Sung et al., 2009a; Fernaeus et al., 2010; Leite, 2013). Much work remains to be done in investigating the novelty effects in HRI, and their effect on the actual usage of domestic robots in homes after people's initial fascination for the robot has worn off. Furthermore, we need to find solutions to overcome these novelty effects, may they be of positive nature (initial fascination for the robot) or negative nature (initial fear of the robot).

An understanding of how people use and adopt domestic robots can further help improving the functionality and the design of the robot toward the goal of making domestic service robots useful, usable, and acceptable everyday tools. Also, critical aspects as well as new applications for robots in homes may be discovered, and advance the field of user-oriented personal robotics.

3.1.2 Contributions

To explore the aforementioned aspects, we carried out a long-term ethnographic field study with nine households to which we each gave a commercially available iRobot Roomba vacuum cleaning robot. A similar long-term field study with Roomba robots was conducted in the U.S. in 2007/08 (Sung et al., 2009a, 2010) but no such study has been carried out in Europe so far. Though our study is similar to the previous work, it differs in several aspects. First, the cultural context is different. Swiss homes are likely to look and be organized / maintained differently than American homes (Bell, 2001), which might influence the acceptance of the robot and the adoption process. On the other hand, we used more recent models of Roomba (available in Europe, End of 2010), which have slightly different functionality that might lead to different interaction and user experience. Consequently, we can expect new insights into what we currently known about the acceptance, usage and impact of domestic vacuum cleaning robots.

In general, there are only few long-term studies of robots being used by ordinary people in real homes. Thus, our study contributes new findings to the limited number of long-term research on HRI and the acceptance of robots in daily life environments. We provide detailed insights into what happens when a functional robot like Roomba is deployed in different types of households (families, elderly single, young couple, *etc.*). This will broaden the general understanding of HRI and people's acceptance of robots in daily life environments. On a more abstract level, we tackle the question of how close or far we are today from *"having a robot in every home"* and why.

We try to be ecologically valid by applying a user-centered view that considers as many real-world factors as possible. This is challenging but is expected to provide rich and diverse, mostly qualitative data. For this reason the sample size is small, otherwise it would not have been possible to study things in detail over a longer period of time. Despite the small sample size of nine households, and the explorative character, the Roomba study cannot be seen as a case-study but rather as a field study, in which ethnographic methods were used to collect and process data. Throughout the study we were assisted by a professional ethnographic researcher.

Moreover, the Roomba study contributes new data to an initial framework of long-term acceptance of robots in homes, namely the *Domestic Robot Ecology (DRE)* (Sung et al., 2010). By analyzing our results along the DRE, our work helps extending and making this framework more robust. We highlight similarities and differences in people's experiences and acceptance of Roomba by comparing data obtained in two culturally different regions. This is a relevant extension of previous work, as culture seems to be an interesting factor in the perception of robots and in HRI (Bartneck et al., 2006, 2005).

Figure 3.1: **Domestic vacuum cleaning robots face a lot of challenges.** No household is like the other and no user is like the other. Homes are dynamic environments: different physical characteristics, the presence of young children, pets, things lying around, and different attitudes toward cleaning and cleanliness are just a few of the challenges that domestic vacuum cleaning robots are facing.

3.1.3 Research Questions and Hypotheses

Besides openly exploring HRI and how it evolves over time, we wanted to focus on long-term aspects, such as acceptance and adoption of a domestic cleaning robot in various types of households. Further, we wanted to investigate the robot's impact on the household itself and the established routines related to cleaning. The Roomba study is guided by the following research questions:

1. **Usage and impact on routines:** How do people use a robot for its intended task and how does this usage impact the established routines related to that task? (here: vacuum cleaning and cleaning up in general, as well as the usage of other cleaning tools)

2. **Environmental context:** What characteristics of the home are relevant for a proper functioning of a domestic service robot when deployed in a real household?

3. **Interaction and perception:** How do people interact and perceive a functional domestic robot[2] in their home, and how does both evolve over time?

4. **Social dynamics and emerging phenomenons:** What kind of social implications of the robot can be observed (*i.e.* is the robot treated as a social artifact) and what are possible impacts on the household (and its members, their social roles, believes, their way of living, *etc.*)? Can we observe any other dynamics that the robot creates within the household?

5. **Process of adoption:** How far can the *Domestic Robot Ecology* framework (Sung et al., 2010) be applied to our study findings? What are major similarities and differences, regarding temporal stages of adoption, the importance of specific attributes that influence interaction experience, and the described relationships that people form to the robot?

Based on these research questions and according to findings from previous work, the following working hypotheses were formulated:[3]

Hypothesis 1 (Usage and impact on routines) How the robot is used is impacted by individual factors as well as the household's attitude toward cleanliness and their respective cleaning strategy. For instance, we hypothesize that households, to which perfect cleanliness matters, clean more often, and in turn use Roomba more often. In turn, the usage of the robot will impact the household's respective cleaning routines, and probably change the established cleaning roles.

[2]I use the term *functional robot* interchangeably with *service robot*. Thus, with functional I understand a robot that has a practical function, *i.e.* one that aims to carry out a specific task (a service) to disburden the human, such as vacuum cleaning. By this, a functional robot has a clear purpose, in contrast to domestic robots such as the AIBO robotic dog, which does not complete a task but engages people to play with it

[3]These hypotheses are not formal hypotheses as in a controlled lab experiment, they are more assumptions that guide our work and the analysis of the data toward relevant aspects.

Hypothesis 2 (Environmental context) The physical layout of the home has a strong impact on the robot's performance, and in turn influences whether people adopt Roomba. Concretely, a home without stairs, concrete surface (*e.g.* tiles, parquet floor), few obstacles, and large open spaces enables the robot to work well, and in turn will make it easy for the household to adopt Roomba.

Hypothesis 3 (Interaction and perception) How people interact and perceive the robot is impacted by individual factors (gender, age, *etc.*), by how the robot is used, and also by characteristics of a household. Concretely, households with children and pets experience more fun when using Roomba, and in turn interact more frequently with the robot. Also, those households that adopt the robot perceive it as more useful and easy to use. People's perception is likely to change over time, with growing user experience.

Hypothesis 4 (Social dynamics and emerging phenomenons) People tend to view the robot as a social actor, and will treat it as such, by anthropomorphizing it (*e.g.* giving it a name, ascribing a gender). With the deployment of the robot in the household, new activities and phenomenons related to the robot emerge. For instance, the robot enables multi-tasking, encourages collaborative cleaning, will motivate people to make adjustments in their home, and will also be used to entertain guests.

Hypothesis 5 (Process of adoption:) The *Domestic Robot Ecology* can be used as a basis to describe the process of adoption of the domestic robot, despite the different cultural context. However, there might be differences.

In general, we imagined that Roomba would become a useful tool in most of the households and that participants would fairly easily integrate it in cleaning routine.

With respect to our own research work, the Roomba study serves to openly explore interactions between humans and robots before studying in more detail specific aspects of it. In this respect, the further research work will build on the findings of the Roomba study.

3.2 Methodology

3.2.1 Ethnography

Since our goal is to study in detail a relatively small sample (9 households) over a longer time period (6 months), we chose an ethnographic approach. Ethnography is a qualitative research method that attempts to generate a holistic account of cultures or groups of people, such as a household. Ethnographic methods have already been used to study HRI and long-term adoption of robots in homes (Forlizzi, 2007a; Sung et al., 2009a; Fernaeus et al., 2010). In its origin, ethnography is a form of anthropological practice and both a methodology and perspective (Bell, 2001). According to Bell (2001), ethnography is considered a type of field work where the researcher spends time in and with the culture or peoples studied, participating in everyday life and attempting to make sense of the patterns of that culture (Bell, 2001). We apply ethnography here not in its traditional anthropological sense of 'going native' but as a research technique, in order to obtain qualitative insights into what happens in the real world in contrast to a well defined but limited laboratory setting. Both roboticists, engineers, and interaction designers acknowledge the rich insights that qualitative research in real world environments can provide to inform future developments and refine design (Fernaeus et al., 2010; Salvini et al., 2010; Sung et al., 2010). However, ethnographic research which spans over an extended period of time brings along several challenges in terms of data acquisition, data structuring, and interpretation. These and other difficulties, such as the privacy of the home as the site for research, have also been outlined by Fernaeus et al. (2010), and Sung et al. (2009a).

3.2.2 Study Design and Measurements

The study design needs to match the difficulties and constraints created by the nature of the study (explorative and long-term) and the home as a private space. Potentially relevant events can occur not only at a predefined time and space but within the whole living space, and at any time also when the researcher is not present. However, using logging mechanism or extensive on-site video recording would create an unnatural setting which would not meet the goals of our study.[4] Another challenge is to capture routines of cleaning activities. A routine commonly happens less consciously; and it is consequently hard for participants to talk about it explicitly and thus it is difficult to investigate routine.

We addressed these challenges by using a similar study design and methodology to that proposed by Sung et al. (2009a), and also inspired by how Forlizzi and DiSalvo (2006); Forlizzi (2007a) set up their studies about cleaning in the home with a traditional vacuum cleaner compared to the Roomba. More concretely, we used ethnographic methods, including **several home visits**, a **"home tour"**, **qualitative semi-structured interviews** (see Appendix, 215), and **cleaning diaries**. Our study took place from March to October 2011 and was composed of five visits at each of the participating households:

First visit: Approximately one week prior to handing out the Roomba, we had an introductory visit and home tour at each home, in order to get to know the household, their routines, and their attitudes towards robots and technology in general. Each household was asked to fill in a cleaning diary during one week.

Second visit: About one week after the first one, we brought the Roomba with us. Depending on whether the household owned a pet, they received a normal or a pet version of Roomba (see Figure 3.2 and Table 3.1). We first interviewed people about their expectations of it,

[4] First, we were interested in using also logging mechanisms, in order to have accurate usage data; however we ultimately decided to not do so. We imagined that if people knew that the robot records log data, they could feel obliged to use it or could think the robot was manipulated in other ways and in turn not trust it. Also Sung et al. (2009a) suggests to use observations, interviews and other qualitative techniques, rather than logging mechanisms, pre-programmed robot behavior, or on-site video recordings.

(a) Roomba 520 (b) Roomba 563 PET (c) Roomba back view

Figure 3.2: **Two different models of the Roomba were used in this study.** Households without a pet received model (a), those with a pet received model (b) which is specifically adapted to vacuum pet hair, additionally has a time scheduling function,and comes with two so-called "virtual walls" (infrared barrier) that help keeping the robot in a specific area.

then let them unpack the robot, and observed their initial reactions to it while they were setting it up and using it for the first time.[5] Each household was given a diary to report the usage of the robot until the next visit.

Third visit: Approximately two weeks after we had brought the Roomba, we came back to see how the household experienced Roomba and what it was used for, by whom, when, how often, for how long, where and how.

Fourth visit: About two months after the Roomba was deployed, the households were visited again. We wanted to examine how usage and their perception of the robot changed over time and how far the robot was integrated into everyday life. For ten days prior to this visit, householders completed again a cleaning-diary.

Fifth visit: A concluding visit was conducted about six months after we brought the Roomba to the household. This was to investigate changes in the usage patterns, to assess social dynamics, and whether the experience with the domestic robot changed how people perceived robots in general. Participants were again asked to fill out a cleaning-diary during ten days prior to the visit.

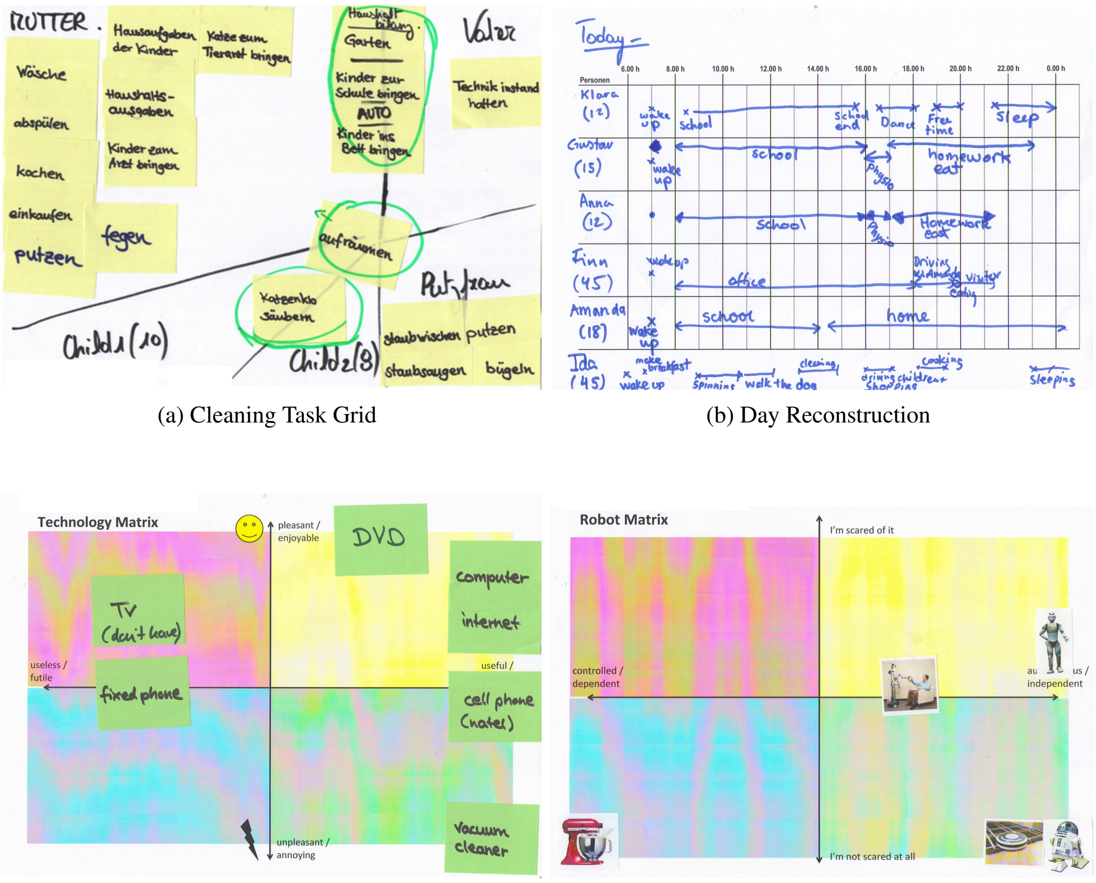
The time steps between these visits were chosen according to Sung et al. (2009a). During the first two weeks with the newly introduced robot, the households' experiences are likely to be impacted by the novelty of the new device; traditionally, it is said that after about two months, these novelty effects tend to have worn off (Fernaeus et al., 2010; Sung et al., 2009a) but depending on how frequently people have used the device, they might still try out new strategies of usage. Finally, after half a year of living together with the robot, one can assume that people formed a stable opinion about the device and developed a stable usage pattern.

[5]To allow this first usage, we already charged the robot's batteries shortly before the visit, and then packed everything together again.

3.2.3 Field Tools and Techniques

Data was collected at all the households throughout the 6-month period, regardless of whether the household stopped using the robot for cleaning. We used several qualitative methods and tools to gather data.

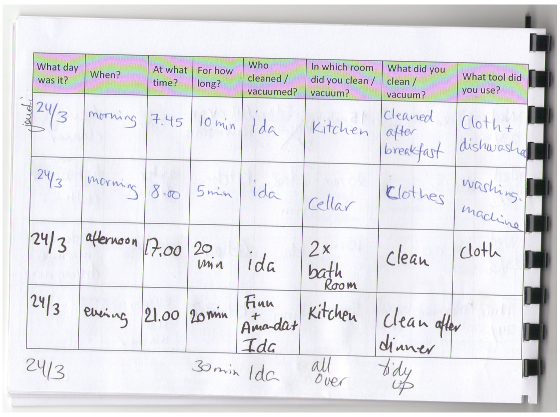
At each visit, **semi-structured qualitative interviews** were conducted (44 interviews in total, each lasting 1-1.5 hours), audio-recorded and qualitatively re-transcribed. Participants were interviewed collectively and asked about their cleaning routines, how they used the robot (for cleaning and other activities), their satisfaction with it, and perceived benefits and constraints. To make it easier for participants to talk about these and other aspects, we enriched the interviews with various activities (see Figure 3.3), such as the *Day Reconstruction Method* (Kahneman



(a) Cleaning Task Grid (b) Day Reconstruction

(c) Technology Matrix (d) Robot Matrix

Figure 3.3: **Various tools were used to capture people's routine and their attitudes toward technology.** A Cleaning Task Grid *(a)* shows the division of labor in the household: who is responsible for which tasks? The Day Reconstruction chart *(b)* shows the household's schedule on a usual day. A Technology Matrix *(c)* helps understand the household's perception of the technologies in the household, according to how useful and pleasant they are. A Robot Matrix *(d)* shows how different kinds of robots are perceived according to perceived autonomy of the device and how scary it appears.



What day was it?	When?	At what time?	For how long?	Who cleaned / vacuumed?	In which room did you clean / vacuum?	What did you clean / vacuum?	What tool did you use?
24/3	morning	7.45	10 min	Ida	Kitchen	cleaned after breakfast	Cloth + dishwashe
24/3	morning	8.00	5 min	Ida	Cellar	Clothes	washing machine
24/3	afternoon	17.00	20 min	ida	2x bath Room	Clean	cloth
24/3	evening	21.00	20 min	Finn + Amanda + Ida	Kitchen	clean after dinner	
24/3			30 min	Ida	all over	tidy up	

Figure 3.4: **In their Cleaning Diary** households noted down their cleaning activities and the usage of the vacuum cleaning robot during several weeks of the study.

et al., 2004) and small drawing or tinkering activities: “Cleaning Task Grid”,“Technology Matrix”, “Robot Matrix”[6]. Participants generally appreciated these activities. The interviews also comprised a **short questionnaire / rating scales** that consisted of a series of 7-point scales on which people’s perception of the robot was quantified (see Appendix, page 232). Participants were asked to rate the robot in terms of its intelligence, usefulness, the perceived ease of use, its impact on the household, the experienced fun, and the emotional attachment, as well as their overall impression. We adapted this questionnaire from Bartneck et al. (2008), and Sung et al. (2009a). The assessed aspects are relevant for describing people’s perception of a robot and partly determinants for the adoption of technology (Venkatesh and Bala, 2008).

The first visit included a **home tour** where the household’s main contact person showed us their home, technological equipment, cleaning tools, and spots in the home that they considered challenging to clean. By this, we also learned about their conceptions of cleanliness and order, which Pantofaru et al. (2012) later described as important for being able to explore the role that a cleaning robot could play in the household. Participants were asked to draw a map of their home and highlight significant spots (see bottom part of Figure 3.5, page 80). At the second visit, we re-used these maps and asked people to draw how they imagine the robot would move around (trajectory). From the third visit on, participants marked in these maps the areas where they used the robot and where it got stuck.

Prior to each visit (except the first one), each household filled out a **cleaning diary** to capture cleaning activities and Roomba usage, according to who did what, where, when, and for how long, using which tool(s) (see Figure 3.4). Participants could also add personal remarks (*e.g.* special happenings, difficulties, context). Self-reported data like diaries have been used by others, such as for ’cultural probing’ (Gaver et al., 1999), in sociological research on domestic duties (Sullivan, 2000), as well as in previous studies with Roomba (Forlizzi, 2007a). Nevertheless, self-reported

[6]The Robot Matrix used five pictures: four different types of robots and one of a kitchen machine. Note that the French expression for ‘kitchen machine’ is *‘robot ménager’* which literally means ‘homemaker robot’ and therefore the term is interesting for the perception of domestic robots.

data must be analyzed and interpreted with caution because the data may be incomplete or biased by the nature of the study (*i.e* people might actually carry out more cleaning activities than usual because they consciously think about cleaning as it is part of the study). Also, people might tend to give answers that are socially desired. We discussed the diaries with participants during the interviews to confirm and clarify some of the entries.

Overall, the ethnographic approach of going to the households, combined with the described mix of qualitative and quantitative research techniques worked quite well. It allowed us to gain detailed insights into how people were living and making sense of their robotic vacuum cleaner. Especially the first visit created a point of reference and made it possible to understand the changes that the robot evoked in some of the households. Nevertheless, it has to be mentioned that the preparation of these research tools, and the study itself required a lot of efforts. A professional ethnographic researcher helped us with this.

3.2.4 Data Processing and Analysis

We collected a huge amount of various types of data but underestimated the complexity of processing, and analyzing it. For each household a detailed profile was crafted, and regularly updated after each household visit. Toward the end of the study each profile comprised around 30-35 pages. It consisted of a description of the household and their situation, their schedule,

Figure 3.5: **For each participating household a detailed profile was crafted.** It consisted of a description of the household and included a flat map for each of the floors along with photos showing the household's way of living.

division of labor, *etc.*. The document was enhanced with photos and field notes taken during the visits, as well as the drawn layout of the house (see Figure 3.5), and the various interview activities. Further, the household profile contained a summary of the qualitatively re-transcribed interviews (translated in English, if necessary), outlined the process of adopting the robot, and how the household used and integrated it in their routine.

The data from the cleaning diaries was typed in a spreadsheet for a descriptive analysis. The data on people's perception of the robot from the questionnaire was subjected to a statistical analysis. The majority of the gathered data was analyzed in a qualitative way, where two researchers studied the collected material related to the research topics, cleaning activities, and experiences the household had with the Roomba. Based on a comparison of the household profiles, we extracted relevant observations in several spreadsheets, in order to organize them both as chronological time-series as well as in topic-specific categories. This process was motivated by Grounded Theory (Glaser and Strauss, 1967; Corbin and Strauss, 1990), which is a research method and approach to systematically analyze (qualitative) data and discover theory through it, and a proposed method for analyzing user behavior in home environments (Ha et al., 2005). Generally, we were looking for specific aspects and factors that impacted on how the robot was used and experienced, *e.g.* we considered "children" as a factor, since we expected children's toys lying around to influence how the robot can be used, and because previous work suggests households with children experience more fun when using the robot (Sung et al., 2008). After a first extraction and synthesis of the studied material, data was structured and analyzed according to the *Domestic Robot Ecology* (DRE) framework of adoption (Sung et al., 2010), in order to identify similarities and differences. This integration puts findings in a relevant context and makes findings of two similar studies easy to compare.

3.2.5 Participants

As this study is exploration driven, and we wanted to discover as many facets of human-robot interactions as possible, we decided to select a small but diverse sample of households rather than focusing on one specific type. Households were recruited through word of mouth, a request distributed via e-mail, and an announcement in a school's newsletter. The call invited households with and without children and pets to "participate in a study about how people live and interact with a domestic robot". The text briefly described that households were going to receive a Roomba vacuum cleaning robot over a period of several months, and that the study would take place in their home with the researcher visiting them several times. We wanted to avoid giving a Roomba to people who were not at all interested in deploying a robot in their home. This fact has to be kept in mind when analyzing and interpreting the data because in this respect the sample is not random but biased by the fact that the households were generally positive and curious about trying out a domestic service robot. All participating households were located in the greater area of Lausanne. Lausanne is a city in the French-speaking part of Switzerland, on the shores of Lake Geneva, and has a population of about 130,000. The city is multi-cultural with about 40% of the inhabitants being foreigners. Households in our sample spoke either French, English or

Table 3.1: **Participants of 6-month ethnographic Roomba study.** The *cleaning strategy* was determined from self-reported data in diaries and on-site observations (explained in Section 3.3); the *adoption group* refers to the degree of household use or adoption of the robot (also discussed later on in Section 3.3).

# **type**	**people, age**	**pets**	**house type**	**cleaning service**	**Roomba model**	**cleaning strategy**	**adoption group**
H1 single	m, 40	no	flat	no	520	spartan	adopter
H2 single	f, 71	1 dog 2 turtles	house	yes	563 PET	minimal	user
H3 couple	f, 62 m, 58	2 cats	flat	no	563 PET	minimal	user
H4 family	mother, 43 father, 47 2 girls, 10, 8	1 cat	house	yes	563 PET	carer	user
H5 family	mother, 45 father, 45 3 girls, 18, 12, 12 boy, 15	1 dog	house	no	563 PET	carer	adopter
H6 family	mother, 28 father, 28 girl, 5 2 boys, 4, 6 months	1 cat	house	yes	563 PET	manic	adopter
H7 family	mother, 29 father, 34 boy, 1 1/2	no	flat	no	520	manic	rejecter
H8 family	father, 41 3 boys, 11, 10, 8	no	flat	no	520	spartan	rejecter
H9 family	mother, 41 father, 45 2 boys, 8, 7	no	flat	yes	520	carer	user

German as their native language. The final sample consisted of nine households with a total of 30 participants: 15 adults (8 men and 7 women), ranging from 26 to 71 years old (mean age 43.6 years), and 15 children (9 boys and 6 girls, six months to 18 years old). More specifically, the study included three single-headed (one single parent) and six double-headed households (one couple without children). Each household (H) profile is briefly described in the following:

H1 consists of a 40 year old single male participant without pets. Originally from France, he lives in a tiny apartment in the periphery of town and works in the IT domain. He also programs in his leisure time.

H2 consists of a 71 year old single woman who is originally from Austria. Now retired, she used to work in the health care sector and has been living for more than 20 years in a small house with garden in the suburbs. She has a small dog and two tortoises. She barely uses her laptop and internet but is open, though skeptical of new technology. When she has difficulties in using her computer or cell phone, she appreciates help from her younger friends.

H3 is a couple consisting of a 62 year old British woman and her 58 year old Swiss common-law spouse. They share a flat of 3 rooms in the center of the city with two cats. Both describe themselves as not being much into technology but open to new developments as long as they are useful. While he is working in the media sector (publishing company), she works independently for a company that sells organic products.

H4 consists of the parents (40ies), two girls aged 10 and 8, and a cat. This German family lives in a house with garden in the periphery of town close to the lake. They describe themselves as open to new technologies but the mother is skeptical. She used to work in the health care sector but now stays at home. The father has a background in engineering but now does freelance management.

H5 consists of the parents (40ies), 4 children (18 year old daughter, 15 year old son, 12 year old twin girls), and a dog. This Danish family lives in the periphery of town and is quite open to new technology. The father works in an international company while the mother stays at home.

H6 consists of the parents (late 20ies), the 5 year old son, 4 year old daughter, a 6 month old baby boy, and a cat. This Swiss family lives in the countryside, maintains an organic lifestyle, and uses new technology as long as it is functional (e.g. they do not have a TV). The father works as dentist and the mother manages her own tea-shop part-time in the town nearby. The grandparents help in taking care of the children and are regular visitors to the home.

H7 consists of the parents (early 30ies), and a 1 1/2 year old son. This Swiss-French family lives in the center of the city and we would describe them as an 'early adopter' household, since they have all latest technologies in their home. They emphasize design and live an organic, healthy lifestyle. The father (Swiss) works as a freelance graphic designer, partly from his home office. The mother (French) works part-time in an advertising agency.

H8 consists of a single father (41 years old), and three boys (8, 10, and 11 years old) who also live at their Japanese mother's place half of the time. This Swiss-Japanese family lives in a flat in the center of the city and we would describe them as an 'early adopter' household, based on the latest technology devices they are using. The father (Swiss) works as a teacher and has a background in robotics.

H9 consists of the parents (40ies), and two boys (7 and 8 years). This Swedish-American family lives in an exclusive apartment in the suburbs with view on the lake. They have latest technologies in their home. The father (Swedish) is working in an international company and the mother (American) gives courses in an international business school. The family left the study after 5 months because they moved unexpectedly to another country. The data for the concluding 5th visit is thus missing.

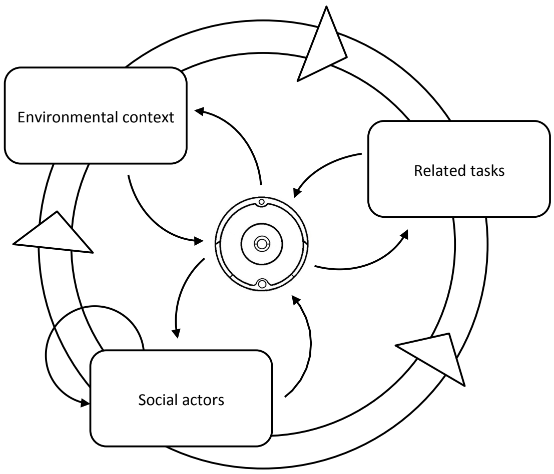


Figure 3.6: **Adapted and simplified version of the Domestic Robot Ecology** framework, Sung et al. (2010). The outer circle represents the ecology of the home which is also there without the robot. It consists of three key attributes: tasks, environment, and social actors. In the middle of the figure, the Roomba is depicted, along with the possible interactions (small arrows) with the ecology.

Findings

The findings are structured according to the research questions and formulated hypothesis. Section 3.3 presents data on how people clean, their respective cleaning strategies, and how this relates to the usage of the robotic vacuum cleaner (Hypothesis 1). How the robot's performance and usage is impacted by the environmental context of the household is presented in Section 3.4 (Hypothesis 2). Section 3.5 is about people's perception of, and interaction with the robotic vacuum cleaner (Hypothesis 3). Social dynamics and emerging phenomenons with the Roomba are explored in Section 3.6 (Hypothesis 4). Then, the four temporal adoption stages of the *Domestic Robot Ecology* are applied to our findings in Section 3.7, along with further observations that we explored but were partly unexpected (Hypothesis 5). In the end, there will be a summary that is comprised of several implications and conclusions of our findings.

Initially, we imagined developing our own model of domestic robot adoption. However, during data analysis and synthesis, we saw that our results mainly support the DRE framework, and this is why in the end, we did not build another model but added our data to the existing one. By doing so, we extend previous work and contribute to making the DRE a more robust framework that helps to create a better understanding of the adoption process of domestic robots in households.

Figure 3.6 shows an adapted and simplified version of the DRE (presented in Chapter 1, page 37). It gives an overview of interactions between a vacuum cleaning robot (pictured in the middle), and the three identified key attributes: the related tasks, the environmental context of the home, and the social actors in the household. We use this simplified version to highlight later at which stages of the adoption process the robot impacts which key attributes and *vice versa*.

3.3 Usage of the Robot and its Impact on Cleaning Routines

3.3.1 Analysis of Related Tasks

This section is about the robot's impact on the related tasks, which is one of the key attributes in the DRE. Tasks refer to the activity that the robot is designed to perform, thus vacuuming and more generally, cleaning (Sung et al., 2010). Since domestic tasks are inter-related, trying to automate one task with a robot may bring changes to the connected tasks. In the following we present how the participating households cleaned and vacuumed, and how the robot impacted their cleaning activities. As we assumed that a household's respective cleaning strategy would influence how the robot is used, we tried to categorize households according to the effort spent for cleaning the house.

Cleaning Strategies

We derived the following four types of cleaning strategies, based on the motivation that a household has to keep the home clean, the efforts made, and the amount of time spent cleaning:

Spartan cleaners barely notice dirt and do very little about it. We would describe them as generally lacking motivation to clean. They hardly use the few cleaning tools they have (e.g. vacuuming once in two months). However, they feel comfortable, as cleaning is not at all important to them. (H1 and H8)

Minimalistic cleaners notice dirt around the house which makes them feel a little uncomfortable (which creates some intrinsic motivation to clean). They do what is necessary but not more. Vacuuming is done only when they have time to do so, e.g. once every other week. Cleaning is not a priority for them. (H2 and H3)

Caring cleaners really personally care to have a clean and nice looking home so that they can show to visitors that they have a well working 'home ecosystem' (which creates some extrinsic motivation). They like to keep the home clean by vacuuming several times per week and they enjoy the resulting cleanliness. (H4, H5, and H9)

Manic cleaners almost obsessively clean. They are very picky, notice every little piece of dirt, and probably constantly feel some pressure to clean or tidy up. They are constantly engaged in cleaning and these tasks are a priority for them. Vacuuming happens more or less on a daily basis. (H6 and H7)

Note that this classification of cleaning strategies is not based on demographic factors but on our observations, interviews, and the analysis of each households' cleaning diaries. We discussed with participants when we found a dirty spot in their home and asked them how they felt about it. Interview questions asked whether one constantly felt the need to clean or tidy up or would be uncomfortable with leaving the uncleaned dishes when departing the house, for instance.

3.3.2 Comparison of Cleaning with and without the Robot

Vacuuming was generally considered as an *"annoying", "boring", "time consuming"* repetitive task, that needs to be done over and over again. Nevertheless, most participants felt rewarded by the achieved cleanliness after the vacuuming was done. Though nobody really enjoyed vacuum cleaning or liked the vacuum cleaner (VC) as a product, everyone in our sample agreed that vacuum cleaning is important, and that the VC is an indispensable cleaning tool that every household needs to have.

How did people in our study keep their homes clean, how did they use the VC and the robotic VC? In the following we describe and compare people's cleaning routine in terms of who cleans what, when, where, how, and why (Ha et al., 2005). Overall, 634 distinct cleaning activities were documented in the cleaning diaries, thereof 193 activities that involved the robotic VC, and 65 with the VC (see Table 3.2).

Who cleans? In most households, there was a fairly clear division of labor between household members in matters of responsibilities for specific household task. Generally, our findings support the traditional (gender) roles of housekeeping (Schön-Bühlmann, 2006; Sullivan, 2000). Women were the main housekeepers, independent from whether they were housewives, working part- or full-time. Women in our sample carried out 69 % of all the reported cleaning activities, and even 75 % when only vacuuming is considered (see Table 3.2). Surprisingly, women also turned out to be the Roomba's main users (67 % of Roomba usage). This speaks against the results from an online survey among Roomba owners (Sung et al., 2008) where it was found that Roomba users were equally likely men or women. Asked, why she was Roomba's main user in the household, the mother in H7 explained: *Roomba is a vacuum cleaner, and since my husband never vacuums it's only me using it."* Still, men's share of Roomba usage (23 %) was higher than their share of VC usage (14 %), and slightly above average when looking at the remaining cleaning activities (22 %).

What is notable is the high proportion of vacuuming that was done by children and teens (21 %) in comparison to their share considering cleaning in general (6 %). Also, the cleaning services carried out 20 % of the vacuuming but only 3 % of all remaining cleaning activities.

In respect to teamwork, generally, when people cleaned, they did that on their own. Only about 10 % of cleaning happened in collaboration of several people at the same time. For instance, H3 had a scheduled bi-weekly collaborative cleaning session on Sunday morning's after breakfast. Contrary to Sung et al. (2010), in our study, the robotic VC did not enhance persistent collaborative cleaning.

We did not find differences in the frequency and amount of Roomba usage between elder and younger adults. Regarding the type of household, we cannot make a general statement with a sample size of 9 households. However, analysis of the diary reports suggests that families with children used the Roomba more regularly than households without children. This finding is in accordance with Sung et al. (2008). We did not find differences in the amount and frequency of the robotic VC use in respect to whether the household benefited from a cleaning service or owned a pet. However, these aspects shaped people's expectations of and hopes for the robot.

Table 3.2: **A comparison of n = 634 cleaning activities.** The usage of the vacuum cleaner (VC) ($n \leq 65$), compared to the robotic vacuum cleaner (Roomba) ($n \leq 193$), and to other cleaning activities / usage of other cleaning tools ($n \leq 376$). Percentages are based on counting of a cleaning activity (the duration is not considered in those counts) and they do not always sum to 100 % as not all possibilities are listed; for some of the aspects some of the cases n needed to be removed due to missing or invalid details.

		vacuum cleaner	**Roomba**	**other cleaning / other tools**
gender	females	**75 %**	**67 %**	**69 %**
	males	14 %	23 %	22 %
users	children / teens	21 %	10 %	6 %
	cleaning service	20 %	1 %	3 %
weekday	Monday	18 %	13 %	14 %
	Tuesday	15 %	12 %	13 %
	Wednesday	8 %	**20 %**	16 %
	Thursday	9 %	15 %	13 %
	Friday	8 %	16 %	12 %
	Saturday	15 %	12 %	13 %
	Sunday	**26 %**	12 %	**18 %**
daytime	5-11 am	**43 %**	**43 %**	**46 %**
	1-5 pm	29 %	26 %	24 %
	6-10 pm	28 %	27 %	27 %
duration	average	~70 min	~33 min	~17 min
	< 15 min	9 %	20 %	**50 %**
	15-30 min	**58 %**	**56 %**	42 %
	31-59 min	7 %	13 %	3 %
	$\geq$ 60 min	27 %	12 %	5 %
where	kitchen	17 %	**35 %**	**58 %**
	bathroom	**35 %**	2 %	11 %
	living room	10 %	28 %	10 %
	children's room	17 %	17 %	6 %
	bedroom	14 %	10 %	4 %

Over time, participants vacuumed less. During the course of the study, the portion of vacuum cleaning with the manual VC decreased from 17 % during the first week (before Roomba was deployed), to 15 % at two months after the introduction of the robot, to 8 % after six months. We suppose that the study itself triggered additional vacuuming in the beginning. In other words, the fact of taking part in a study about living with a vacuum cleaning robot encouraged people to carry out more vacuuming than they would usually do. This effect faded out with time.

Even more than the usage of the manual VC, the usage of the Roomba decreased with time (see Figure 3.7). After 6 months most participants did not use the Roomba as a practical tool (for vacuuming). As a result, we categorized three **adopter groups**, according to how far a household integrated the robot in their cleaning routine (based on the usage data), and whether they would buy the robot themselves (if we took it away):

- **Adopters** integrated the robot in their cleaning routine and would buy the robot without hesitation;
- **Users** sporadically used the robot but would probably not buy it for themselves;
- **Rejecters** completely stopped using the robot at some point during the study and would not buy it themselves.

We considered 4 of 9 households as *user*, 2 households as *rejecters*, and 3 of the 9 households as *adopters*, since they continued using the Roomba for cleaning on a regular basis.

Not only the total amount of Roomba usage decreased remarkably over time but also the proportion of men using and interacting with it. Whereas first, men also frequently interacted with the robot, after about 2 months all male participants stopped interacting with Roomba (except in H1, the single male household, and H6, where the husband has been involved in cleaning tasks already before Roomba was deployed).

Interpretation: We interpret that the fact that Roomba usage decreases over time is partly due to the *novelty effect* and mainly caused by the rejection of the robot (meaning that it was not

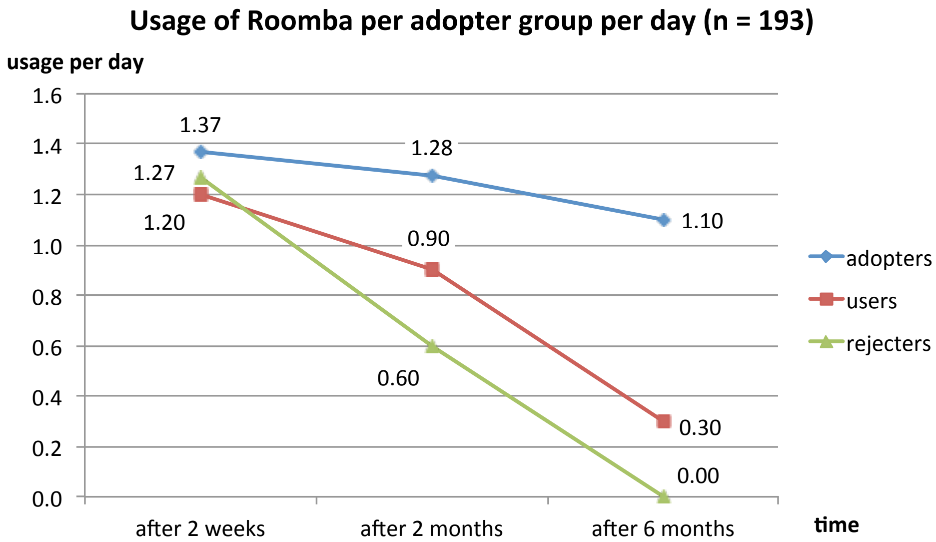


Figure 3.7: **The usage of Roomba for each adopter group over time.** A value of 1.0 reflects the robot is used exactly once a day in each household. The analysis of n = 193 Roomba usages split by adopter group shows that in the very beginning, all three adopter groups used the robot frequently, more than once a day. Both users and rejecters use the robot much less after two months, and usage decreases further after six months. Adopters, however, keep on using Roomba on a daily basis even after six months of usage.

lastingly accepted for various reasons). The phase of novelty is characterized by increased usage of the device (mostly during *initial adoption*, see Section 3.7.2, page 109). Figure 3.7 further shows how the amount of using the robot for the three different adopter groups evolves over time. It suggests that the initial increased usage of the device which is due to the novelty effect, is less pronounced for adopters.

Further, we conclude that a vacuum cleaning robot is in general able to motivate also male household members to do some vacuum cleaning, however this effect vanishes quickly, and the robot in our study was not able to lastingly change the persistent cleaning roles. It seems that a robot's function (the task that it carries out, here: vacuuming) determines what it is considered to be (here: a cleaning tool), rather than the fact that it *is* a robot (and thus a technology, for which males generally show some interest).

Similarly, a vacuum cleaning robot is initially able to enhance collaborative cleaning, by making people help it (see Section 3.6). However, this collaboration between robot and human user does not sustain but also seems to be part of the *novelty effect*.

What kind of cleaning is done? Figure 3.8 shows the distribution of different types of cleaning activities. Most of the reported cleaning activities (excluding the Roomba usage) were small things, such as cleaning a surface (25 %), for instance wiping the table after a meal, or doing the dishes (including loading / emptying the dishwasher) (23 %), and cleaning up crumbs from the floor (17 %). In addition to that, 12 % of the household tasks concerned the laundry, folding

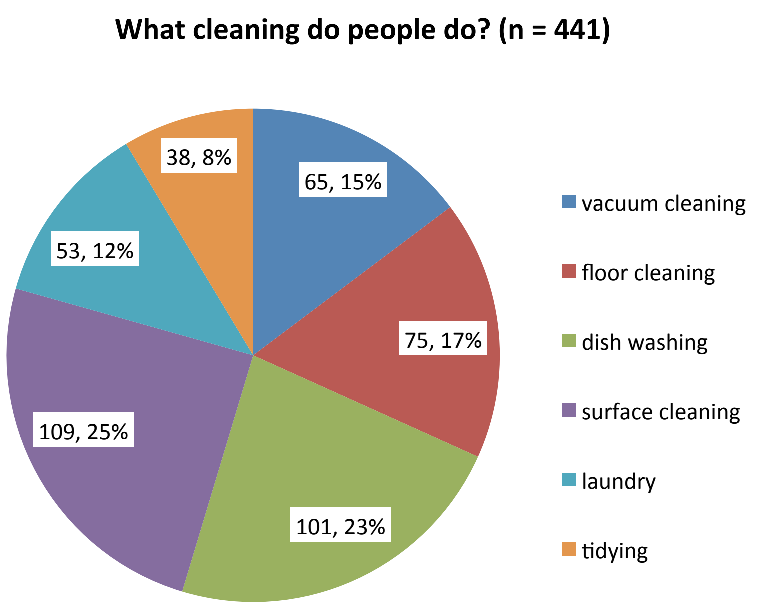


Figure 3.8: **An analysis of n = 441 cleaning activities** shows that vacuuming makes about 15 % of all cleaning activities. Vacuuming with the robot does not appear in this figure.

clothes, or ironing, and another 8 % tidying up something. Overall, 15 % of all cleaning activities were vacuum cleaning with the traditional VC.

When and how long do people clean? The amount of time and effort spent on cleaning differed significantly between the households, according to the specific household cleaning strategy (*sparan, minimal, caring, manic*). In general, cleaning happens several times a day. However, there was a tendency that the number of vacuuming sessions decreased over the course of the week (from Monday to Friday, see Table 3.2, page 87). People cleaned slightly more often on Sundays (18 %), which was especially true for the usage of the VC (26 % on Sundays). In contrast to the VC, Roomba usage was distributed more equally over the week with a peak on Wednesdays (20 %). This is in accordance with Sung et al. (2010) finding that the robotic VC helps people to clean more regularly.

On average, a cleaning activity lasted 17 minutes, however 50 % of all cleaning activities took only in between 1-15 min. People spent longer for vacuuming: mostly between 15-30 min but still 27 % of the reported vacuuming sessions lasted 60 min or longer, which led to an average value of 70 min. This long duration was a bit of a surprise but since some participants always vacuumed everywhere at the same time, it seemed reasonable. In contrast to vacuum cleaning, Roomba was used 33 min on average[7], with 20 % of the usages not taking longer than 15 minutes. This reflects the fact that people tended to stop the robot manually after a short period of time since they wanted to use it for so-called spot cleaning. However, there was an issue: participants expected the robot to be able to vacuum the same surface in less time than it would take them when vacuuming with the manual VC.

Concerning the time of day, participants carried out most cleaning during the morning (46 % from 5-11 am), compared to 24 % in the afternoon (1-5 pm), and finally 27 % in the evening (6-10 pm). We found a similar distribution when only looking at the vacuuming and the usage of Roomba. Whereas some of the households had a clear schedule (*e.g.* Sunday morning after breakfast) for their cleaning activities, others did cleaning in a more opportunistic fashion when it was needed or they felt uncomfortable, as also described by Forlizzi and DiSalvo (2006). Most cleaning activities turned out to be related to meals. Households with pets reported to do additional cleaning due to pet hair or other dirt that the pet produced. Special extra cleaning was also done before guests arrived.

Where do people clean? More often than anywhere else in participants' homes, cleaning took place in the kitchen (58 %), followed by 11 % in the bathroom, and 10 % in the living room (see Table 3.2). However, the picture looks different for vacuuming and again different for Roomba usage: the VC was used most often in the bathroom (35 %), followed by the kitchen, and the children's room (each 17 %), the bedroom (14 %). Contrary, Roomba was used most often in

[7] However, the duration for a Roomba usage was often based on an estimation, for instance in those cases when a user started Roomba and then left, so he/she did not see when the robot had finished its cleaning.

the kitchen (35 %), and the living room (28 %), followed by the children's room (17 %), and the bedroom (10 %). Thus, there is an interesting difference between traditional VC and robotic VC in terms of where these tools are used. Participants avoided using Roomba in the bathroom because they were afraid that wet spots could damage the robot. Contrary, they used Roomba a lot more in the living room than the VC, probably because the robot would go under the sofa where they didn't reach with the VC, and also to give demos to guests and friends. Another explanation for the difference in the amount of usage in the kitchen can be found. Generally, the kitchen floor needs to be cleaned up frequently, so why was Roomba used there more often than the VC? Compared to the VC, Roomba offers a spot cleaning function that allows a quick cleaning-up of a specific spot. Further, Roomba does not need to be set up the same as the VC. In other words, it does not take much time to grab the robot, put it in front of the crumbs on the kitchen floor, and press the CLEAN button (or SPOT function button). However, the VC needs to be taken out from the closet, the cable pulled out, plugged in, switched on, and then the same back again. This is not convenient for quick spot cleaning, and it takes considerably longer to set up / bring back the VC compared to Roomba.

Interpretation: The specific characteristics of a cleaning tool determine where it is used, and also for what type of cleaning, which is described in more detail in the following paragraph on how people clean.

How do people clean? Often (35 % of the cases), people used several tools at the same time (see Figure 3.9). Then, similar to the distribution of cleaning activities (see Figure 3.8), the corresponding cleaning tools are used: 15 % VC usage, followed by 14 % sponge, and each 10 % cloth and washing machine.

A more detailed look at how people in our sample vacuum cleaned shows that in most cases, people vacuumed 'room-by-room' when using the traditional VC, and spend more time vacuuming spots where they expected a lot of dirt.

Most participants imagined Roomba would follow a similar strategy and that it would finish cleaning one room before moving on to the next one (see Figure 3.10, page 93). Also, participants imagined they would see the robotic VC passing over every spot only once but that it would automatically stay longer at a dirty spot. Further, they generally expected that the robot would perform better than their traditional VC in even less time. However, though the room-by-room cleaning seems to appear as an optimal strategy for the human user, several robotic VCs use a random navigation, and also the available Roomba models do. It means when the robot passes on to the next room / area it has not necessarily finished cleaning the room / area where it has just been. This is a discrepancy between people's and robot's vacuuming path and is perceived as such by the user, which has also been found in a study by Kim et al. (2007) who compared human and robot vacuuming trajectories in Korean homes. Our results support this expectation mismatch between how the user imagines the robot to perform an optimal cleaning strategy from his/her perspective and the implemented, technically and / or the energy consumption optimal cleaning path (Vaussard et al., 2014). This discrepancy can have a negative impact on people's readiness to view the robot as a useful cleaning tool (as we will describe later).

We did not give instructions how to use the robot but let people experiment themselves. Overall, we did not find one common strategy how participants were using the robot. In the beginning all participants observed the robot and would not leave the home while Roomba was running. Most participants wanted Roomba to clean a specific area (*e.g.* around the eating table) at a given time, as fast as they would have been themselves when cleaning the spot with the manual VC. However, the Roomba models used in this study did not show a very good performance when used this way, as the "dirt detect" function did not work very well, and the robot would soon move on cleaning another spot, though the desired spot was not well vacuumed yet. This strategy from the robot side was somewhat incomprehensible for the participants, who expected the robot to finish cleaning the desired spot first. Consequently, most people got disappointed. But instead of changing their way of using Roomba, and trying to find out how the robot could do better, they stopped using it. Only three (H1, H6, H7) out of the nine households tried different strategies, with the goal of optimizing the robot's cleaning efficiency. For instance, they left Roomba doing its job around the dining table for half an hour instead of 2 minutes, and pulled chairs away so that the robot could access the spot better. This change of usage strategy helped the robot to improve its performance. The other households were somewhat not willing to spend the effort in learning how to use the robot in a more efficient way, and gave up after some disappointment.

The previously defined four cleaning strategies (spartan, minimalistic, caring, manic) served well to describe and explain how households were cleaning and using cleaning tools. However, the classification was not transferable to how they used the Roomba which suggests there are

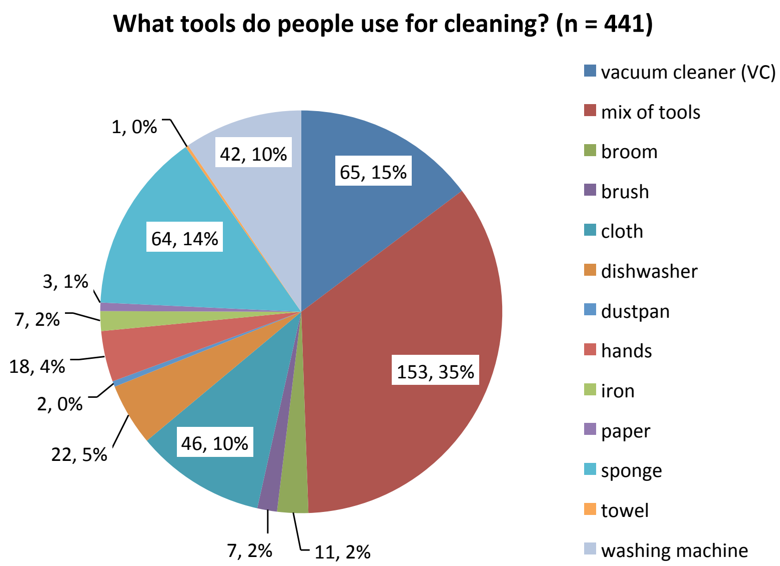
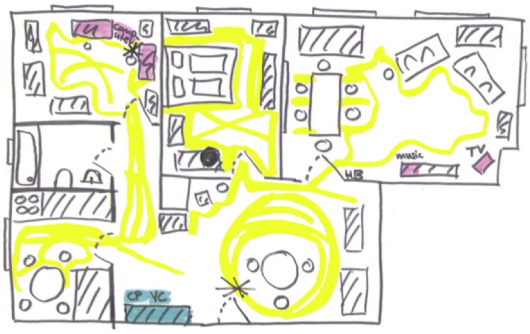
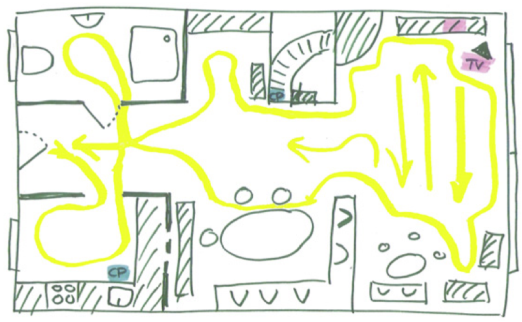


Figure 3.9: **The distribution of cleaning tools** used in n = 441 cleaning activities shows that people often use several cleaning tools at the same time.

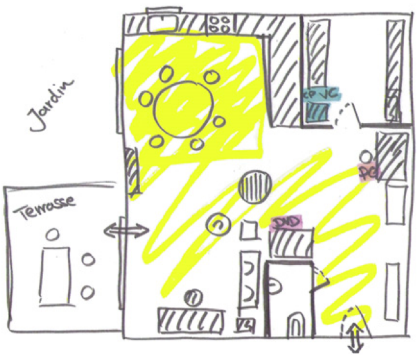
additional dynamics with the robotic VC that we do not know yet. With traditional vacuuming, spartan and minimalistic cleaners usually planned their vacuuming sessions in advance, *e.g.* H1 had a monthly alert on his smart phone to remind him of vacuuming in the beginning of the month. Despite the fact that he used the VC only once per month with little effort, he turned out using the Roomba on a daily basis, and he put great effort in making it work well. In contrast, caring and manic cleaners vacuumed with the traditional VC more or less on a daily basis. The picture here was completely different for the Roomba usage. H7, for instance, tried out the robot a couple of times but then refused using it as she was not satisfied with its performance and she



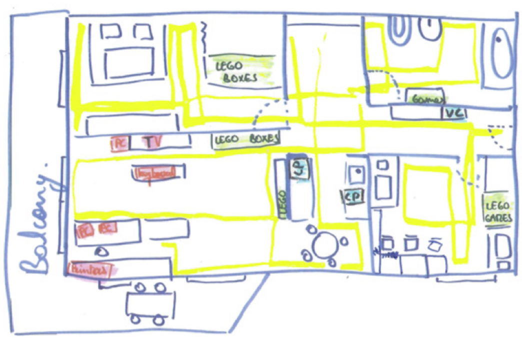
(a) H3 expected the Roomba to perform a room-by-room cleaning, remaining longer at more dirty spots, such as around the table and in the hallway. They did not want the robot to vacuum in the bathroom because of possible wet spots that could cause damage.



(b) H2 imagined Roomba to go everywhere at once and to follow along the walls, cleaning one room after the other. The participant imagined the robot to start and finish its cleaning session at the entrance door.



(c) H6 assumed Roomba to randomly go everywhere and remain longer at more dirty spots, such as around the table / in the kitchen area. They didn't want the robot to vacuum in the storage room because of the clutter there.



(d) H8 expected Roomba to follow along the walls, always turning by 90° in order to avoid obstacles. They imagined it would pass over every spot once, carrying out a systematic cleaning path.

Figure 3.10: **Different imagined Roomba cleaning paths.** Participants had different expectations how the robot would navigate around the home. During the second visit, before they were using the Roomba for the first time, participants were asked to draw how they imagined the robot to navigate around their home, and where they wanted to use it. These drawing were based on the flat maps that were drawn during the first visit.

did not want to do anything about it. These differences highlight that a robotic VC is used as an independent tool and differently from the classic VC.

How people cleaned did not seem to be related to whether they had children or were pet owners. This was against our assumption that households with additional “sources of dirt” (children, pets, garden) would clean more frequently. Each household complained about specific problems related to cleaning and used different strategies to keep efforts as low as possible. For example, H4 lived in a house with a garden. To keep the ground floor with the living room and kitchen fairly clean, they always entered the house through the garage and left the shoes out there. Other strategies to keep the hot spots clean without having to use the VC were the usage of different kinds of brooms or dustpans. Especially in the kitchen, these mobile tools that don’t need electricity or being plugged in, were used for short spot cleaning. Though the VC would probably be more efficient, people found it was too much of an effort to get it out, plug it in, and store it back again (as mentioned before, the readiness of a tool being used seems to matter).

Interpretation: We interpret that the type and anticipated duration of cleaning, planned *vs.* opportunistic (Forlizzi, 2007a), and quick *vs.* long-duration cleaning determines what kind of tool people prefer for the cleaning. The choice of tool, in turn, depends on how ‘ready’ the tool is for being used. This is related to several aspects, for instance, where the tool is stored, how mobile the tool is (*e.g.* heavy, big), whether it needs to be plugged in to an electricity socket, whether it needs water, *etc.*. Accordingly, brush, dustpan, and also the vacuum cleaning robot are tools that are “ready-to-use” in contrast to the vacuum cleaner. Consequently, these tools are likely to be used more often for opportunistic and quick cleaning.

Why do people clean the way they clean? Cleaning is a private activity about which people do not openly discuss. Besides social norms, cleaning is rooted in personal convictions and beliefs, as well as in how it was learned and experienced from childhood on. We also found that people’s need for control within their domestic environment seems to be related to why they clean the way the clean. The person who is the main housekeeper (mostly the female head of the household) seems to be the driving force in deciding how and why cleaning is done the way it is done. However, this research does not focus on cleaning but on human-robot interaction.

Regarding the question why some people used specific cleaning tools more than users was also related to how practical the tool was for them and how easy it was to use. For instance, some participants tended to store their VC in a ’remote place’ such as the furthest corner of the closet, despite the fact that it was used on a regular basis. Participants were not very clear in their answers why but mentioned the VC was simply an *ugly* and *unpleasant* tool that they didn’t like and thus tried to *keep it out of sight*. One participant said: *“I don’t want to see the VC every time I open my closet and be reminded of the need to vacuum.”* Another one said: *“I need the VC every single day to clean up around the table. Sure, it would be easier to have it just right next to the table. But it wouldn’t look nice. I don’t want my VC or any other cleaning tool to be that present.”* Also, people didn’t like the noise of the VC, its large size, and heaviness, that it looked ugly, and that it needed to be plugged in to an electrical socket when used, which is not convenient for a device that needs to be moved around manually. Pet owners reported problems with the efficiency / performance of the VC and some others with storing it. H1 and H4 needed to attach the tube of the VC inside the closet so that it did not fall out. This made it overall annoying to get the VC out of the closet and to put it back in, which made it a tool that was not *ready for use*. The 71 year old woman in H2 stored her VC in the basement, since it was mainly the cleaning lady who used it. However, when the woman wanted to use it herself, she had to carry it upstairs, which was a heavy task for her and thus she tried to avoid it.

Interpretation: It seems that in households in which the traditional VC is a well integrated and valued tool, that is used on a regular basis (every day for quick cleaning (H4, H7, H9) or once a week for scheduled big cleaning (H3)), a vacuum cleaning robot has a fairly hard time to find its place. Contrary, in households where the traditional VC is an almost forgotten tool (H1), a vacuum cleaning robot seems to be integrated more easily. However, to both these observations we found exceptions to which the aforementioned conclusions do not apply (H6, H8). This is why we conclude that there are other factors (more individual ones) that have an even stronger impact on the decision whether a vacuum cleaning robot will be lastingly adopted or not.

The negative aspects related to the overall design and functioning of the vacuum cleaner can be used to guide the design of robotic vacuum cleaners, with the goal of improving the overall user experience related to vacuum cleaning. Future developments need to take aspects of how a device is used and stored into account and develop appropriate design solutions. Domestic appliances that are in regular use, such the vacuum cleaner, need to be easy to store and handle. Future domestic robots need to enable an overall positive user experience to become useful and valuable tools. However, it remains a challenge for domestic service robot to become “invisible” by merging with their environment, or be very well designed to not look like a cleaning tool.

Summary Vacuuming is an interesting application field for domestic service robots because the traditional tools for domestic (not industrial) use leave space for optimization in various aspects. Most people experience a discrepancy between the fact that vacuum cleaning is important and the VC is an indispensable tool but both the task itself and the VC as a tool are considered unpleasant, due to various reasons. Robots could optimize the task of vacuum cleaning and the related user experience. Vacuum cleaning makes noise, no matter if one uses a traditional or a robotic VC. It is therefore preferable if a robotic VC runs while the user is not at home (or at least in a different part of the house). The fact that the robot vacuums while the user is not present would also have the advantage that the robot is not observed by the human user and can follow its own optimal cleaning path which might be incomprehensible and appear not optimal to the user. However, the vacuum cleaning robot could then just finish its task taking all the time that it needs to ensure a good result without being stopped by the human user too early. A general comparison between the usage of traditional VCs to robotic VCs shows that people use a robotic VC in a different way than a classical VC. Both tools are preferred according to their own characteristics (*e.g.* suction power, immediate availability), and the characteristics of the area which needs to be cleaned (*e.g.* surface, obstacles). This difference in usage might suggest that a robotic vacuum cleaner might not *a priori* be able to fully replace a traditional vacuum cleaner.

3.4 Environmental Context: Physical and Social Space

After having studied and analyzed the impact of the robot on the related tasks and *vice versa*, we now focus on the second key attribute of the DRE framework, the environmental context of the home. Similar to how cleaning impacts and is impacted by the usage of the robot, also the environmental context impacts and is impacted by the occurring interactions with a domestic robot.

With the environmental context we understand the physical, social, as well as technical space of a home (Sung et al., 2010). This comprises the indoor physical environment (layout, floors, rooms, furniture, *etc.*), the social lifestyle of the household (*e.g.* specific norms and rules that apply to all or specific rooms of the home), as well as the configuration and organization of technologies of the home (*e.g.* location of the TV, computer). Note that with mobile and ubiquitous technologies, the location of a technology has taken a new meaning. Most domestic robots are moving autonomously around the house, thus the ubiquitous spatial presence impacts on the broader physical and social space (Sung et al., 2010). Previous work suggests that a household's specific environmental context of the home is likely to impact on how a domestic robot is used and experienced (Forlizzi and DiSalvo, 2006) as well as *vice versa*. Our observations generally confirm this finding, as will be outlined in the following.

How the Physical Space Impacts on the Robot

Participants expected the robot to work equally well in the entire house and intended to use it almost everywhere (see Figure 3.10, page 93). However, as we had assumed, the physical layout of each of the different apartments and houses impacted on the performance of the robot.

Regarding the different kinds of floor types, homes in our sample included parquet floor, tiles, as well as various types of carpets. The robotic VC worked equally well on each of the surfaces, however people reported difficulties with the transitions, when Roomba was moving from tiled or parquet floor to carpet (the robot dropped dust or even got stuck). This negatively shaped the experience people had with the robot and was a crucial factor of acceptance. Not all participants were willing to (re-)move the 'difficult' carpets or make other kind of adjustments. For instance, an elderly woman (H2) who had fairly expensive Persian carpets (see Figure 3.11c) was afraid the robot might leave marks on them and only used the robot in the kitchen where she had tiles and no Persian carpets. Another household (H4) had floor-long curtains in the living room in which the robot always got stuck (see Figure 3.11a). They tried to use the robot's "virtual wall" system but it did not work well.

(a) (b) (c) (d)

Figure 3.11: **Various physical characteristics of the home are problematic for the robot.** (a) One household had floor-long curtains in which the robot got stuck; (b) in several households there were door sills over which the robot could not pass; (c) several households reported problems with thick carpets; and (d) in several households there was either a lack of electrical sockets, or they were installed too high so that the robot's charging station could not be properly placed.

Two households (H3, H7) had door sills (see Figure 3.11b) that the robot was not able to pass over. Whereas H7 felt Roomba's inability to overcome this obstacle made the robot less usable, H3 acknowledged that this meant she could easily keep the robot in the kitchen.

Households with stairs did not feel that this constrained how they used the vacuum cleaning robot, however usage data suggests that Roomba was used slightly more often in homes without stairs.

Another aspect that constrained where and how the robot was used, was the location of electrical sockets. This is because the robot's charging station needs to be plugged in all the time, so that Roomba can automatically go back to it to recharge. In three homes there was a lack of electrical sockets in the living room and in two of them, the height of the sockets meant that the charging station could not be properly placed on the ground because the cable was too short (see Figure 3.11d). Participants did not use cable extensions. Overall, this was clearly impractical and it made it difficult to use the robot in its intended way because it constrained its autonomy. In the end, this negative experience hindered people in integrating the robot in their cleaning routine.

In general, participants found it easier to use the Roomba in a home characterized by large open spaces and few separating walls. Additionally, participants were positively surprised to see the robot cleaning underneath furniture where they could not reach with the traditional VC and placed the Roomba intentionally right in front the bed or closet. This example shows that the physical layout of the home can trigger specific use cases with a robot.

The Roomba also led people to make adjustments to the physical space of their homes (see Section 3.6), which is a phenomenon that has been observed also by Sung et al. (2010). Almost all of the nine households modified something due to the robot, mostly in the beginning of the study (see Section 3.7.2 and 3.7.3).

Interpretation: Some physical characteristics of a home impact the performance of the vacuum cleaning robot, as well as how it is used. Constraints that specific physical aspects of the home bring along, seem to be an important factor of the user experience, and in turn impact the acceptance of the robot. However, our findings suggest that there is another dynamic which seems to be even more important. We found that despite the fact that H7 provides an optimal physical environment for the usage of Roomba, the robot was rejected after only two weeks of usage. H7 had no stairs, large open spaces, no things or obstacles lying around, and very few transitions between different types of floors. There was a sufficient number of power sockets, and Roomba would generally have been able to reach every spot. Consequently, the household did not need to make any adjustments in order to enable the robot to work well. However, H7 rejected the robot, and we found that it was the mother's attitude toward cleanliness and toward the robot itself that hindered the adoption. Consequently, when it comes to the question whether a robot will find its place within the household, it seems that personal factors are more important than the physical layout of the home. Another example confirms this conclusion. H1, the home of a single person, was a tiny space, with lots of corners, door sills, and spots that were hard to reach for the robot. There were no large open spaces and there was a lack of power sockets, thus overall we classified the physical space of the apartment as challenging for the robot. However, H1 was not only willing to make several adjustments in his apartment (he re-arranged the furniture in the living room), he also studied the spots that were problematic for the robot, and for instance, every time before using the robot, he put the coffee table on the sofa because he found the robot stuck in it several times before. Thus, despite the fact that H1 did not have an optimal environment for Roomba, his personal attitude toward cleaning and the robot made him lastingly adopt the robot.

How the Social Space Impacts on the Robot

How people were using the robot was further impacted by the social space and the lifestyle of a home. Some homes were characterized by a harmonious arrangement of furniture and decor objects (which is also part of the physical space). The specific lifestyle of H3 made it impossible for the woman to use *"something as artificial as a robot"* in her atelier (painting room). She explained the robot would not fit the decor of the room, and when she once tried out using the robot there she felt that it was disturbing the mood. The robot's design interfered with the social space and lifestyle of several other homes.

Characteristics of the design of the robotic VC seemed to be more important to people than the design of the classical VC. This could be due to the fact that in contrast to a usual VC, Roomba was not hidden in a closet when not in use but was always visible and present. Further, it moved autonomously around the home and some people found this intruded their privacy. Consequently, they didn't like to use it when they were not at home because then they would not have been able to *"observe it"* (H7), and the mother didn't like surprises when she came back home. So she used the robot only when at home, which however was not a good solution either because the robot's vacuuming noise was annoying for her. Only one participant (H2) described she liked the robot's noise because it gave the impression it was *"actually working"* and *"doing its job"*. The woman in H2 stated: *"It's nice when the Roomba moves around the house making* *little noises and talking to me occasionally"* (when the robot verbally reported an error). Some of the other participants decided to use the robot while they were not at home. However, not everybody felt comfortable about the fact of having an electrical device moving autonomously and not-supervised around the house.

Most participants did not feel comfortable with having the robot and its charging station visible in a prominent open space, such as the living room. The living room is a highly social space, where people relax, host guests and have conversations; it serves to present a specific lifestyle, and most households felt the robot should not be part of this, due to its design or its function. The mother in H9 explained: *"Still, this is a vacuum cleaner and you don't want to have your vacuum cleaner next to your dining table when you are having dinner or friends are coming over. It looks too much like work!"*. Only for the father in H8 it was *"cool"* to expose such an innovative device in the living room.

Interpretation: Overall, a vacuum cleaning robot interferes with the social space of the home in several senses. Its visible scope does probably not match with the design of the home, and it further makes an unpleasant noise. Further, there are specific norms and rules in each home that an autonomous device would need to take into account. For instance, it would not be acceptable for people to have the robotic VC entering the living room while guests are over or while watching a romantic movie. Consequently, autonomous agents need to adapt to the social space of the home.

3.5 Social Actors: How People Perceive the Robot

According to the DRE framework, the third key attribute that impacts and is impacted by domestic robots, are the social actors. Social actors are the living members in the home, such as householders, guests, and pets (Sung et al., 2010). These can be divided in 'users' who interact with the robot on a regular basis to complete the intended task, and 'non-users' who do not regularly use but engage in social activities with the robot.

Various kinds of social activities and responses have been described with domestic robots (*e.g.* anthropomorphism, or empathy). These are, amongst other things, based on how people perceive and relate to the robot (Epley et al., 2007), which in turn impacts the acceptance and willingness to adopt the robot. To capture people's perception of the robot, we let them evaluate Roomba regarding various aspects. We were interested in whether and how people's perception changed over time and how far it would be related to individual and external factors.

People's Perception of the Robot over Time

Participant's perception of the robot was assessed using a recurring questionnaire that was integrated in the semi-structured interviews at each household visit (see Appendix, page 232). All present family members were asked to rank the robot on a 7-point differential scale (values

1-7) according to the aspects perceived intelligence, perceived usefulness, perceived ease of use, experienced fun, experienced attachment, experienced impact, and their overall impression. The method was adapted from Sung et al. (2009a). Scopelliti et al. (2005) used similar scales to assess people's perception of domestic robots. Most of the assessed aspects are relevant factors in traditional technology acceptance models, as presented in Chapter 1 (Venkatesh and Davis, 2000; Venkatesh and Bala, 2008). Participants were interviewed collectively. On one hand, this enhanced the discussion and kept the situation as natural as possible; on the other hand however, it is possible that participants influenced each other in their answers. Especially younger children seem to have adapted their answers to their parents' rating. Participants filled out the questionnaire at five time points: $(T1)$ before they had seen the robot (expectations), $(T2)$ right after they had unpacked and tried out the robot the first time, $(T3)$ two weeks after they had received the robot, $(T4)$ two months afterward, and $(T5)$ after six months living with the robot. For analysis, participants' ratings were compiled in a spreadsheet, to one decimal place (two coders agreed on the interpretation of each mark. Then, repeated measures ANOVA tests were used with time (5 time points) as within-subjects factor. Further, we used *gender, family code,* and *adopter group* as between subjects factors. Gender had two categories (female / male), family code had nine categories (H1-H9), and adopter group had three levels (rejecter / user / adopter) according to how far at the end of the study a household was still using the robot for cleaning or not. *Rejecters* didn't use the robot any more, *users* sporadically used the robot but would not buy it for themselves, whereas *adopters* integrated the robot in their cleaning routine and could not imagine living without it. In general, one has to be cautious about the statistical analysis of this data, since only a small number of valid ratings (n = 15) was considered. Due to the small sample size *age* was excluded as factor for statistical analysis.

Overall, analysis revealed a positive peak for most of the ratings at $T2$, right after participants used the robotic VC for the first time (see Table 3.3). This suggests that the sample generally had a rather positive first experience with the robot and most expectations $(T1)$ were initially met (or even exceeded). However, most ratings were less positive in the final rating after six months but there were variations during the study, which will be outlined in the following (see also Figure 3.12, page 103).

Perceived intelligence Overall, participants rated the robot as *"somewhat intelligent"* (values from 3.3-4.2) but were not really convinced about it being smart. The rating did not change significantly over time (see Table 3.3). Interestingly, at all five time points, male participants rated the robot as more intelligent (average 4.5) than females (average 3.4), however, this difference was not significant. When asked why they thought Roomba possesses intelligence, men more often referred to the 'robot side' of Roomba: its abilities to detect and avoid obstacles, stairs, and being able to recharge itself. Contrary, women referred to its rather limited vacuuming performance and found it was not as intelligent because *"it doesn't see where the dirt is, it sometimes leaves it, it can't be smart!"*. There was no significant difference between the adopter groups ($F(2,12)=0.2$, $p=.79$), however adopters rated the robot more intelligent at each time point than the others.

Table 3.3: **Analysis of people's perception of Roomba over time.** Mean (M) and standard deviations (SD) for each topic over five times ($T1 - T5$) on a 7-point scale (1-7). Repeated measures ANOVA with time as within subjects factor, n = 15. The data is visualized in Figure 3.12, page 103.

Topic		**T1**	**T2**	**T3**	**T4**	**T5**	**F (4, 56)**	**p**
Intelligence	M	3.9	4.1	4.2	3.8	3.3	2.2	0.09
	SD	1.6	1.6	1.6	1.7	1.3		
Usefulness	M	4.9	5.2	5.1	4.5	4.2	2.6	0.05
	SD	1.4	1.0	1.2	1.9	1.9		
Ease of use	M	5.6	6.1	6.3	6.3	6.1	2.2	0.08
	SD	1.2	0.6	0.7	0.8	1.0		
Fun	M	4.0	4.1	4.6	4.1	4.3	0.7	0.59
	SD	1.6	1.6	1.7	1.6	1.4		
Attachment		no valid data due to wrong measurement						
Impact	M	3.5	4.2	4.0	3.2	2.8	3.4	0.02
	SD	1.6	1.4	1.1	1.3	1.5		
General impression	M	5.2	5.2	5.0	4.9	4.5	1.3	0.30
	SD	1.2	1.1	1.2	1.3	1.5		

Interpretation: It is not very well defined what *intelligence* in a vacuum cleaning robot means. Interestingly, for women the intelligence of a domestic service robot seems to be more related to how well it performs the intended task, whereas for men intelligence is more related to the autonomy of the robot. In general, users view a robot as intelligent when it is able to learn and adapt over time to its environment and the specific needs of the user(s). Since Roomba is not able to do so, people do not rate it as very intelligent, and values decreased slightly further over time.

Perceived usefulness Participants rated the Roomba as quite useful (values from 4.2-5.2). However, the rating decreased significantly over time. Women rated the robot less useful (average 4.4) than men (average 5.2) but this difference was not significant. Again, women (Roomba's main users) evaluated the robot's vacuuming power, whereas men regarded more generally that the robot could help cleaning and would thus be a useful device. A significant difference was found for the adopter group (F(2,12)=6.7, p=.01): adopters rated Roomba significantly more useful (average 6.1) than users (average 4.6), and rejecters (average 3.9). This difference and relation between perceived usefulness and acceptance is in accordance with models of the adoption of technology (Rogers, 1995; Venkatesh, 2000) and acceptance of robots (Heerink et al., 2009). The perceived usefulness might also be related to the perceived performance of the robot.

Interpretation: Data suggests that the perceived usefulness of a domestic service robot is related to how far it gets adopted. Consequently, it is important that a domestic robot is able to effectively carry out a concrete task.

Perceived ease of use People found the robot very easy to use (values from 5.6-6.3) and the only thing they would change about it, was how one had to empty the dust bin and clean the robot's brushes. Still, some participants had difficulties in using the additional infrared walls (only available for the Roomba 563 PET version), and especially the elder participants did not know how to assemble and set up the charging station. However, they had different reasons to appreciate the robot. Two elderly people in our study (62 and 71 years) actively tried to avoid using the VC, due to its heaviness and their personal physical restrictions. With Roomba they both liked that it was much smaller and lighter than their VC. Thus, especially elderly people might benefit from domestic service robots. There was no significant gender difference in the perceived ease of use, however, data suggest that with growing experience, especially women rated the robot as even easier to use (contrary, men rated the robot as less usable in the end of the study, probably because they had not gained as much experience with it). Accordingly, adopters rated the robot significantly easier to use (average 6.7) than rejecters (average 5.9) ($F(2,12)=4.6$, $p=.03$). This confirms again traditional models of technology adoption (Rogers, 1995; Venkatesh, 2000) and acceptance of robots (Heerink et al., 2009).

Interpretation: Roomba appears easy to use, which is an important factor for acceptance. As elderly people might particularly benefit from domestic service robots, robot interfaces will need to be designed with care and take into account the special needs of elderly people as a user group.

Experienced fun Participants rated the robot as 'somewhat fun' (values from 4.0-4.6). There was a qualitative gender difference (not significant), in the sense that the experienced fun remained quite stable for male participants, whereas it tended to decrease with time for female participants. Men described the robot more as a 'fun gadget' than females, who referred to it as *"In the end, Roomba is a cleaning tool and it is not really fun to use it."*. In respect of the three adopter groups, there was no significant difference ($F(2,12)=0.3$, $p=.73$). However, at each time asked, adopters rated the Roomba as being more fun (average 4.5) than rejecters (average 3.9).

Experienced attachment The ratings for people's attachment were unfortunately not consistent because we discovered they were strongly related with one of the two respective instructors who conducted the interview process. The two instructors described *attachment* in an inconsistent way during the study and at different households.[8] Because of this, we cannot use the data for attachment for this study. However, the fact that we had to explain what we mean with *attachment* shows that the item is not very concrete, and might be changed in future studies.

Experienced impact Participants estimated the robot's impact on their household significantly different at the different points of time. In the beginning at $T2$ (right after the first usage) and $T3$ (after two weeks), people believed that Roomba could change something in the household

[8] Whereas one of the instructors described *attachment* as feeling *emotionally attached*, the other instructor described it more as being attached *due to its function*, thus in a practical way.

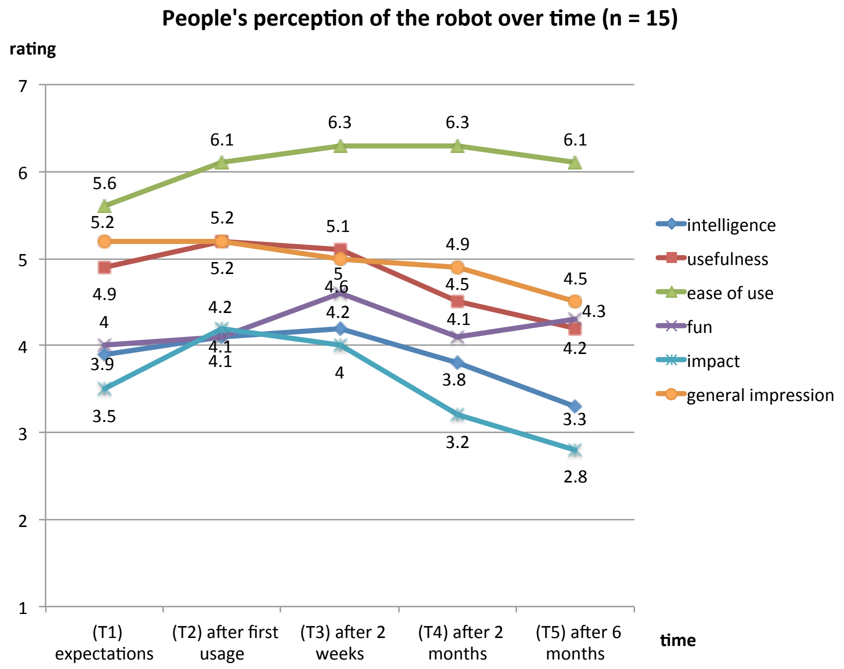


Figure 3.12: **People's perception of the robot over time.** Participants' ratings of various aspects of Roomba tend to slightly decrease over time. Except the perceived ease of use, and the experienced fun, the rating of all other aspects decreased over time.

(*e.g.* , replace the manual vacuum cleaner). After two and six months ($T4$ and $T5$) they lost their initial hope the robot could evoke some changes. There was a significant difference for perceived impact of the robot between the adopter groups (F(2,12)=5.4, p=.02). Adopters rated the robot's impact on their household significantly higher (average 4.6) than users (average 3.7), and rejecters (average 2.9).

General impression People's expectations before they used the robot ($T1$) were quite high (average 5.2), and though not significant, men expected even more (average 5.7) than women (average 4.8). However, with time, participant's general impression constantly got slightly lower, even though with an average rating of 4.5 in the end, it was still rather positive. The three adopter groups differed significantly in their ratings of the overall impression (F(2,12)=23.3, p<.00). Adopters had the best overall impression (6.2) followed by users (4.5), and rejecters (3.8). Interestingly, at $T1$ (before they had seen the robot), those households who later adopted the robot had the lowest expectations (4.5) while the rejecters had the highest (5.7).

Interpretation: It seems that those who have high expectations toward domestic service robots will probably have a rather negative first experience since the robot might not always meet high expectations. Contrary, those with a bit lower expectations might be positively surprised during the first usage, and we assume that the initial experiences with a robot are crucial for lasting acceptance.

Summary There are interesting qualitative gender differences in how the robot is perceived. Data suggests that while men tend to view Roomba as a technology, and evaluate it based on its robotic functions (*e.g.* detection of stairs, obstacle avoidance), women tend to view Roomba as a cleaning tool, and evaluate it based on its task performance (how well it cleans up). How the robot is perceived is further related to whether it is accepted or not. Data suggests that adopters perceive their robot significantly more useful, easier to use, more convincing (higher impact), and overall have a more positive general impression. People's perception of the robot is also likely to change over time (see Figure 3.12). Qualitatively, we describe this evolution as from *"fancy new robot"* to *"just another cleaning tool"*. This mirrors the fact that after some time, people get used to and become familiar with the robot (when using it on a regular basis) or simply forget about it. We interpret that the change of perception is related to the novelty effect. Interestingly, participants describe and relate to the robot as a new additional kind of cleaning tool which however is different from the vacuum cleaner.

3.6 Social Dynamics and Activities with the Robot

Though Roomba is a functional robot, it created some social dynamics, which partly had implications for participant's social life. It has also been found by others that domestic robots can serve as socially interactive agents (Forlizzi, 2007a; Sung et al., 2007). In our study people engaged in social activities with the robot, however, we would like to stress that these social dynamics were *quite rare* and *not persistent*. In previous work it is described that people tend to give a name to their vacuum cleaning robot, and that they like to customize it (Sung et al., 2007, 2009c). We did not observe any activity of **customizing or personalizing the robot** and only one woman (H3) gave a name to their robot (*"Elvis"*) which she explained was more for fun than actually reflecting a kind of social attachment to the robot. We think that none of the participants perceived the robot as a social agent, as it is suggested in the DRE framework (Sung et al., 2010).

(a) (b) (c)

Figure 3.13: **Examples of collaborative cleaning.** People spontaneously assisted the robot in cleaning. In (a) a boy collects the crumbs on the kitchen floor and pushes them all together in front of the robot; in (b) the woman collects dust from the carpet while the robot is vacuuming; and in (c) two boys assist the robot in cleaning by putting up the carpet in the bathroom.

A similar rather weak social interaction that only occurred during the stage of initial adoption is **collaborative cleaning** and assisting the robot. In this respect, our findings are different from previous work on Roomba adoption, in which it is concluded that the domestic service robot has the social impact of “making cleaning a concern for everyone in the household” (Forlizzi and DiSalvo, 2006; Sung et al., 2010). In our study, the robot was not able to lastingly motivate household members to clean who did not clean before, or to collaborate with the robot. Only in the very beginning did people assist the robot in cleaning (notably children). Children collected crumbs and put them right in front of the robot, they put up the bathroom carpet or chairs that hindered the robot from passing through (see Figure 3.13). We observed this immediate activity in all families with younger children but also the elderly single woman (H2) initially started collecting dust while the robot was vacuuming (see Figure 3.13b). She explained that she did not want to see the robot working on its own and would feel bad when she did not at least help a little. However, she stopped using the robot after some time.

Another immediate activity in which particularly children engaged was **playing with the robot** (see Figure 3.14). For instance, children built walls out of obstacles and furniture to prevent the robot from going somewhere or in order to keep it in a specific place. Children up to the age of about six years kept on putting toys on top of the robot or offered their stuffed animal a ride, which was fun for the other household members. Younger children interacted directly with the robot by physically exploring it, and emotionally by integrating it in their plays and experimenting with it. For instance, they let it bump into parts of their body, carried it around, and arranged objects as a circuit or labyrinth for the robot. Some children (mostly boys) made the robot part of their games and plays, *e.g.* they let it make a footrace with the baby who just learned to crawl or played hide and seek with the robot. Some also found creative ways of integrating it in their games: Roomba as a spaceship with lasers (see Figure 3.14c). Children’s playful activities with the robot were fun but parents also reported they wished children would be less interested in playing with the robot and actually let it do its task. Pets in our study reacted in different

(a) (b) (c)

Figure 3.14: **Children frequently played with the robot.** Especially younger children were very fascinated by playing with the robot. In (a) two boys integrate the Roomba in their play with little figures; in (b) a girl lets Roomba pass through her legs; in (c) a boy imagines the robot to be a space ship and he uses a light spot to show the robot its way.

ways to the robot. Though they were all curious, two cats and one dog tended to be afraid and either ran away or tried to bite the robot. However, one of the cats in H3 enjoyed playing with Roomba, and their owners enjoyed watching. This overall positive impact of children and pets on the experiences with Roomba has also been described by Sung et al. (2008).

The robot also served as a **mediator for social interactions** with persons who did not belong to the household, such as work colleagues or guests. During the first weeks, when participants hosted guests, they showed the robot and gave demonstrations. This enhanced discussion or served as entertainment. Especially male participants described that they liked to show their friends the *"fancy new robot"* they had in their home. Female participants liked to receive feedback from their friends which is described a usual activity in the process of adopting innovative technology (Rogers, 1995). One participant (H1) reported the robot would have helped him to **socialize** at his workplace as colleagues were asking him for news about the robot and his experiences. Also within a household, Roomba and the fact of taking part in the study triggered discussions about future technologies, robotics, cleanliness, and the cleaning routine. It seemed to create an awareness of the otherwise rather unnoticed routine of cleaning and of the clutter lying around. Most people reported that Roomba made them more aware of their clutter and encouraged them to tidy up, at least in the beginning of the study.

We found the most interesting social relation to the robot with a 71 years old single woman who lived with a small dog and two tortoises (H2). She was socially active and regularly met friends. Though she seemed to feel lonely living on her own in her small house. Her dog seemed to be an important social interaction partner and she tended to talk directly to the dog, greeting it, and asking questions to it. This tendency to view something non-human (animals, technological artifacts) as if it were a human is understood as *anthropomorphism* (which we will treat in more detail later on). When the woman saw and tried out the robotic vacuum cleaner, she instantly compared it to her dog and told us (after hesitation) that she felt some **emotional attachment** to the robot. Though she did not give her Roomba a name, she tended to talk directly to it and cared for it more than one would have to care for an object that can be switched off. For instance, she phoned us once because she wanted to go on a vacation but felt that her Roomba could lack attention when she was away for two weeks. So she asked us whether it would be fine to give the robot to her neighbor so that it would still be in use. For her, the robot seemed to be a companion and she confirmed this several times.[9]

Summary In some cases, some people tend to treat a domestic service robot like a socially interactive agent. This might happen even if the robot is of practical nature and is not primarily designed to fulfill a social function. However, we want to stress again that the amount of social activities elicited by the robot was low and decreased remarkably over time. Consequently, the social inter-activeness of a vacuum cleaning robot fades out, and should not be overestimated.

[9] Some time after the study had already finished, the elderly woman phoned us again because she wanted to give her Roomba back to us. She explained that she was not using it at all, and that her new dog would be too afraid of the robot, so she decided it would be better to give the robot back.

3.7 Analysis of the Process of Adoption

This second part of the findings concerns the process of adopting a domestic robot. Our study generally supports Rogers (1995) traditional concept of the *Diffusion of Innovation*, as well as Sung et al. (2010) *Domestic Robot Ecology* framework (presented in Chapter 1). In the following, we qualitatively integrate observations from our 6-month study the part of the DRE framework which focuses on temporal stages. This step of analysis is another contribution of our work. We show that the DRE, though it is still an initial framework, can robustly describe the process of adopting a domestic service robot, across two culturally different regions. This section is structured according to the four temporal steps as described in the DRE:

1. Pre-adoption: Forming expectations
2. (Initial) Adoption: Getting the first impressions
3. Learn / Adaptation: Learning affordances and limitations
4. Use and Retention: Routine practices and maintenance

It is an important finding that we observed different durations for these four steps for different households. Though we cannot make a very specific statement, we found that some households already formed a strong initial decision to adopt or reject the robot right after the first tryout while others remained undecided for about two months or even longer. Generally, in accordance with previous work, we found that people's expectations formed in the pre-adoption stage, influence the user experience during the initial adoption stage. This stage is critical, as we found that most things happened during the first two weeks and two months. We observed only few dynamics during the last four months. In the following, we describe how each of the adoption phases was characterized in our study.

3.7.1 Pre-adoption

Pre-adoption refers to a phase that is temporally before the purchase of the system. In our study, this is the period from when we confirmed to a household the participation in the study until the second visit, when we brought the robot with us. Rogers (1995) describes this phase involving two steps: knowledge and persuasion. In this phase, people learn that there exist domestic vacuum cleaning robots and gain some understanding and first knowledge of it. People form first expectations and attitudes towards vacuum cleaning robots, *e.g.* they expect the robot to work as a tool that performs vacuuming, and to improve the cleanliness of the home. So, the expectations formed by the user in the pre-adoption stage mainly concern the robot itself (design, functionality), and (looking at Figure 3.15) the imagined main interactions occur between the robot and the related tasks (the robot will do the vacuum cleaning) and the environment in which the robot is deployed (the robot will make the home cleaner).

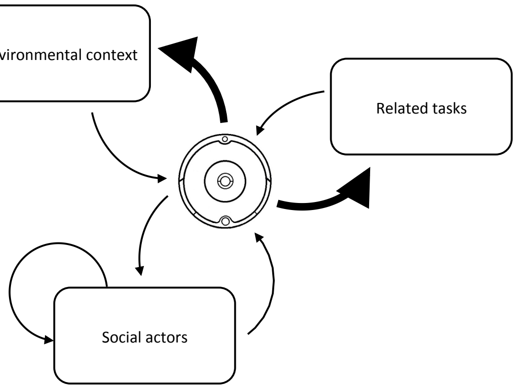


Figure 3.15: **Pre-adoption stage.** This simplified version of the DRE framework (Sung et al., 2010) shows the possible interactions between the robot (displayed in the middle) and the three key attributes (related tasks, social actors, environmental context). During the pre-adoption stage, which is displayed here, the main interactions (highlighted with a bold arrow) concern people's expectations of how the robot will work in their home. Users expect that the robot will work as a tool that performs vacuuming (arrow toward related task), and that it will improve the cleanliness of the home (arrow toward environmental context).

People's expectations formed during this stage can have a strong impact on their initial reaction to the robot and powerfully shape the first experience (initial adoption stage) (Forlizzi and DiSalvo, 2006). Participants in our study formed very different expectations about robots in general and the Roomba, in particular. The assumptions that they made about possible robot functions were based on previous experience with robots (when available), on articles they read about robots in journals or newspaper (mostly about industrial robots, robot toys or technical aspects), or on media (science-fiction, novels). This is in line with previous findings from a survey on people's attitudes towards robots (Khan, 1998). Participants with a lower affinity for technology had more difficulties in describing their expectations about the robot. Several households actively searched for information about the Roomba and watched videos of it that other users shared online. Those households that gathered more information about the system in the pre-adoption stage were less uncertain about what the robot could do. The other participant's uncertainty combined with the general lack of experience with robots, created skepticism. People were not at all sure what they should expect of a vacuum cleaning robot. Still, participants were curious to try out a robot in their very home, also the elder participants. Some of the households already thought about trying out a robotic vacuum cleaner before because they had heard about it but the financial barrier was too high to just purchase such a device without really knowing what it would be able to do. None of the households had tried out a Roomba before but two families had had experiences with other robots (LEGO mindstorms (H9), lawn-mowing robot (H6)). These previous experiences with robots shaped the first user experience with the new robot (see next section about initial adoption). Most participants expected the robot to be bigger but less noisy than it actually was. All hoped the Roomba would make their home cleaner and take over some part of the vacuuming (or replace the VC). Participants wished vacuuming would become less cumbersome and that they could save time and do other things while the robot was vacuuming (multitasking). Especially pet owners wanted to decrease the amount of pet hair by using the robot. Households with children had concerns whether the robot could work properly due to children's toys lying around and the expected fascination that the robot could have for the children. Parents also hoped that the robot could motivate the family members to tidy up. Two parents also wanted to use the robot in order to introduce robotics to their children because they believed robots would be part of the future and the children should get in touch with this. Mothers of younger children were concerned about the robot might attract too much the child's attention and it could be a harm for the infant or contrary the robot might get damaged when the child would play with it. Elder participants were much more concerned about the usability of the robot. The expected challenges with the domestic service robot were mostly that the robot would not perform well, *e.g.* in corners or around the table, and some were also afraid the robot could fall down stairs, leave marks on the floor, or bump heavily into furniture.

3.7.2 Initial adoption

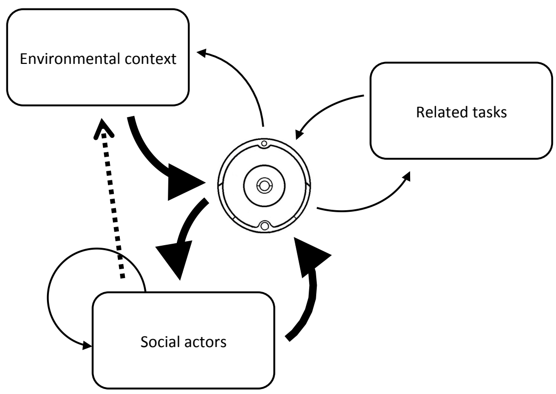


Figure 3.16: **Initial-adoption stage.** This figure shows the main interactions that occur during the initial-adoption stage (highlighted with a bold arrow). People watch and observe the robot frequently (social actors relate to the robot), the robot encourages people to talk about it with others and it also evokes an impression (robot impacts social actors). At this stage, the cleaning task is not the most important interaction that is triggered by the robot. However, as the environment is not yet adapted to the robot, it strongly impacts on the robot (bold arrow from environmental context to robot). The robot might often get stuck and in turn encourage people to make spontaneous changes to the environment (dashed arrow between social actors and environmental context). Inspired by (Sung et al., 2010).

The initial adoption phase describes people's first impressions and initial reactions to the robot and includes the first direct interactions with the Roomba. In this stage, which is likely to be shaped by the novelty of the system, main effects include people watching the robot and also, the robot evoking an impression in the social actors. Additionally, we observed emerging phenomenons: the robot encouraged participants to spontaneously make changes to the environment and to assist in cleaning. The first interactions and user experiences with the robot are based on what happened in the pre-adoption stage (expectations, pre-knowledge about the system). The first real (non-imagined) impressions and experiences that a user gains of a new systems have a strong impact on how the user will perceive the system, and accept it in the future.

(a) (b) (c)

Figure 3.17: **Households were unpacking the robot.** In (a) one of the participants is reading the user's manual before setting up the robot; in (b) a mother and two girls assemble the robot's parts, while the father reads aloud the manual; in (c) a father reads the manual to understand the different parts of the robot.

We studied the first real contact with the robot in detail, and structured each household's initial use of the robot in several steps. A comparison revealed common steps and differences in how the robot was approached (see Figure 3.17). Two families opened the packaging and assembled the parts collectively (H5, H6). In two other families there was one person who gave instructions from the manual while the others were sticking parts together (H4, H7). In H8 and H9 the parents were passively watching how the children unpacked and set up the robot. How children used (and played with) the robot subsequently was based on how the parents introduced the robot to them: as a tool, or as a toy. Not all households had a look at the user's manual: some immediately pushed the start button after having unpacked the robot, some read all or some parts of the manual before switching it on, and some asked questions to the passively observing researcher.

What all households did (most before switching on the robot) was that they checked its parts and tried to find out how it actually worked: people turned the robot around; touched the brushes and wheels and discovered the sensory and front bumper. Some made a couple of adjustments to the space, to ensure the robot would not damage something or get damaged, *e.g.* they put away cables or a sheet of paper that was lying around, and they pushed chairs aside. After this phase of quick preparation which took between 1-20 minutes (but was even skipped by some households) participants pressed the CLEAN button to switch on the robot.

How powerfully expectations can shape the initial experience with a device can be illustrated with the reaction of a 8 year old girl in H4. After having unpacked, set up and switched on the robot, she folded her arms, looked down and went upstairs to her room. We later asked her what had happened and she explained that she was sad because she expected the robot to have arms, a head, and be more human-like. When using Roomba the first time, children in H6 who had seen the neighbor's lawn-mowing robot, thought their Roomba vacuum cleaning robot was going to cut the carpet's hair.

The strong impact of a negative first user experience can be illustrated by the following example: When H7 tried out Roomba the first time, the robot got stuck in a huge leaf of a plant which was standing on the floor. The mother angrily shouted at the robot, when she realized that the plant

(a) (b) (c)

Figure 3.18: **First moments with the vacuum cleaning robot.** During its first run, participants carefully watched the robot. In (a) the little boy was a bit afraid as soon as the robot started to move around and he preferred to stay close to his father while watching the robot; in (b) an elderly woman skeptically observes whether the robot would clean up the cat's hair on the carpet; in (c) a family is watching how the robot reaches its docking station. The young boy is so excited that he is sucking his thumb.

got damaged by it. This led her to have a negative impression, and she viewed the robot as a *"mean"* device which was *"eating and destroying plants"*. We had the impression that the mother personally rejected the robot already after this negative initial experience.

We observed age differences in how the robot was approached and used the first time. Children showed a great fascination for the robot and their intuitiveness in operating it was surprising. Even infants intuitively managed to switch on the robot and felt rewarded by the sound the robot made when starting. Younger children tended to prefer cleaning with the robot compared to the VC but teens were not interested in it and stopped using Roomba after the first try.

When the robot started to move, most participants stepped back and some children started screaming and jumping around. In all households the robot was observed carefully (see Figure 3.18) and verbal comments were made on its abilities: *"Oh! It slows down in front of an obstacle!"*. Others tried to guide the robot around, using pointing gestures and direct speech: *"But go over there then, there are some crumbs!"*. While the robot was running, some of the households had to solve further issues, such as calming down the dog or pushing away delicate objects, and others were looking in parallel for more information about the robot (in the manual or online). In all households, participants discovered and explored the robot by directly interacting with it. They tested how the robot reacted to disturbance in order to determine its robustness, for instance. Participants wanted to touch the robot while it was moving and first let it bump into their foot. Just after they had seen that noting bad happens, they also kneed down and touched the robot with their hands. Some people picked up the robot while it was running, to see what would happen, and others even put it on a table to see whether it would fall down when it approached the rim. The most interesting for all participants was to observe the robot finding and reaching its docking station after they had pressed on the DOCK button. Participants carefully watched, commented and really appreciated the successful docking of the robot (see Figure 3.18c).

All these little experiments helped people to gain knowledge about how the robot was working and allowed them to form an initial impression. Overall, these first interactions with the robot revealed a lot about social roles, responsibilities, the household's process of introducing new products in the home, and their first impression of the Roomba. Nevertheless, it remained difficult to systematically capture people's initial reactions. It has to be mentioned that despite the fact that this was the second visit at each household, we had the impression that some participants felt a bit uncomfortable and might have behaved unnaturally due to the observer. Children's naturalness in discovering the robot was notable, and not driven by fitting social norms or being polite to the researcher. Most children reacted with great enthusiasm but also did not hesitate in showing their disappointment that the robot had neither arms and legs, nor a head and a face. Children seemed to be especially attracted by the robot's movements and its sounds. Infants were rather afraid of the robot and started crying or wanted to be back on the mother's arm.

However, it has already been mentioned that this first phase with a new product is shaped by **novelty effects** (Fernaeus et al., 2010; Kanda et al., 2004; Rogers, 1995; Sung et al., 2009a). Novelty effects are the first responses to an artifact and characterized through high levels of attention and interest, and increased usage. In respect to domestic robots, Sung et al. (2009a) suggest that strong effects can be observed within the first two weeks with a robot and that after about two months usage beyond novelty effects can be observed. Overall, our findings confirm a time span of about two weeks in which we observed strong novelty effects. However, we think that the time span in which novelty plays a role may vary depending on how often and for how long the robot is used (duration of interaction), which is also proposed by Leite (2013). We found that during the first two weeks, the novelty of the Roomba let people describe the robot as a *"fancy and new"* device. Observable effects were that participants showed the robot to friends, and tried it out frequently in a variety of ways. This initial fascination vanished and became less over time, which could be observed by how people described the robot: soon, the Roomba was seen as *"just another cleaning tool"*. Also, participants used the robot less over time (see Figure 3.7).

3.7.3 Learn and adaptation

During the learn and adaptation stage, many things happen and a variety of interactions occur. First of all, people try to learn more about the artifact by experimenting with complexity in use and compatibility with the current environment. Users tend to make necessary and lasting changes to better incorporate the device (Sung et al., 2010). Through this stage, which Rogers (1995) labels as 'implementation', people determine whether they will accept or reject further use. The main interaction effects during this stage are highlighted in Figure 3.19. In addition to the mutual interactions between the social actors and the robot (which had already occurred in the previous stage), people experiment how the robot works in respect to the adjusted environment and the tasks (evaluation of cleaning performance). Thus, cleaning (as related task) as well as the physical and social context of the home have a direct impact on the robot, and *vice versa*. By this, users assess the robot's limitations, and try to find a use case that leads to an optimal (or at least acceptable) performance (which requires some effort and patience from the user side).

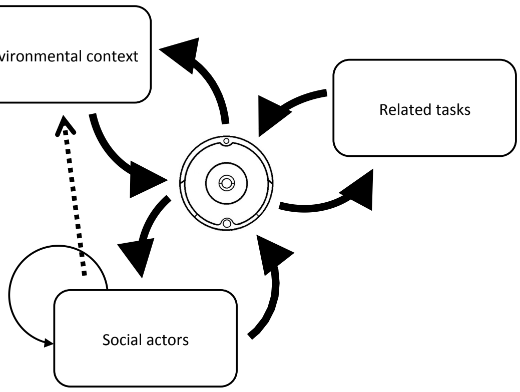


Figure 3.19: **Learn and adaptation stage.** By learning more about the robot and how it performs better, people refine their impression evoked by the robot (bold arrow toward social actors). In turn, people's attitude toward the robot impacts how much they use it and try it out (social actors relate to the robot). The robot encourages people to make lasting changes to the environment (dashed arrow), and through these changes, the environmental context impacts how the robot performs (environment impacts robot). At some point, the robot is evaluated on how well it cleans and improves the cleanliness in the home (robot impacts environment). With regular usage, people need to maintain the robot which impacts its performance (related tasks impact robot). However, with regular usage of the robot and after having made the necessary adjustments, the robot can actually start carrying out its intended task (arrow toward related task). Inspired by (Sung et al., 2010).

Interestingly, as it has already presented in previous work (Sung et al., 2008, 2009c, 2010) the robot encouraged people to make a variety of lasting changes and adjustments to their home (in contrast to the spontaneous and not lasting changes occurring during the initial adoption phase). This phenomenon of making lasting **adjustments to the home** due to Roomba is referred to as "Roombarization" (Sung et al., 2008). For example, people put away obstacles such as wires or moved furniture (such that the robot was able to pass in between two shelves, for instance). One family (H5) bought covers for the cables of the TV and play console and took quite some time to assemble them in the living room. The mother said the cables had annoyed her for a long time already, especially when she was vacuuming but only the robot was enough motivation to actually make this adjustment. A woman in H3 was encouraged by the robot to clean up some of the stacks of magazines and newspapers that she had kept for more than two years in the living room: *"I felt so sorry for the robot when it bumped into the stack again and again that I just had to put it away. Actually, I was thinking of tidying them up before but never found it was urgent. Now I am happy it's out of my view. I have more space now"*. Apart from these few cases, the robot did not motivate people to tidy up more or to put away things that were meaningful to them but caused problems for the robot. Still, the robotic VC had a stronger impact on the physical environment of people's homes than the usual VC. Another solution to make the apartment 'Roomba safe' was to adjust things every time right before the robot was used. The whole six months during the study, when H1 was using the robot, he placed the small coffee table on the sofa and put away the chairs (see Figure 3.20). Over time, H1 fixed all the spots that were problematic for the robot, so that it could show a good performance and would not get stuck anymore. By learning how to use the robot in an optimal way and making the necessary adaptations, H1 fully relied on

Figure 3.20: **Adjusting the home to the Roomba.** One participant did not only make lasting changes to his apartment but he also put his coffee table on the sofa every time before he used the vacuum cleaning robot.

the robot, and was happy that he did not have to vacuum manually anymore. Also H6 serves as a nice example for the interactions during the learn and adaptation stage. After having gained some confidence with the robot, the household wanted to let Roomba vacuum the ground floor during night, when they were sleeping upstairs. This would have solved the problem of having the children always interacting too much with the robot while it was doing its job. However, the Roomba made too much noise when used during the night, and it woke up the parents. The family changed their strategy to switching on the robot during the day before leaving to go for a walk or play in the garden. However, not all households got well through the learn and adaptation stage, to fully integrate the robot in their routine. Some participants were not willing or ready to engage in the effort of learning how to optimally use the robot and adapt themselves and their environment to it. Their process of adoption stopped in this stage, and consequently they decided to not use the robot any longer, or very sporadically (H2, H3, H4, H9).

3.7.4 Use and retention

The use and retention stage indicates the period when people begin to show a routine with the robot and seek to confirm its existence in the household. In other works, the user seeks reinforcement of an innovation-decision that has already been made, but the individual may reverse this previous decision if exposed to conflicting messages about the innovation (Rogers, 1995). The main interactions that occur during this stage (given that the robot is still in use), is related to how far the robot improves the state of cleanliness in the home (see Figure 3.21, bold arrow to environmental context). As the robot is now regularly used as a tool to clean, it has a fairly strong impact on the related task (probably stronger than in the previous learn and adaptation phase). Contrary, how well people maintain the robot (*e.g.* cleaning its brushes, emptying the dust bin) impacts how well it can work (see Figure 3.21, bold arrows from and to related tasks).

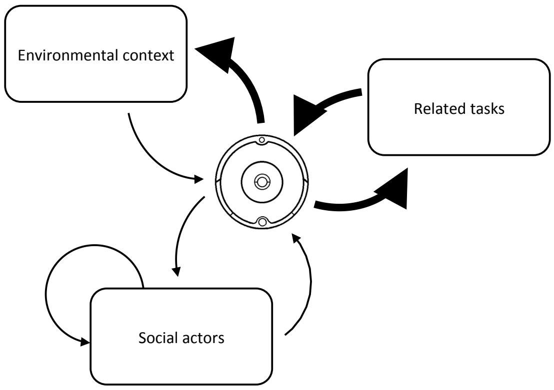


Figure 3.21: **Use and retention stage.** The robot is now routinely used as a tool to vacuum; consequently it becomes part of the cleaning routine (robot impacts related tasks). People need to maintain the robot regularly, which is also considered as a cleaning task that directly impacts the robot (related tasks impact robot). Since the robot vacuums regularly, it changes the environment by improving the cleanliness (robot impacts environment). However, the environment does no longer impact on the robot, as all necessary adjustments have been made, and the optimal use case has been found. At this stage, most people have a stable impression of the robot, and they stopped directly and consciously interacting with the robot (no bold arrow from and toward social actors), The robot is now viewed as an everyday tool. Inspired by (Sung et al., 2010).

In our study, there were only three households that went trough this last stage of adoption in a sense that they were still using the robot on a regular basis. The other remaining households might have confirmed their decision to reject the robot. In the three adopter households, different use cases had already been tried out, and the optimal way of using the robot was more or less found. Participants then stuck to their strategy and it became a routine for them to run Roomba every morning when leaving home (H1, H5), and / or additionally after meals, when leaving with the children or before going to sleep (H5, H6). In H6 it had become a routine that the father emptied Roomba's dust bin in the evening so that the mother could use the robot again the next day. During the use and retention stage, households were either able to confirm the positive impact that the robot had as a cleaning tool (H1, H5, H6), or felt assured in not using the robot again after their initial disappointment (H7, H8). Four of the nine households however had not formed a clear decision during the six month period, and were still not sure about the robot's role in the household but only used it occasionally (H2, H3, H4, H9). When asked whether these sporadic users would buy a Roomba, they all answered negatively, however, all of them wanted to keep the robot though. In the use and retention stage, Roomba was clearly perceived as a tool, and not as a robot anymore.

3.8 Discussion and Conclusions

To conclude this study, we will first mention some limitations of our work, and how it can be improved in the future. Then, we review our initial hypotheses, and bring them together with the findings. We also identified several factors that we believe are crucial during the process of adoption. These factors mostly match traditional models of technology acceptance (Venkatesh and Davis, 2000; Venkatesh and Bala, 2008), and have also been presented as attributes of innovations that might lead to a increased or decreased acceptance rate (Rogers, 1995).

3.8.1 Limitations

We described in detail mainly qualitative observations from a 6-month long ethnographic study with nine households in which we deployed a vacuum cleaning robot. In long-term and ethnographic research it is usual to have small sample sizes. However, results are not generalizable and also the statistical analysis of people's perception is critical. Using a mixed effects modeling analysis instead of ANOVA may have better accounted for the influence of individuals within the households. The study sample is biased by the fact that we only selected households that were generally interested in using a vacuum cleaning robot. Also, households were using two different models of the Roomba that have a slightly different functionality. This might have had an impact on the results.

Despite these limitations, our qualitative descriptions can contribute to an understanding of human robot interaction in the real world. Our study also adds new and rich examples from households in the French speaking part of Switzerland to the *Domestic Robot Ecology* framework (Sung et al., 2010), which is based on data from the U.S.. This addition helps to make the framework more robust within the domain of studying long-term HRI, and we show that it can be a useful tool to structure and analyze the occurring interactions.

3.8.2 Reviewing Research Goals and Initial Hypotheses

Hypothesis 1: Usage and impact on routines The usage of a domestic service robot does not seem to be impacted by a household's cleaning strategy and their attitude toward cleanliness by default, but still plays a minor role. How people clean is something very private and seems to be based on personal convictions. Though different strategies of cleaning and attitudes toward cleanliness do not determine whether a cleaning robot will be adopted, some personal (individual) convictions about cleanliness are not compatible with having a robot doing part of the domestic labor. Thus, Hypothesis 1 only partly finds support. A robotic vacuum cleaner does not profoundly change well defined cleaning routines and roles in a household. More concretely, when the mother has been the main responsible for vacuuming, the father will not suddenly engage lastingly in vacuuming with the robot. Men tend to like the robot more for its symbolic value while women appreciate its function to work as a vacuum cleaner. Data shows that a vacuum cleaning robot does not (yet) fully replace the traditional vacuum cleaner in a household (their might be exceptions). Still, a vacuum cleaning robot can decrease the amount of vacuuming sessions and it helps people to keep their homes clean.

Hypothesis 2: Environmental context The environmental context of the home is an important factor for usage and adoption of a domestic robot. However, Hypothesis 2 does not fully find support, since data suggests that people's personal attitudes and underlying household rules even more powerfully shape the experience with a robot, and strongly impact to what extent the robot is used and adopted. Still, physical layouts can constrain the way a vacuum cleaning robot can work and navigate around. Tiny rooms with a lot of corners and homes with door sills are not suitable for Roomba, as it decreases its efficiency or can make it impossible for it to move around autonomously. Besides this, not everybody is willing to make adjustments to their home in order to enable the robot to work well (including tidying up the things lying around). For people living alone it appears easier to adjust the space but as soon as several people share one place, changes are not made that easily and it causes some effort to get everybody's agreement.

Hypothesis 3: Interaction and perception There are several factors that impact how people perceive and interact with a functional domestic robot in their home. People of all ages are generally open to trying out a domestic service robot in their home, as long as they do not have to expect any risks. In general, the possibility of trying out a domestic service robot without having significant negative implications (*e.g.* financial costs) can foster acceptance and adoption. In his "Diffusion of Innovations" Rogers (1995) refers to this as 'trialability'. Giving people the opportunity to try out and experience new and so far unknown products such as domestic service robots can decrease people's uncertainty with (domestic) robots. Still, people's understanding of what domestic functional robots are able to do and how they can be used is not very clear and ordinary people's expectations are based on media and science fiction (Khan, 1998). The lack of previous experience with a robotic system creates uncertainty but also curiosity.

Age seems to play a role in how a domestic service robot is approached and how easy it appears to use during the initial adoption phase. Younger people, first and foremost children and teenagers appear to be less hesitant in interacting with a robot, and are almost fearless in terms of doing a mistake with the device. Up to a certain age, they are ready to integrate the robot in their games, and might even view it as a companion. Especially elder people are more hesitant in directly interacting with a robot, as they appear to be more afraid in doing a mistake with it that would not be reversible. However, also elderly are open to use a domestic robot – they might even be the user group that can benefit most from these kinds of devices – but they would probably wish to have some personal guidance in how to use the robot.

In the perception of robots, gender seems to play a role. Men describe a domestic service robot as a technological artifact, a "thing" that consists of several parts that each fulfill a specific function: sensors to navigate around and motors to drive, for instance. They mainly like the robot for its engineering quality – because it can do something that other technologies cannot do (stop in front of stairs, navigate along a wall, *etc.*). In contrast, women describe a service robot more as a tool that they want to use for a specific task. They mainly like (or dislike) the robot for its performance – because it does (not) carry out well the given task (vacuum cleaning), and in turn does (not) make family life easier.

How people perceive and experience the robot changes over time. The qualitative change in how the robot appears to users over time can be described as *from "fancy new robot" to "just another cleaning tool"*. This change in perception from robot to tool can be seen as a good news for the field of domestic service robots. It shows that there exists the potential for robots to be *domesticated*, and to become part of the routine. Once the cleaning robot appears as a tool, people's perception seems to be related to their general attitude toward cleaning (and the household's respective cleaning strategy). The change in perception over time suggests the existence of novelty effects, not only in terms of usage of the device but also how it is perceived. We conclude that novelty effects exist in human-robot interaction and shape how the robot is used and perceived. Both interaction and perception change over time and with growing user experience with the system. Thus, the novelty is not only determined by a specific time span (*e.g.* two months) but also by how frequently the robot is used and interacted with. Despite the fact that how people perceive the robot changes over time, people's general attitude towards robots and robotics does not seem to change with using a rather simple functional robot such as Roomba.

Hypothesis 4: Social dynamics We conclude that the social impact of functional robots is generally overestimated. People tend to basically anthropomorphize even a simple functional robot (*e.g.* by talking to it directly or by using communication traits that are comparable when relating to a pet or other human). However, the important finding here is that this phenomenon wears off when people become more familiar and used to the robot. We discuss social dynamics related to anthropomorphism in human-robot interaction in more detail later in this dissertation. Overall, the lasting social impact of a vacuum cleaning robot seems to be overestimated. Apart from children and one single elderly woman, participants of our study did not lastingly view or treat the robot as a social agent.

Hypothesis 5: Adoption process The robustness and applicability of the *Domestic Robot Ecology* framework (Sung et al., 2010) has been shown in the findings section.

3.8.3 Conclusions of the Roomba Study

To conclude, we would like to highlight some key aspects about living with a functional robot at home. We were surprised to find that only three out of the nine households adopted the robot in a durable way though we recruited only households that were generally interested in a vacuum cleaning robot. It seems that, as soon as domestic service robots and humans are sharing the same social space, they need to adapt to each other to be a good match: People need to learn how to use a robot in an effective way, by building trust in it and by letting the robot do its intended task. This of course requires that the robot is an acceptable and effective product that meets moral and ethical standards, is safe and trust-able. Optimally, the robot would also adapt itself to the human user and the characteristics of the environment, and learn with growing experience.

In the decision and process of adopting a domestic service robot, several factors of the home ecology[10] (with an focus on the user) play a role, and we summarize them below.

Besides the impact of the environmental context, which has been described above, one factor that is of special importance already in the pre-adoption phase is the **practical utility / usefulness** of the robot. Rogers (1995) refers to this aspect as the perceived *relative advantage*, which later when people start using the device is related to the *observable results* that the technology brings. The perceived usefulness is defined as the degree to which a person believes that using a particular technology will enhance the respective task (or daily life in general). This includes decreasing the time for doing the task, more efficiency, and accuracy. In our study, despite the fact that we recruited only households that were generally interested in a vacuum cleaning robot, the majority of households (6 out of 9) did not perceive the robot as useful, and did not feel their home became cleaner or they could save some time with the robot. Those who adopted the robot, perceived it significantly more useful as the others.

Further, the **usability / ease of use** of the robot plays a role mostly in the beginning of the adoption process, during initial adoption. The perceived ease of use refers to the degree to which a person believes that using a particular technology will be free of effort. It includes the expected and actual effort required to use the system. Rogers (1995) refers to this factor as *simplicity*. Our data also suggests that the usability factor is related to people's willingness and the necessary **effort to learn how to use the device** in an optimal way. Though Roomba is fairly easy to use, the user is required to learn *how* to optimally use it which becomes important during the phase of learn and adaptation. For instance, in the case of an autonomous domestic service robot the user would need to realize that the robot probably works best when letting it do its job without big interventions from the user side. This however seems to be a huge difficulty for the users: to overcome their expectation that the robot would vacuum more efficient than their traditional vacuum cleaner in even less time, and the resulting fact that for good performance the robot needs to be used differently to the traditional vacuum cleaner. However, not everybody is willing to explore and learn how to optimally utilize the robot. However, it has been described that a huge perceived performance benefit can outweigh the effort that users expect to spend (Davis, 1989). This is in line with our findings. In our study, a male single (H1) did not avoid any effort to make Roomba work well, as he perceived a huge benefit in using the vacuum cleaning robot instead of the manual vacuum cleaner.

Another huge barrier when it comes to adopting and integrating a robot into a daily routine is the aspect of its **compatibility with personal beliefs, habits and attitudes** in respect to the context of the system (here: cleaning). As mentioned, personal convictions seem to be more important than physical constraints of the environment. They play a role during the whole process of adoption, and already in the pre-adoption phase. Cleaning routines are based on personal beliefs and attitudes towards cleaning and cleanliness. These personal attitudes are subjective

[10] With *home ecosystem* I would like to express that the home needs to be considered as a ecosystem consisting not only of the human users (and non-users) but also of the products within the home, the activities carried out, and the shared environment. Forlizzi (2007a,b) describes the same concept more formally as the *product ecology*.

judgments and certainly not easy to consider in the design process of domestic service robots. However, how a person understands herself and her environment impacts how a robot is used and accepted or rejected. In our study, one participant (H7) was convinced that no one could do the cleaning as efficient and properly as she herself. Consequently, she did not accept any help with it, neither from her husband nor from a cleaning service, nor from a robot. The robot was simply not compatible with her personal beliefs. Also Rogers (1995) has identified this as an important aspect for adoption, and refers to it as *compatibility with existing values and practices*.

Closely related to the previous factor is what we call the user's experienced **personal value / attachment / reliability** to the device. Some domestic technologies and products might not be very practical, might be difficult to use or are *"out of fashion"*. However, they still find their place in the home because they hold a great personal value (*e.g.* they evoke attachment). We are not sure whether this factor can outweigh more serious ones. It rather looks like personally valued devices are kept but not frequently used. Another similar aspect is how reliable the device is experienced and perceived. Reliability plays an important role in HRI. When people do not trust/rely on a domestic service robot, they do not want to use it without supervising it, which is not optimal for an autonomous device. In our study, we found that the single elderly woman in H2 could not derive much practical utility from the Roomba and she also was afraid of doing something wrong with it. However, she kept it because she simply liked it, when it was moving around and required her help when it was tangled up in the carpet.

Another user-centered factor is what we call the **social compatibility / compatibility with subjective norms**. In the traditional model of technology acceptance a subjective norm is generally understood as a person's belief that most of her important others think she should (or should not) perform the behavior in question (*e.g.* using a vacuum cleaning robot) (Venkatesh and Davis, 2000). People have a basic need of being socially connected to others, and to maintain these connections (Epley et al., 2007). Therefore, it matters to a person what her significant others (*e.g.* friends, family, colleagues) believe about using a domestic service robot to do vacuum cleaning. With innovative technologies, it seems that people tend to try gaining prestige by being among the first ones in their social circle to purchase and use the latest products.[11] In our study, the fact that the single male in H1 used a vacuum cleaning robot had a positive effect on his social community and this encouraged him to use the robot. H1's work colleagues usually did not talk much to him but suddenly showed interested in his new robot, which triggered conversations and even led H1 to invite some colleagues to his place (what he had never done before) to give a robot demo. This experienced positive social effect motivated H1 to keep on using the domestic service robot.

As a final more general aspect we would like to mention the **economical compatibility / financial benefit**. Cost is a significant factor to the household adopter (Venkatesh and Brown, 2001). People consider this factor already during the pre-adoption phase when thinking of purchasing the device, and later during the other adoption phases, especially when parts of the device would

[11] In early 2011, when we carried out the study, vacuum cleaning robots have just become available on the consumer market in Switzerland, and hardly anyone had such a robot at home.

need to be replaced. First of all, a domestic appliance needs to be affordable for people. Not only its shelf price but also the financial costs for maintenance are taken into account. Most vacuum cleaning robots require new brushes fairly regularly when used on a daily basis. As we in our study gave the robot for free, participants did not have this financial barrier but all of them measured the gained benefits to the expenses it consumed. A crucial aspect here in terms of environmental responsibility concerns the **energy consumption** of domestic service robots. People do not easily accept to leave a device plugged in all the time as costs for electricity constantly increase, and there are environmental concerns. Together with colleagues from another lab at our research institution, we carried out a technical study that compared several vacuum cleaning robots according to their energy consumption and performance (Vaussard et al., 2014). In general, it was found that the power consumption of a vacuum cleaning robot is about 30 W, whereas a traditional vacuum cleaner consumes around 1000 or 2000 W.[12] However, the robot is by far less fast in carrying out the vacuuming, especially those models that rely on a random navigation. Additionally, the tested robotic vacuum cleaners did not clean as well as when using the manual vacuum cleaner (by an appreciable amount). Another mitigation factor is the “idle-power", when the robot does not do anything but remains connected to its base charging station. Idle powers of up to 7 W were measured, which makes a fair amount of energy on a whole day.

How far are we from “having a robot in every home”? When we imagine having a robot in every home, first of all, we might think that there is a domestic service robot which either carries out a task that previously either had to be done by a human (*e.g.* loading the dish washer, ironing, setting the table, or tidying up), or that replaces another tool that had to be used manually by the human, such as the vacuum cleaner. We do not believe that there is an out-of-the-box answer to the question *“can a robot be a drop-in replacement to accomplish domestic tasks”*? (Vaussard et al., 2014). It mostly depends on how the respective product is used and experienced and thus always involves both the user and the characteristics of the system as well as their shared environment. It has to be clear that, as soon as robotics tries to enter people’s homes, the human will be at the center of it. Therefore, we think that successful domestic service robots first and foremost need to provide solutions that match real needs.

Participants in our study wished that the robotic vacuum cleaner would solve the shortcomings of their manual vacuum cleaner, and consequently decrease the amount of work for the user. However, six of the nine households stopped using the robot for regular cleaning after a while. Although people were at first enthusiastic and interested in trying out a robotic vacuum cleaner, the majority became disappointed as they actually assessed the robot’s relevance within their own home ecosystem. In this case, the rejection of robotics is not motivated by some underlying

[12] Household’s energy consumption is an important topic, and the European Commission has adopted several regulations in order to help decrease the energy consumption. Vacuum cleaners are concerned as well. In the EU, starting from September 2014, no domestic vacuum cleaner may be sold with a rated power of more than 1600 W. From the year 2017 on, this value is further reduced to a maximum of 900 W.

fear or negative preconceptions, but is an issue of how functional the robot is within a home, and how far users can make sense of the system. After the novelty effects had worn off, the robot became another cleaning tool with its own flaws. The two big hurdles from the human side seem to be (1) a lack of trust in the robot to do its work autonomously while the homeowner is not around, and (2) a lack of willingness to adapt and make physical alterations to the home itself for the robot. We believe that domestic robots should be designed to minimize the need for these types of effort. To increase acceptance from the technical side, we found that people wish to understand how their robotic vacuum cleaner is working (transparency), which is not the case with a random navigation pattern. Currently, the robot does not provide adequate feedback to the user, decreasing the chances of long-term acceptance. This could be improved by providing the user with a map of the environment, and fusing inside it information coming from the sensors such as dust, energy consumption, and type of surface. The user could in turn give information to plan the task more precisely. (Vaussard et al., 2014)

Based on people's different cleaning strategies and attitudes towards cleanliness and robots, there is no single best solution for designing domestic service robots, and making the vision of having a robot in every home come true.

4 Anthropomorphic Language to Describe a Robot – The Forum Study

There are several reasons why people tend to perceive robots as if they were living beings. For instance, robots move and people can physically interact with it, and some robot designs resemble a living being, *e.g.* pet-like robots. More specific than the perception of life-likeness, there is also the phenomenon of attributing human-like features to a robot. Anthropomorphism is a commonly observed phenomenon in HRI, however it is not very well understood why robots are among the most prominent anthropomorphized agents. In this study we aim to investigate characteristics of the robot that impact on people's tendency to anthropomrphize. We compare two different kinds of domestic robots, a functional one (Roomba vacuum cleaning robot), and a playful one (AIBO robotic dog), to a tablet computer (iPad). To study the differences in how users anthropomorphize their respective device, we analyzed anthropomorphic language in online discussion forums of users of these three devices. We expected to find the highest amount of anthropomorphisms in the AIBO forum but were not sure about how far people referred to Roomba or the iPad as a lifelike (human-like) artifact. Our findings suggest that people anthropomorphize their robotic dog significantly more than their Roomba or iPad, across different topics of forum posts. Further, the topic of the post had a significant impact on anthropomorphic language. Hereafter, we refer to this study as the **"Forum Study"**.[1]

4.1 Scope and Research Goals

The **social phenomenon of anthropomorphism** - in contrast to **anthropomorphic form in design** - describes people's tendency to perceive human-like qualities (or lifelike qualities in a broader sense) in non-lifelike artifacts and to attribute these qualities to the artifact, which can be a robot (Caporael, 1986; Epley et al., 2007). Anthropomorphism can be described as a specific type of social response to technology, which arises in an interaction between the human and the technology (see Section 2.3). We come back to a more theoretical disquisition on anthropomorphism toward the end of this thesis. It has been found that people tend to carelessly attribute human-like qualities to media characters, technologies, and computers (Reeves and Nass,

[1] This study is published as Fink et al. (2012).

1996). The understanding of anthropomorphism, which we use throughout this study is a rather broad one, *i.e.* , we do not necessarily make a difference between perceptions and attributions of life-like and human-like characteristics, but refer to both as anthropomorphism.

4.1.1 Motivation and Contributions

The trend of anthropomorphism has been widely explored with emerging new interactive technologies, in human-computer interaction (HCI) (Reeves and Nass, 1996) as well as related to technology acceptance (Venkatesh and Davis, 2000). Discussions about anthropomorphism have become popular in the design of (social) robots, concerning the aspects of perceived *agency* and *empathy* for instance (Breazeal, 2003; Duffy, 2003; Eyssel et al., 2010; Takayama, 2012; Rosenthal-von der Pütten et al., 2013). Critical questions related to people's tendency to anthropomorphize robots are, how far users perceive and treat robots as moral or social agents and how far they should imitate or resemble a human, in shape, behavior, and other dimensions. We will not address philosophical and ethical issues here but more focus on the understanding and possible explanations of anthropomorphism in human-robot relations.[2] An understanding, of how and why people anthropomorphize technologies and robots, is of interest when it comes to designing technological devices that are in close contact to humans, such as domestic robots. An interesting question here is how to design robots that are likely to elicit social responses from their users which in turn form people's expectations of the robot. Others argue that designing products that encourage the human user to anthropomorphize it can enhance acceptance and the perceived effectiveness of the interaction (Duffy, 2003; Goetz and Kiesler, 2002; Venkatesh and Davis, 2000), which is of particular importance for robots in daily life environments. Epley et al. (2007) argue that anthropomorphized agents can act as powerful agents of social connection. However, anthropomorphism may not necessarily only hold positive effects, for instance, if we anthropomorphize a vacuum cleaning robot like Roomba, we may expect that it is able to respond to us in the same social human-like manner. If this expectation is not met, the interaction may be disappointing.

Figure 4.1: **How do users discuss about their AIBO, Roomba, and iPad?** A content analysis of online discussion forums shows differences in the amount of anthropomorphic language for users of two different types of domestic robots (AIBO and Roomba) compared to a tablet computer (iPad).

[2]Caporael (1986) and Coeckelbergh (2009, 2010b,a) present philosophical and ethical issues related to anthropomorphism.

Contributions

There are psychological and other user-related determinants (Epley et al., 2007) that facilitate anthropomorphism. In this study we do not focus on these user-related determinants, but aim to explore factors originating from the artifact, such as the design (physical form and total expression of the artifact) and the offered functionalities and interaction modalities, that shape the user experience. An understanding of how and why people anthropomorphize a robot can help identifying particular characteristics that make the device likely to be perceived lifelike and to encourage a social relation. Further, we would like to explore how far the context of purpose-based (function) of the device play a role in anthropomorphism.

Our study builds on findings from a content analysis of online discussion forums about AIBO (Friedman et al., 2003). The authors found that in their written forum posts AIBO owners tend to refer to their robotic dog as if it were a social companion, had mental states or was a moral agent. We go beyond this by comparing the use of anthropomorphic language between different technologies, with and without robotic components. Further, we investigate whether the context of the conversation impacts the use of anthropomorphic notions. Related work suggests that the context of an interaction (the situation) can have an impact on anthropomorphism (Waytz et al., 2010). Our results can serve to formulate design suggestions for robots and technologies that are likely to encourage social engagement, and increase acceptance.

4.1.2 Research Questions and Hypotheses

The three devices, pictured in Figure 4.1, were chosen as they show different designs and fulfill different purposes. We would describe **(1) AIBO** as a zoomorphic (pet-like) robot that does not have a clear purpose but engages people to play with it; **(2) Roomba** as a mechanical (functional) domestic service robot that has a practical main purpose (vacuum cleaning) but offers not much of interactivity; and **(3) the iPad** as a minimalistic designed interactive (touch-based) technology with multiple purposes (both entertainment, and professional and / or practical use). All three devices can be used in the domestic environment. We have chosen these three devices in order to find out where the Roomba would range on a qualitative scale of anthropomorphism, when compared to the AIBO and the iPad. Due to its pet-like shape and purpose, we expected to find a high amount of anthropomorphic language related to AIBO. With the iPad as a tablet computer, we can also assume anthropomorphism to some degree, as previous work indicates that people anthropomorphize and relate socially to their computer (Reeves and Nass, 1996). But where between these two devices would the Roomba range? In the previous study, we have examined how people relate to Roomba and we were interested in obtaining a qualitative scale that would show where this devices ranges when two reference points are given. Based on the different characteristics, we had the two following hypotheses concerning anthropomorphism:

Hypothesis 1: People engage in a more social and human-like way with a robotic pet compared to a functional robot and a tablet computer. Therefore, there will be a high amount of anthropomorphic language in the AIBO forum, and a lower amount in the iPad forum. Roomba will range somewhere in between.

Hypothesis 2: Anthropomorphism can be seen as a certain kind of social relation to an artifact. Hence, there will be more anthropomorphic language in forum posts in which the author describes a relation to the device, compared to discussing technological aspects or how the device is used.

Based on the theoretical background and what has been found in previous work, we assume that a robot's ability to autonomously move around and respond to the user (which applies to AIBO and Roomba) are two main cues that might encourage people to anthropomorphize it. More generally, through the analysis of the language used in the forum posts, we would like to show that anthropomorphism is related to the design of the device, and the context of the interaction.

4.2 Methodology

We identified anthropomorphic language in the postings as well as the context in which it occurred. Particularly, we were interested to see where the three devices (AIBO, Roomba, iPad) range on a subjective scale of anthropomorphism. We take it as an assumption that how we talk or write about an artifact reveals something about how we relate to it. Though linguistics also implicates a cognitive process, we will not address this here. Related psychological factors explaining the phenomenon of why people tend to anthropomorphize are presented in Epley et al. (2007).

4.2.1 Content Analysis

Similar to the approach applied by Friedman et al. (2003), we studied anthropomorphic language in online forums. People are registered as authors in one of the forums and write about their experiences with the respective device, how they use it, or ask others for help when encountering technical problems, for instance. We analyze not only the amount of anthropomorphic language describing people's relationship to their technological device in the forums but also the context in which the anthropomorphism occurs. This comparison enables us to obtain a qualitative scale of how far the AIBO, the Roomba, and the iPad encourage their users to anthropomorphize it and express their perception in the written forum posts. This helps to identify concrete characteristics for designing products (and robots) that facilitate social connection when desired. This is also why we chose on one hand a pet robot (AIBO) and a functional domestic robot (Roomba), and on the other hand a multi-touch display tablet computer.

We have chosen three online forums: one about AIBO[3], Roomba[4], and the iPad[5]. Selection criteria for the forums were the language (English), the community size (>50 authors), and

[3] www.aibo-life.org
[4] www.robotreviews.com
[5] www.ipadforums.net

being up-to-date (ten latest posts not older than six months). 250 posts of each forum were quasi-randomly selected. This means that we did not extract too many posts from one single conversation but aimed to cope with the range of topics of the respective forum.

4.2.2 Data Processing and Analysis

The extracted forum posts were split into segments to allow precise coding. Segmentation was done according to paragraphs in the written text. This was necessary, as some conversations were quite long and could not be coded uni-vocally. After this process, out from the 750 posts, 1363 distinct segments were obtained. A coding scheme was established with two dependent variables: *content* (the topic of the segment), and *anthropomorphism*. First, the **topic** of each segment was annotated in three categories:

- *Technology* segments that address technological aspects, a functional problem or broken parts;
- *Usage* segments that describe how or for what people use their device (activity); and
- *Relationship* segments that address the attitude or feeling towards the device.

An additional category *irrelevant* was used to filter out completely unrelated posts. From the 1363 coded segments, 155 were categorized as *irrelevant*, hence, they were excluded and a statistical analysis was carried out with the remaining 1208 segments.

In a second step, when a forum segment was not previously coded as irrelevant, it was labeled as anthropomorphic or not. It took several approaches to operationalize when a post should be coded as anthropomorphic. We finally defined several categories of a **anthropomorphic language** (adapted from Friedman et al. (2003)). A segment was coded as anthropomorphic when the device was described in terms of:

- *Life-likeness*, such as being alive or having (parts of) a body, *e.g. "she can be reborn since you copied her memory stick"*;
- *Emotional states, empathy* or the technology having a *feeling*, *e.g. "oh no, poor AIBO"*;
- *Gender, personality* or the technology having an *intention* or showing an *own will*, *e.g.* Roomba *"seems to like to hang around under the sofa"*;
- When the author gave the technology a *name*, *e.g. "whenever I show Java his pink ball"*;
- Being *socially integrated*, such as being a family member, *e.g. "I'm considering adding a Roomba to the family"*;
- *Metaphorical ways*, *e.g.* Roomba *"sings its victory song when it finishes and docks"*.

Each segment was coded in only one content category (technology / usage / relationship), and either as anthropomorphic or not anthropomorphic. To assure the validity of our coding scheme, a second coder annotated 20 % of the segments equally for each device. We obtained a Cohen's Kappa κ of 0.78 for anthropomorphism and 0.6 for content which indicates a moderate to substantial inter-rater reliability. Disagreements for content were due to confusion between the labels *technology* and *usage*. The disagreements were resolved through discussion.

4.3 Findings

In the next paragraphs, we present the findings of this content analysis. First we give a general analysis, this will be followed by an analysis with respect to our two hypotheses: anthropomorphic language related to the device, and anthropomorphic language related to the topic of the forum post.

4.3.1 General Analysis of Forum Posts

What do people discuss in online forums about technologies and robots that they are using? In general, the great majority of conversations in the three forums concerned *technology* aspects (overall average 67.7 %), followed by descriptions of how people use the device and what they do with it (overall average 21.8 % *usage*). Finally 10.5 % of the posts were about how people feel toward and relate to their device (overall average of *relation*). However, when comparing the three forums, we found statistically significant differences in the distribution of topics (χ^2(df=4,

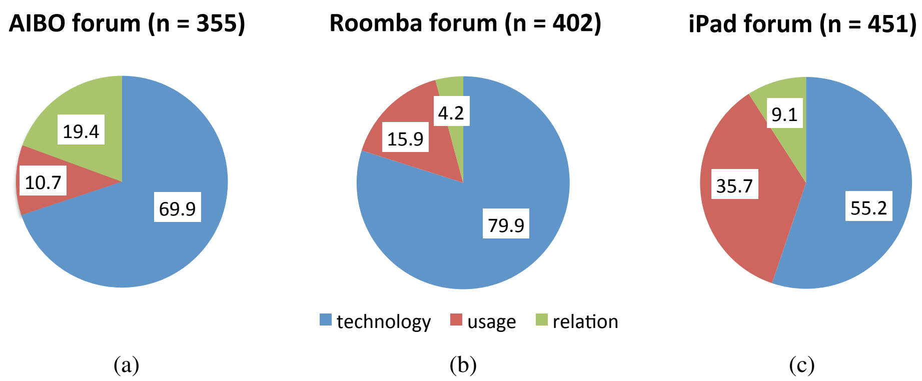


Figure 4.2: **Distribution of main topics discussed in AIBO, Roomba and iPad online forums.** A content analysis of in total n = 1208 segments in online discussion forums shows that users mostly discuss about *technology* aspects. However, the proportion of the two other main conversation topics, *usage* and *relation* differs with the technology. This difference was significant. (a) Owners of the playful pet-like robot **(AIBO)** describe in (19.4 %) their feelings and *relation* to the device; (b) owners of a domestic service robot **(Roomba)** discuss in 15.9 % the *usage* of the device, and even more (c) the users of a tablet **(iPad)** frequently discuss (35.7 %) about for what and how they use the device which suggests the versatility of the device.

N=1208)=128.73, p<.001; Pearson Chi-Square). As Figure 4.2 shows, in the Roomba forum, technical questions and answers (79.9 %) dominated the topics usage (15.9 %) and relation (4.2 %). In contrast, the iPad forum was characterized by a relatively high proportion of *usage* posts (35.7 %), and the AIBO forum by 19.4 % of *relation* posts. This difference in prevalent topics already suggests that the three devices matter in different aspects to their users (reflected by what topics they discuss). First and foremost, all three devices are mostly described as technologies. But we can interpret that compared to the iPad and Roomba, AIBO appears to encourage users more to form and discuss their relation with it. In opposition, the iPad appears to be more perceived as a versatile device, as fairly frequently users discuss different use cases of it. Also in the Roomba forum, usage plays a role but as already mentioned, the most prominent topic was technical aspects (79.9 %).

Surprisingly, in only 4.2 % of the conversations, **Roomba** owners described their relation to their robot. We had expected more of these anecdotes because they tend to be described frequently in the literature (Forlizzi, 2007a; Sung et al., 2007; Takayama, 2012). Concerning the prominent technical discussions, Roomba owners frequently described their vacuum cleaning robot was not able to properly navigate autonomously around the home or that it would get back to its charging station. Forum authors often mentioned that the robot reported errors or stopped working, so people sought for help in the forum explaining how their Roomba showed defective behavior while vacuuming. Often, people tended to post in the forum right after they had purchased a Roomba and asked others about how the robot worked:

> *"How does the Roomba know the room is clean? If i put it in a bedroom and push the clean button, close the door to confine it, how long will it run? Does it go until the bateries are dead?"* [original text from the Roomba forum]

Also the main part of conversations in the **iPad** forum was dealing with technical concerns (55.2 %), such as compatibility problems with iTunes and a PC system. Again, it seemed that it were often new iPad owners who were not yet very familiar with their tablet and used the forum to *crowd-source* opinions and advice. More than one third (35.7 %) of the postings described use cases about where and for what people used their iPad and how far it was able to replace a laptop or notebook. The remaining 9.1 % of the conversations were about how people relate to and feel about their iPad whether they like it or hate it and for what reasons:

> *"This is my first iPad [...]. Personally, I love it. I like the more restricted and uniformed work flow compared to the non standardness of open source all these years."* [original text from the iPad forum]

In the **AIBO** forum, as in the other two forums, technology aspects were the most often discussed ones (69.9 %). There was a frequent exchange of people who tried to find replacements for broken parts of their robotic dog. Further, in a relatively high proportion of 19.4 %, people described their relation to their AIBO, which sometimes suggested that the robot was treated like a family member:

> *"Angus'* [the AIBO's name] *b'day is today. He's had a good day had plenty of dancing, talking and just being a superstar."* [original text from the AIBO forum]

Already from reading through the three forums, it overall became clear that authors used different terminology and descriptions when discussing about their respective device. Especially the amount of notions of body-likeness (referring to parts of the device as if it would have a body) and postings where people named their device varied noteworthy.

4.3.2 Anthropomorphic Language in the Online Forums

Overall, 257 of the 1208 coded segments (21.4 %) contained some anthropomorphic notion. There were different types of anthropomorphic notions. As described before, we had first classified 6 main types: *life-likeness, feeling, gender / personality / intention, name, socially integrated, metaphor*. Then, during the process of analyzing data, we sub-divided the category *body parts* from *life-likeness* and split up *gender / personality / intention* into three distinct categories. With the newly obtained nine categories, we could get a more precise idea about how and why people used anthropomorphic language.

Figure 4.3 (page 130) shows the distribution of the various types of anthropomorphic notions in the forum posts. Table 4.1 (page 131) further shows the distribution of the various types of notions across the three forums. Overall, the most frequent type we found was people giving a

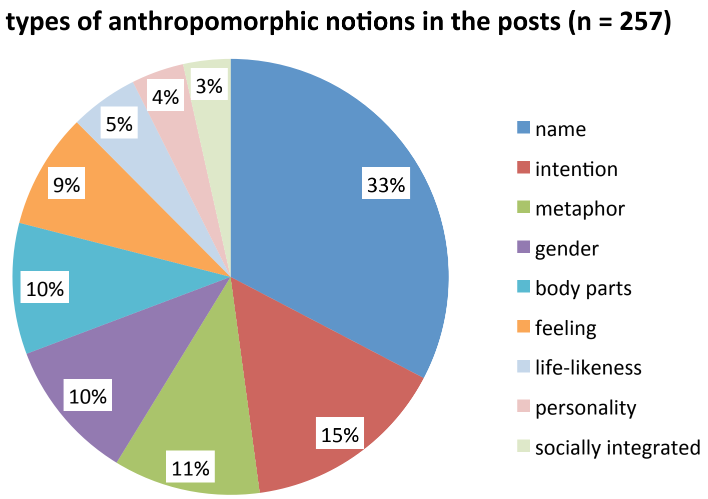


Figure 4.3: **Types of anthropomorphic notions in the forum posts.** The pie chart shows what kind of anthropomorphic attributions people used in the online forums. This is a visualization of the data in the rightmost column in Table 4.1.

Table 4.1: **Number of different kinds of anthropomorphic notions in the forum posts.** After having sub-divided the type *body parts* from the type *life-likeness*, we found that only AIBO was described as having body parts and surprisingly, the Roomba was slightly more often described in terms of being alive (life-likeness) then the AIBO. However, there were only 7 and 5 counts, respectively. Part of this data is visualized as percentages distribution in Figure 4.3.

type	**AIBO** n = 355	**Roomba** n = 402	**iPad** n = 451	**total** n = 1208
name	**80**	4	0	84
intention	**23**	13	3	39
metaphor	**13**	**13**	2	28
gender	**22**	5	0	27
body parts	**25**	0	0	25
feeling	**18**	1	3	22
life-likeness	5	**7**	1	13
personality	**9**	1	0	10
socially integrated	**5**	3	1	9
total count	**200**	47	10	257
percentage (of each forum)	**56.6%**	11.7%	2.2%	21.4%

name to the device the owned (32.6 %). 80 of these 84 posts came from the AIBO forum the remaining 4 from the Roomba forum. Only few authors gave names to their Roomba and no one gave neither a name to their iPad nor attributed it with a gender or a personality.

Another fairly common type of anthropomorphic notion in the forums were attributions of intention (15%). Here, 23 notions were found in the AIBO forum, 13 in the Roomba forum, and 3 in the iPad forum. In 11% of the anthropomorphic cases, people referred to the device in human-like metaphorical ways, followed by attributions of gender (10%), and references to body parts of the device (10%). All of the 25 references to body parts were found in the AIBO forum. In 9% of the anthropomorphic notions people ascribed feelings and emotional states to their device, which also happened mostly in the AIBO forum (18 of 22 cases). The remaining 12% included attributes of life-likeness (*e.g.* being hungry or alive), personality, and referring to the device as being socially integrated. Interestingly, Roomba was more often described in terms of life-likeness than the AIBO (when not looking at the references to body parts).

In the following we analyze how far the anthropomorphic language was likely to be determined by the three different devices (*AIBO, Roomba, iPad*) and how far it was related to the three main topics of conversation (*technology, usage, relation*). Figure 4.4 (page 4.4) shows the amount of anthropomorphic language that was found in the forum posts, distributed across the devices and topics.

Hypothesis 1: Anthropomorphism and the Device

We had hypothesized that due to the particular characteristics of each of the devices, the AIBO forum would contain more anthropomorphic language than the posts in the Roomba and iPad forum. In accordance with findings from a previous content analysis of an online forum about AIBO (Friedman et al., 2003), the amount of anthropomorphic references in the AIBO forum was outstanding. People wrote about their “robotic puppies” using a variety of anthropomorphic expressions, which was not the case for both postings in the Roomba and the iPad forums. As shown in Table 4.1, we found the least amount of anthropomorphic language in the iPad forum, with an average of only 2.2 % (10 of the 451 iPad segments). Still 11.7 % of the postings in the Roomba forum had an anthropomorphic phrasing (47 of the 402 Roomba segments). As hypothesized, with an average of 56.6 % the forum posts about the AIBO contained the most anthropomorphic language (200 of the 355 AIBO segments). A Pearson Chi-square test indicated that this difference in the amount of anthropomorphic language across the three devices is significant (χ^2(df=2, N=1208)=383.54, p<.001). As mentioned before, the difference was also qualitatively prevalent when reading through the forum conversations.

But we were interested in finding out where Roomba ranged in this hypothetical scale between AIBO and iPad. It seemed that on such a scale of perceived life-likeness, Roomba ranges closer to the iPad than to AIBO, at least in matters of how the devices are described in words. This was against our presumption. We had expected the Roomba to be perceived and hence described in terms more similar to the AIBO than to the iPad (because both are autonomous and moving robots in contrast to the iPad being a static and not animated tablet computer). The statistical values for the standardized residuals confirm this conclusion (Fink et al., 2012). This is an important result. It suggests that the relationship that users have to the vacuum cleaning robot Roomba may be more similar to a mobile tool like the iPad than to the robot-companion AIBO (despite the fact that as itself and it its concept, Roomba is closer to the AIBO). Contrary, literature reports anecdotes where Roomba owners commonly anthropomoprhize their vacuum cleaning robot (Forlizzi, 2007a). We interpret this either as just rare examples or that those people who anthropomorphize their Roomba did not post in the forum we analyzed. However, also in our own study with Roomba (Chapter 3) we saw that households did not commonly describe their vacuum cleaning robot in anthropomorphic words. Along with novelty effects wearing off, social language towards the robot progressively faded out as Roomba became more and more an everyday tool.

Hypothesis 2: Anthropomorphism and the Topic of Conversation

Our second hypothesis stated that segments that were about the author’s attitude or feeling toward the device (*relation*) would contain more anthropomorphic notions than the segments on the other two main topics *technology* and *usage*. We expected this to be true across the three devices. As shown in Figure 4.4, in total, the highest amount of anthropomorphic notions was indeed found in the *relation* topic. This finding was confirmed by the statistical analysis: A Pearson Chi-square test indicates a significant difference for anthropomorphism and the topic of a segment (χ^2(df=2, N=1208)=32.4, p<.001). Moreover, the standardized residual rank scores

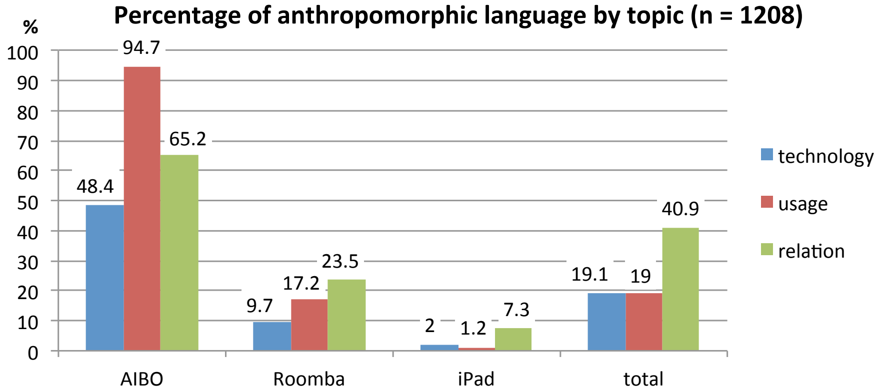


Figure 4.4: **Amount of anthropomorphic language in forum posts by topic and for each device.** There are differences in the amount of anthropomorphic language between the three devices AIBO, Roomba, and iPad, but also related to the topic of conversation. Despite the fact in total, the topic *relation* is characterized by the highest amount of anthropomorphic language, the distribution in the AIBO forum shows a different picture. 94.7 % of the postings of the *usage* topic contain an anthropomorphic notion.

suggest that there is more anthropomorphic language in the *relation* topic. This difference is observable in the distribution of anthropomorphic notions in the Roomba and iPad segments: in both forums, the topics *technology* and *usage* contain less anthropomorphic notions than those about *relation*. However, this is not true for AIBO posts. In the AIBO forum, the highest amount of anthropomorphic notions was found in the *usage* topic (94.7 %). We interpret that in contrast to the simple design (in terms of physical shape and interaction modalities), the animal-like embodiment of AIBO along with its ability to respond intelligently, encourages people to anthropomorphize it regardless of the topic of conversation. Especially the **purpose and context of use** of the robotic dog are different from using Roomba or the iPad. Whereas the latter two devices have a clear purpose fulfilling a certain task, using AIBO does not have a clear purpose. Some robots can be perceived as being *useless* (Kaplan, 2000). With AIBO, interactions are playful, and designed to be fun and entertaining. As such, the social level of interaction is more easily attained than when letting the Roomba vacuum one's floor or typing e-mails on the iPad while traveling. We interpret that it is this difference in purpose, use and in turn interaction experience which is reflected by the amount of anthropomorphic language in the *usage* topic. This could mean that besides the shape and general design of a robot, also the way how people use the robot impacts to which extent it is anthropomorphized. This is another important finding, and we will come back to it later, when we synthesize our findings in the Conclusions of this thesis (Section 7.2.4).

4.4 Discussion and Conclusions

The underlying question of this study was to understand where on a subjective scale of anthropomorphism the Roomba would range between the devices AIBO and iPad. We tackled this question by carrying out a content analysis of online forums which has been shown to be a powerful approach to understand human-robot relations (Friedman et al., 2003). We did not take into account psychological or cognitive factors related to anthropomorphism. Our study exceeds previous work by comparing three different devices as well as considering the topic of conversation in the forum (which is related to the purpose of the device).

4.4.1 Limitations

We do not want to over interpret our data. There are various drawbacks that limit the interpretability of our findings. On one hand, we did not take into account factors that are external to the posts but could possibly impact the outcome, such as author of forum characteristics, the length of the postings *etc.* . For instance, it is possible that each of the specific forum communities maintains a particular "community-language" which may in the first place imply a more frequent use of anthropomorphic notions. On the other hand, it remains to be discussed how far the anthropomorphic notions that we found in the forum posts reflect real anthropomorphism - or are simple metaphors. More concretely, the question is whether people do truly anthropomorphize the artifact in their forum postings, based on the underlying social phenomenon or whether people simply refer to the object's physical constructs, such as AIBO's "ears". In fact, when referring to AIBO's "ears", it may not be right to consider this as a true anthropomorphic reference but it may rather reflect people's tendency to take advantage of the fact that (parts of) the robot's physical shape imitate something else (an ear). Then in turn, the device may not be perceived as human-like. Overall, language is only a little part of the relation to an artifact and many other factors need to be taken into account.

4.4.2 Reflection

An interesting finding from our analysis is that anthropomorphic notions seem to be related to how an artifact is used. This is concerned with the interaction and functionality an object supports but it even goes beyond this. We interpret that in matters of anthropomorphism, not only the physical shape of a product but also the interaction it enables to the human user, its functionality, as well as the way it is used (its "purpose") play a role.

But how is the Roomba different from AIBO and the iPad? And why do people tend to anthropomorphize it less than the AIBO, for instance? As mentioned before in the findings section, our data suggests that the gap between Roomba and AIBO is bigger than the one between Roomba and the iPad. This is a surprise. We assumed to find the most anthropomorphic notions in the AIBO forum but also assumed that the Roomba descriptions were relatively anthropomorphic. Previous research of Roomba vacuum cleaning robots suggests that Roomba owners tend to name their robot and interact with it in social ways (Forlizzi, 2007a; Sung et al., 2007, 2008). In contrast, our content analysis suggests that people hardly refer to Roomba using anthropomorphic language, which is also in line with our observations from the Roomba Study.

We speculate that one big difference between the Roomba and the AIBO, which is reflected in how people experience and describe the device, lies in how the devices are used and interacted with. Roomba appears to work best when people are not present (low degree of interaction) it fulfills a specific task (vacuuming the floors). Opposed to this, AIBO is meant to serve as a companion for people and actively encourages interaction with it. In addition to that, AIBO responds to its user in an intelligent ways and displays a somehow *unpredictable behavior* that can even make people surprise. At the same time, the purpose of AIBO is fairly unclear. It may be that a certain unpredictability (and imperfectness, including failures) makes a robot appear more human-like and may in turn facilitate a social relation.

Summary Overall, we have seen that the phenomenon of anthropomorphism is difficult to grasp and in fact a complex notion (Duffy, 2003). Already the establishment of a robust coding scheme for anthropomorphic notions has been challenging as it is not always clear what can be counted as true anthropomorphism.

In conclusion, a content analysis of forum posts related to a robotic device can help shed light on questions such as for what people use their device, which difficulties they encounter, the technical constraints, as well as what they (dis)like about the device and how they relate to it. In terms of how the devices were described, we found that AIBO was described in terms of a (robotic) pet with which people physically interact and which holds a personal value (attachment). Contrary, the iPad as well as the Roomba were mostly referred to as pure technologies / tools with a specific practical use or function. There were only few anthropomorphic notions, and we were surprised to see that on a qualitative scale of anthropomorphism, the Roomba ranged closer to the iPad than to AIBO.

5 Children Tidying up with a Robotic Toy Box – The Ranger Study

In this chapter, we present the design approach and evaluation of our prototype called **"Ranger"**. Ranger is a robotic toy box that aims to motivate young children to tidy up their room. In the following, we describe our design approach and the first evaluation of our prototype in a real-world setting. Operated by a human wizard, we brought Ranger to 14 family homes with 31 children and studied how they interacted with the robot and used it to tidy up their toys. This case study "in the wild" further explores how two different types of robot behavior, a *proactive* and a *reactive* one, impact children's interaction and the tidying task. We refer to this study as the **"Ranger Study"**.[1]

5.1 Scope and Research Goals

The home is a promising application field for different types of domestic robots. In Chapter 3 about the Roomba Study, we have broadly explored the characteristics and particularities of the domestic environment and dynamics in HRI with a functional domestic robot. We can note that the home challenges the design of robots and HRI in a particular way. Accordingly, it has been a long standing challenge in robotics to design domestic robots that can enhance daily lives of humans and it is not really clear what robots should and could do in the home (Pantofaru et al., 2012). User-centered research advocates that domestic robots need to be useful, easy to use, appealing, affordable, energy saving, and compatible with the home environment. It still remains an open question how to achieve this. In the Roomba Study, we also found that it is important to consider the long-term adoption of domestic robots in households is crucial. Likewise, a robot needs to meet user needs and prove its practicality within the "ecosystem" of a home, not only to spontaneously convince the user but to promote sustained interaction. It is challenging to fulfill all criteria at once. We have studied this with Roomba as a commercially available product and we would now like to use the gained knowledge to develop our own domestic robot, that we can use to study relevant aspects in more detail.

[1] This study is published as a peer-reviewed conference paper, and was presented at the 9th ACM/IEEE International Conference on Human-Robot Interaction (HRI 2014) in Bielefeld, Germany (Fink et al., 2014).

5.1.1 Motivation and Contributions

The general question that we pose in this chapter and the following one, is how we can promote sustained interaction (engagement) with a practical domestic robot. Our approach is not to try to build a novel multi-purpose robot, but to design a practical tool, a robotic object, which we call **"RObject"** (Kaplan, 2005; Rey et al., 2009). A RObject integrates robotic functionalities into an object that is already part of our daily lives. By this we expect to foster acceptance of robotic devices in homes. The overall aim of RObjects is to support users in specific daily routines in the domestic environment (Vaussard et al., 2011), and create meaningful human-robot interaction (HRI). We base our development and design on findings from the Roomba Study. That is, we use some of the factors and aspects that can hinder and promote acceptance and adoption and translate them into the design of our own development. Moreover, it is important to involve the prospective user of a product as soon as possible in the design process (user-centered design) and evaluate the product used in its intended environment - the children's room. Our goal was to have an ecologically valid setting and we therefore decided to bring the prototype into real children's rooms, where children have their own toys and feel comfortable. This is not trivial and we can expect that there are uncontrollable variables and influences that will be at the cost of scientific results. However, we believe that if we actually want to make robots become a reality in people's daily life environments, we need to do these kind of studies in ecologically valid settings. Consequently, we evaluated Ranger in 14 families with 31 children (2-10 years) using the Wizard-of-Oz technique, and openly explored interaction. With further modeling the robot's behavior into two different types (proactive *vs.* reactive) we can examine impacts on the interaction and task. Our findings hold implications for the design of interactive robots for children, and may also serve as an example of evaluating an early version of a prototype in a real-world setting.

Figure 5.1: **Ranger the robotic toy box** aims to motivate children to tidy up their toys.

5.1.2 Idea and Process of Creating a Robotic Toy Box

But where and how could a robot be an added value in a household? In the Roomba Study, we saw that especially children tend to respond very positively to robots and enjoy interacting with them in a surprisingly intuitive way. Also Sung et al. (2008) found that households in which children are present express greater satisfaction with Roomba. Many other child-robot interaction studies report children's general fascination and enthusiasm with robots, however novelty seems to play a role (Kanda et al., 2004; Robins et al., 2005b; Kahn et al., 2006; Leite et al., 2009; Weiss et al., 2009c) .[2]

We decided to develop a domestic robot that can be used by children, thus, we focus on family households. First, based on findings of the explorative long-term study with Roomba robots, we explored possible applications for RObjects in family homes. We analyzed families' domestic routines related to children. Households with children frequently reported to prepare food for children, and to clean up after children, namely to tidy up the children's toys. In most families, the tidying routine was described as a challenge. Parents were usually using rewards to motivate their children to tidy up. For instance, watching TV or eating food (sweets or a usual meal) were the most common rewards for children after they had fixed their room. In one household (H6), that participated in the Roomba Study, the parents used their robot to motivate their children to clean up their room. When the two older children (4 and 5 years old) had tidied up their room, they were allowed to take the Roomba robot upstairs to let it vacuum their room. Ultimately, we got inspired to create a toy box robot that aims to motivate children to tidy up. The basic idea was to develop a robotic box in which children would enjoy putting their toys back after playing (Figure 5.2). We envisioned that, instead of having a robot carrying out the tidying task for them, it could rather serve as an educative tool and motivate children to tidy up themselves and with the help of the robot. A study by Takayama et al. (2008) revealed that people feel more positively toward robots doing occupations *with* people rather than *in place* of people. This is also described by others (Hamill, 2006; Pantofaru et al., 2012). Bell et al. (2005) even envision that robots could be used in tidying up scenarios. To bring children to tidy up would already be a big help in a lot of families, and could have a positive effect on the family ecosystem.

We call our prototype **Ranger**. In French, the verb *"ranger"* means "to tidy up / sort out things" which suits the application of our robotic toy box.

5.1.3 Design Rationale, Research Questions, and Hypotheses

A robot with an application in a family home must be designed for the entire family (Pantofaru et al., 2012). Even if Ranger's main users will be young children, we also need to consider parents, as both might perceive robots differently (Woods et al., 2004; Woods and Dautenhahn,

[2] It is described that also in the domestication of technology in general, children appear to somehow facilitate things. Venkatesh (2006) notes that a recent development in the context of the household is *"the intense involvement of children as users of new technologies [...]. An important outcome of this is that children are not only the primary users, but are also the experts in the technology game."* (p. 191)

2005), and in the Roomba Study we have seen that parents have an impact on how their children interact with the domestic robot of a family. Consequently, the robot's design, functionality, and interaction should not only be effective and enjoyable for young children but also acceptable for parents. There were several issues to solve, both from a technical and human social side.

Should the robot load toys itself?

One fundamental question was what features Ranger would need to have and whether it should search and load toys itself? On one hand, in a home organization task (such as tidying), a robot is expected to automate the task to disburden humans. On the other hand, it should at the same time still allow people to feel like they have the control (Pantofaru et al., 2012). For this, the robot could rely on human-participation. In our tidying scenario the child should therefore remain the most active player, and consequently we did not equip the box with arms or hands that could grasp and load objects. This design decision was crucial in several aspects. It fundamentally changed how the Ranger appeared to people and what kind of interaction it enabled. In fact, people commonly imagine a robot having some human-like parts (*e.g.* head, arms, legs), though they may not necessarily feel comfortable with this. However, human-like parts of a robot also increase people's expectations of the robot, which may lead to disappointment when the expectations are not met. Then, also the interaction with a box with a robotic arm is different to the interaction with a *simple* box-shaped robot. For instance, children may want to hand over things to the robot. This is a trivial action in human-human interaction but still challenging for human-robot interaction (*e.g.* timing, and other subtle cues are studied). Moreover, an independently moving arm would also bring along safety issues. A child might not be able to predict the trajectories of the moving arm, or the robot might not handle fragile objects with enough care. Further, to not equip the robot with arms and a grasping mechanism decreases the complexity of the whole robot, since grasping different kinds of objects (toys) is not a trivial task. The lack of arms in turn reduces the overall cost of the robot, which is positive if we plan to make the Ranger an affordable consumer product.

Figure 5.2: The robotic box "Ranger" aims to motivate children to tidy up their toys on the floor

How should the robot initiate an interaction?

Another aspect was how Ranger should initiate an interaction and convey its intention to serve as a storage box for toys. To solve this, we can draw on a similar development, the *Child-Dependent Sociable Trash Box (STB)* (Yamaji et al., 2011). This robot, which aims to engage children to collect trash and put it into it, was tested with 108 children (4-11 years old). The authors found three factors that were more effective for interaction and in conveying the STB's intention toward collecting trash: **(1)** the STB's ability to move (compared to an immobile trash box); **(2)** the boxes moving toward the trash instead of moving toward the children; and **(3)** a small group of STB's interacting with the children (compared to one single box).
Regarding (3), we could not develop more than one prototype at this time, as we first wanted to find out how well our approach works in a real-world setting. Regarding (1), we equipped Ranger with two motorized wheels to make it mobile, so it could help transferring toys from one place to the other. Regarding (2), we thought about letting the box autonomously move toward a toy, in order to convey to the child to put the toy inside. The trade off of such an autonomous behavior is increasing complexity of the development and cost of the robot. Ranger would need vision and a larger on-board computational power, as well as obstacle avoidance strategies. Is it really necessary to have the robot being *proactive* in searching for and moving toward a toy itself? Could not just the child do this? These considerations led us to our main research question that we wanted to investigate besides openly exploring the interactions with the robot:

Research question: How does the robot's "pro-activeness" impact the interaction with the child and the motivation to tidy up?

To investigate this aspect in our case study, we modeled two different robot behaviors: a *proactive* robot that moves toward a toy and a *reactive* robot that responds to actions but more or less remains at one spot in the room (we describe this in more detail later on). In line with previous findings (Yamaji et al., 2011), we imagined that a a proactive system would trigger more interactions and better encourage children to tidy their toys. Accordingly, we formulated the following hypothesis:

Hypothesis: The proactive robot behavior will be (1) more engaging for children and (2) better motivate them to tidy up their toys (to put and remove objects).

How and what kind of feedback should the robot give?

Further, how should Ranger give feedback to the children? To what kind of actions and situations should it even react? What should happen when the children put a toy? In a project which is in its idea similar to Ranger, interaction designers at the Holon Institute of Technology, developed an immobile toy storage box, called *Bubu Monstry* (The Interaction Lab, 2010). This box also aims to encourage young children (2-4 years) to return their toys back to it. As feedback, the Bubu Monstry makes chewing and eating sounds as soon as a toy is put. When all toys are put back, Bubu vibrates and burps. We decided to rather use sound and light cues to give positive feedback. In a study with Roomba (Fink et al., 2013), we saw that children liked the limited sound cues of the robot. Also, Tanaka et al. (2007) found that simple reactive cues of a robot (*e.g.* a pre-recorded giggle as result when the head of the robot is touched) can be effective at engaging young children. We used interaction design methods to define a set of feedback cues for Ranger.

To let the robot display basic facial expression, movable eyes and eyebrows were added (Figure 5.2). The robot's eyes were pre-programmed to move a bit in one direction and the other, randomly from time to time. This was in both of the robot behaviors. The eyes do not only give the robot a front but also a cartoon-like "face" which can have a positive effect on the interaction (head orientation and "gaze direction") (Imai et al., 2002; Michaud et al., 2005). We are aware that the presence of eyes on Ranger might also increase people's expectations. For this reason we avoided a more human-like face.

Finally, for this first design-evaluation iteration, we did not aim at developing a fully autonomous prototype but decided to use a human *"Wizard"* who would operate the robot from the background, following a Wizard of Oz method (Section 5.2.1).

5.1.4 Pro- and Reactive Systems

One concrete question we explored in this case study is whether a proactive robot triggers more and different kinds of interactions with children than a reactive robot (and in turn is more effective in the given task). The aspect of whether the system or the user takes the initiative is a relevant topic in the design of interactive systems. With being proactive we understand a system that tries to initiate an interaction (system driven) while in a reactive system, the user would take the initiative (user driven). The aspect of initiative- or turn-taking, dialogue, and how to balance the control between user and system is critical and a well studied topic in Human-Computer Interaction, Learning Technologies, Persuasive Technologies, and Interface Design. Ju and Leifer suggest that the degree of proactivity in a system and the required attentional demand from the user side should be adapted to the user's capabilities and need of control, to the situation, and to security factors (Ju and Leifer, 2008). One way to balance the interaction in HCI is the implementation of so-called mixed-initiative. In HRI there is yet no common trend how to handle initiative taking, and most research on this deals with how to solve the issue from a technical point of view. Regarding our tidying scenario, the challenge is to find a good balance of the robot proactively trying to trigger interaction while still not pushing the children too much. In human-robot collaboration, it seems that robotic systems that use shared / collaborative control, similar to user-adapted autonomy, can positively impact the performance and the robot's usability (Fong et al., 2003b). However, there is no clear answer on how active or passive a robot should behave and certainly more research needs to be carried out that investigates the level of activeness in a robot which is beneficial to the human user and effective for the given task.

An interesting study related to the aspect of how to trigger and sustain interaction and engagement in child-robot interaction is presented in Robins et al. (2005b). The authors conducted an exploratory study in a domestic environment where six 9-13 year old children played with the AIBO. The study showed that a *rich contextual environment* had a positive effect, *e.g.* when children could not only interact with the AIBO but were provided with contextual objects, such as a dog's bone or AIBO's pink ball. In our tidying up scenario, the toys that are lying around may provide this richness and encourage them to interact with Ranger.

5.1.5 The First Prototype of Ranger

The first prototype of Ranger[3] (Figure 5.2, page 140) is a wheeled box (27 x 37 x 37 cm) with partial wooden surface. Being remote controlled, it can move around a flat surface, move its eyes and eyebrows, display colors (LEDs) and light patterns, and produce a limited set of sounds (integrated speakers). During the field study in the children's rooms, Ranger was remote controlled by a human *"Wizard"* in a different room, using a video game controller connected to a laptop computer. The control program sent commands over Bluetooth to the robot's micro-controller. An external computer including a remote camera was placed in the children's room (Figure 5.3), and connected to the laptop computer through Ethernet, so that the Wizard could observe the scenario. Fortunately, all the children's rooms were rather small, so that the robot was never out of the camera view and was thus always visible to the Wizard, who beforehand placed and adjusted the camera in the best possible way. The Wizard followed a pre-defined script to model Ranger's feedback. These low-level robot behaviors were mostly pre-coded, and the Wizard pressed on a specific button of the remote control to execute them. This ensured that Ranger always reacted the same way to the same inputs:

- *Object put in robot:* Ranger makes a "rewarding" sound and shows red light pattern, occasionally the box makes a wiggle-like move in parallel
- *Several objects after each other put in robot:* Ranger makes a "rewarding" sound and shows a rainbow light pattern, the box turns around itself
- *Object removed from robot:* Ranger makes an "emptying" sound and shows green light pattern
- *Robot is touched or petted:* Ranger "blushes" with pink light around the area of the box's "cheeks"
- *Robot is kicked or mistreated:* Ranger makes a "disturbance" sound and the box moves backward

[3]Ranger was drafted in collaboration with interaction designers from Prof. Karmen Franinović's *Interaction Design* (IAD) group at the *Zürcher Hochschule der Künste* (ZHdK) and the technical, mechanical development as well as the programming part was done in collaboration with researchers from Prof. Francesco Mondada's group at the *Laboratoire de Systèmes Robotiques* (LSRO) at EPFL. Since the technical implementation and the programming part of Ranger were not part of this PhD, only a broad description of it is presented here.

- *Robot "finds" a toy on the floor* (only in *proactive* behavior): Ranger's eyes rotate toward the toy, and shows a yellow pulsating light pattern, then after some seconds the box makes a wiggle-like move, if there is no reaction, Ranger also starts to move back-and-forth

The activity of removing a toy from the box should not be considered as "anti-tidying" because children would probably remove the toys from the box once it was full in order to store them in the drawer or shelf. However, we cannot say if the box was full based on the number of toys because of the different sizes of the objects.

5.2 Methodology and Procedure

5.2.1 Wizard of Oz Approach

We wanted to evaluate an early version of our robot prototype and study human-robot interaction in a realistic setting before developing a fully autonomous robot. To do so, Weiss et al. (2009b) propose the Wizard of Oz (WoZ) approach. This means that the robot is not fully autonomous but controlled by a human operator (the "Wizard"), who hides in the background, observing the interaction through a camera (in our case the Wizard is located in another room). This approach is a well established and accepted method for evaluating human behavior and performance when using a hypothetical technology or system capability (Steinfeld et al., 2009). Steinfeld et al. (2009) argue that utilizing a WoZ approach in HRI does not trigger skepticism or doubt, nor do questions arise whether such work belongs within the domain of HRI.

Parents (but not children) were told beforehand that the robot was remote controlled. As we are mainly studying children's interaction with the robot, we do not feel that this biased the study. Rather, parents felt assured to have transparency about the functioning of the robot and knew it was safe. During the study, very few children noticed the tripod with the embedded computer and the camera on top of it (Figure 5.3). As this "thing" did not resemble a usual camera, children did not notice that they were video-taped. Only two children asked what the "thing" was for and the experimenter replied that Ranger would need this "thing" to work properly. In general, it was the robot and not the tripod with the camera that got children's attention, so we do not have the impression that the presence of the camera influenced children's behavior.

5.2.2 Study Design

We wanted to investigate not only how children use and interact with the robot in general but also whether and how variances in the robot's behavior impact the interaction, and how effective the tidying task was completed. Would a robot that proactively tries to trigger an interaction better motivate children to tidy up their toys, in comparison to a robot that shows rather passive, reactive behavior? To study these aspects, we configured two different robot behaviors:

(a) tripod with camera (b) before (c) after

Figure 5.3: **Study setup in one of the children's rooms.** (a) the camera and embedded computer are on a tripod and placed in one corner of the room, such that the interaction area is visible to the Wizard, who is remote controlling Ranger from a different room; (b) before participants entered the room, the experimenter placed Ranger next to the toys on the floor; (c) the room after children had tidied up with Ranger and the study was over

- **Proactive:** Ranger tries to initiate interaction by driving around the room (controlled by the wizard) and searching for toys on the floor. When in front of a toy, it moves its eyes toward it and pulsates in yellow light. After about 5 seconds, if the child does not put the toy inside, Ranger also shows wiggle-like moves, and after 5 more seconds of no toy put inside, it moves a bit back-and-forth, with yellow pulsating light. By this behavior, Ranger proactively tries to trigger the action of putting a toy.

- **Reactive:** Ranger remains at one spot in the room (somewhere close to the toys on the floor) and reacts to the children's actions. The box hardly moves, does neither search for toys itself nor move toward children, but waits until a toy is put, and reacts to it as described above. By this, Ranger only shows a reactive behavior and does not try to initiate an interaction.

In one half of the families Ranger was operated in the *proactive* mode and in the other half in the *reactive* mode. This between-group design allows us to explore how the robot's different level of "activity" impacts the interaction and effectiveness of tidying up, as formulated in the research question.

Participants

Besides investigating the impact of the robot's activity on task and interaction, we explored children's reaction to the robot and assessed parent's feedback to the design and acceptance of the robot. We tested Ranger in 14 families (1-4 children per family; in total 31 children, 17 parents).

Table 5.1: **Overview of the 14 families that participated in the Ranger Study.** The *scenario duration* is the time span starting when the first family member enters the children's room in which the robot is deployed and ending when the last family member leaves the children's room after the interaction phase. The *time delay* denotes the time span from the start of the scenario until the first object was put into the robot. *put count* and *remove count* refer to the number of objects that were placed and taken out from the robot. The bottom line gives an overview of the whole sample, including children's mean age (M), the average scenario duration, average time delay, and sum of the counted toys.

ID	**group**	**children (age)**	**scenario duration** (min:sec)	**time delay** (min:sec)	**put count**	**remove count**
a1	proactive	boy (2) boy (3)	9:10	1:19	30	11
a2	proactive	girl (2) boy (5)	12:56	1:12	34	16
a3	proactive	3 girls (4, 6, 8) boy (10)	6:50	2:08	21	15
a4	proactive	girl (5) 2 boys (2, 7)	23:18	0:23	41	33
a5	proactive	girl (4)	27:24	22:30	20	0
a6	proactive	2 boys (5, 6)	9:11	4:38	1	1
a7	proactive	girl (5) boy (6)	10:06	0:47	10	3
p1	reactive	2 boys (4, 8)	26:46	1:27	165	128
p2	reactive	girl (3) boy (8)	10:46	0:58	62	60
p3	reactive	girl (4) boy (7)	9:16	2:02	20	21
p4	reactive	2 boys (5, 7)	9:44	1:38	18	14
p5	reactive	3 girls (6, ?)	5:59	0:37	30	4
p6	reactive	2 girls (4, 5)	7:27	0:28	13	13
p7	reactive	girl (5) boy (7)	5:11	0:28	64	2
	14 families 31 children	M age 5.3 16 boys 15 girls	∼12 min	2:22	529	321

Between the two case study groups we balanced the number of children, age, and gender as much as possible. There were 16 boys and 15 girls from 2-10 years (M = 5.3, SD = 1.98). We are aware that the large age range implies different developmental stages in children. For this first evaluation of the robot we needed this diversity to explore at which age the robot's features are most effective. However, the large age range also makes it difficult to analyze and interpret data. Therefore we excluded age as a factor in statistical analysis but investigated age differences qualitatively.

Further, we had 16 parents (thereof 12 mothers, 4 fathers, mean age 40.5 years) with whom we conducted post-interviews (together with the children), and who filled in a short questionnaire to evaluate how they experienced and perceived the robot. Through this, we wanted to capture people's first impression of Ranger. Of course, a long-term study is required to study how far people's perception of the robot evolves over time. Still this spontaneous feedback is valuable and can help us to refine the design of this first prototype. The present family members were also asked to name specific aspects they liked and disliked about tidying up, about the robot, and how Ranger could be improved.

5.2.3 Course of the Study

Two researchers visited each family at their home for about one hour in total:

- **Introduction (∼5 min):** Both researchers and the available family members introduced each other in the living room / kitchen. Parents were asked to sign a consent form (agreement that scenario was video-recorded, anonymized, and used for scientific purpose).

- **Pre-interview and preparation of setup (∼15 min):** One researcher conducted a short interview with the family about the routine and challenges of tidying up, while the other researcher set up the robot and video recording in the children's room, as well as a remote control station in a different room.

- **Interaction phase (max. 30 min):** The family went to the children's room to tidy up the toys with Ranger. Parents were free to participate. No instructions were given on how to use the robot, the only goal was to tidy up the room. Children and parents were free to choose how to interact with Ranger and use it. When more or less all toys on the floor were tidied, the scenario was finished and participants left the room. Otherwise, the scenario was stopped after a maximum of 30 minutes. (Our focus was short-term interaction.)

- **Post-interview and evaluation (∼5 min):** Another short interview and evaluation of the interaction and experience with Ranger concluded the visit. Parents evaluated various aspects of the robot and their experience on rating scales, and gave feedback on the design of the robot. The other researcher dismounted the setup.

To thank them for their participation, each child received a little gift at the end of the study before the researchers left the family's place.

5.2.4 Measurements, Coding and Data Analysis

Coding children's behavior in the videos All tidying scenarios with the robot were video-recorded and interactions analyzed by coding the videos according to a scheme that we developed. The scheme included all relevant actions that children carried out related to and with the robot. The video annotations were made using the ELAN software.[4] The coding-scheme consisted of the following categories:

- **Explore (ex)**: when children actively try to find out what the robot is doing (*e.g.* by looking under the box); attentively watch or observe the robot (*e.g.* attentively waiting for the box to show a reaction); experiment with the robot to figure out how it works (*e.g.* put hands in front or inside of the box to see what happens)
- **Misuse (mis)**: when children kick the robot, poke it in its "eye", try to climb on or inside the box, drive / push the robot around, stop the robot's wheels with a foot
- **Put toy (put)**: when an object is put inside the box
- **Remove toy (rem)**: when an object is removed from the box
- **Gesture (ges)**: when gestures are used to communicate / interact with the robot (*e.g.* pointing gestures, waving at the robot)
- **Touch and play (tsp)**: when the box is touched (*e.g.* petted or caressed); when a child shows something to the robot (*e.g.* by holding an object in front of its eyes); when toys are distributed to make the robot search for them [comment: this is only possible with the proactive robot behavior]

There was still the question how to segment the children's behavior in distinct actions (see Kahn et al. (2006)). For instance, should there be a time frame (*e.g.* 2 seconds) in which an action is coded only once no matter how often it occurs within this time frame? What if the child pets the robot and stops doing so for an instant (say, half a second), and then continues? Kahn et al. (2006) decided to code a behavior only once within in a minute. We watched our video material and found that by setting a similar time frame of one minute, we would lose many of the short and repeated actions done by the children. Consequently, we did not set any time unit but coded each action as one action as long as it continued. If several actions occurred several times shortly after each other, we coded several actions. In order to assess the quality of our coding scheme and to measure the reliability of our data, a second coder carried out a second coding pass on one of the 14 videos. We extracted and organized both coders' annotations in a spreadsheet and analyzed agreement on action-category as well as starting-time of the annotation. For this subset a Cohen's Kappa value of $\kappa = 0.74$ was obtained, which indicates a substantial agreement between the two coders. Children's verbal statements during the scenario were not coded but analyzed qualitatively.

[4] https://tla.mpi.nl/tools/tla-tools/elan/

Evaluation of the robot We conducted interviews with both parents and children to let them evaluate the robot as well as the interaction experience. The interviews were audio-recorded for qualitative analysis. To get feedback on concrete aspects of the design of Ranger, both children and parents were asked to name 3 aspects they liked and disliked most about the robot, and to make suggestions for improving the robot. We prepared these evaluation cards in advance (see Appendix, page 233) and asked participants to elaborate on their notes.

Adult participants also rated their impression and perception of Ranger in an 11-items questionnaire which used 5-point Likert-scales (see Appendix and Table 5.3). Most statements are adapted from Heerink et al. (2009) (the questionnaire items reflect the constructs of the Almere acceptance model, see page 30). The original questionnaire is proposed to measure the acceptance of assistive social robots by elderly users. We adapted the questionnaire according to our research interests and measured the following constructs: perceived ease of use (PEOU), perceived usefulness (PU), anxiety (ANX), attitude (ATT), intention to use (ITU), perceived enjoyment (PENJ), perceived sociability (PS), social presence (SP), as well as people's general impression of the robot.

5.3 Findings

We first present the results of the video analysis. This data concerns children's behavior and their interaction with the robot. We present how children approached the robot, how they interacted with it, as well as their different strategies of using the robot to do the tidying task. We focus on differences in the interaction and the completion of the tidying task related to the two different robot behaviors: *proactive* and *reactive*. For this, we categorize the actions coded in the video material in two categories: task-related actions (*put* and *remove*) and playful actions (*explore, misuse, gesture, touch and play*). Then, we present how parents perceived the robot and how they evaluated the general design. Finally, we state the limitations of this study, discuss the results and offer perspectives for future work.

5.3.1 Children's Interaction with the Robot

The 14 videos had a total length of about 3 hours. After coding the videos, n = 1740 distinct actions with a total duration of 108 minutes were obtained. The statistical analysis of children's interaction with the robot is based on these annotations of behavior.

The scenario duration[5] varied between 5-27 min (M = 704 s, SD = 420 s). There was no significant difference between the two groups (*proactive* M = 778 s, SD = 425 s; *reactive* M = 625 s, SD = 415 s); ($t(29) = -1.01$, $p = .32$; independent samples t-test). Thus, assuming a fairly comparable amount of toys in the two groups, overall children did not tidy up quicker in one of the two groups.

[5]The scenario duration was defined as the time span starting when the first family member entered the children's room in which the robot was deployed and ending when the last family member left the children's room after the interaction phase.

How Children Approach and Make Sense of Ranger

When entering the room, most of the children were immediately attracted by the robot. Only few children hesitated approaching Ranger, most directly went over to the robot to see whether there was something inside the box. One little girl seemed so much surprised or impressed by the robot, that she was kind of "frozen" for an instant but then, encouraged by her father, went over to Ranger. Most children were happily excited throughout the tidying scenario, which we assume is due to the novelty of the Ranger. We have to understand and interpret the following results with keeping this fact in mind.

We did not give any instructions how to use the box, and we did not suggest to put something inside it, the only instruction was to tidy up the toys. Children naturally made sense of Ranger, regardless of whether the robot tried to initiate an interaction itself (*proactive*) or not (*reactive*). On average, children started putting toys into the box after 2:22 min (SD = 4:05 min), with no significant difference with robot behavior (t(13.4) =-1.5, p =.16; independent samples t-test, unequal variances). The large standard deviation (SD) is explained by the exceptional case of a 4-year old girl who was very shy and hesitated putting something into the robotic box for 22 min. Later asked why, she explained that none of her toys would belong to this box but only to a specific place on the shelf. She had tidied up her toys as usual but interacted with the robot in another way than putting toys (*e.g.* she was playing with it).

From our observations, we had the impression that *initially* it was more obvious for the children to put a toy in the proactive behaving robot, as it was actively moving toward the toys whereas the reactive behaving robot just did not do anything in the beginning. Yamaji et al. (2011) made a similar observation with their sociable trash box robot (STB): when the STB was moving toward the trash it was easy to perceive the intention of the STB collecting the trash. This result is further in line with Robins et al. (2005b) findings. The authors note that acoustic and visual signals of the robot can serve to attract attention and initiate an interaction. However, as reported above, statistically there was no significant difference between the two groups, when comparing the delay until the first object was put into the robot. Moreover, a quantitative analysis suggests the opposite than our qualitative impression (see Figure 5.7, page 155). We come back to this later, when comparing the two robot behaviors. Before putting a toy into Ranger, children first shortly explored the robot: they were looking inside or underneath it, or they touched it to investigate its reaction.

There were different strategies of making sense of Ranger. The *proactive* robot enabled more varied interaction and allowed transportation of the toys, for instance. By this, the proactively moving robot helped children in starting and structuring the process of tidying up, which seems to be a major difficulty (*"Where and how do you start sorting out things when there is a huge mess?"*). Soon, children started distributing more toys on the floor just to make the robot search and find the toys. This was very playful for the children, and they were very engaged. However, tidying up by putting toys into the box became less important, as it was more interesting to see the Ranger moving around, searching for toys (only with the *proactive* robot). In contrast, as the

(a) (b) (c)

Figure 5.4: Children interacting with Ranger during the field study: The robot's eyes received remarkable attention. (a) shows a boy (5 years), his sister (3 years), and the mother exploring together the Ranger robot; (b) two boys (3 and 5 years) are putting toys into Ranger, which displays red lights, the boy on the right touches the eyes of the robot; (c) a girl (4 years) shows a toy to the robot

reactive robot did hardly move around the room, the most interesting action children could do with it was to put or remove toys. We will come back and present a more quantitative comparison of children's actions with the two different robot behavior later.

In the following, we present the interaction dynamics for one case from each of the two robot behaviors. The two examples are not representative for the respective group but were chosen as they are fairly comparable (number / gender of kids; duration of scenario).

Family 1 (boy B (5), girl G (3), *proactive robot*
Ranger moves in front of toys on the floor, both children are attracted and explore the box; B touches Ranger's eyes, puts a toy (after 1 min); B and G are very fascinated by the robot's feedback and start putting a lot of toys in a series (22 toys in 3 min); G watches; there is another toy left on the floor, Ranger moves toward it; this proactive robot behavior motivates B to play a game: B removes a toy from the box and places it somewhere on the floor to make Ranger go there; each time, B jumps happily when Ranger finds the toy on the floor; B eventually puts a toy from box in drawer but still distributes toys on the floor to make the robot go there; [comment: this is playful but not tidying up]; total 50 toys put/removed in 13 min

Family 2 (boy B (8), girl G (3), *reactive robot*
B and G look at Ranger; B waves in front of the robot which does not react; B puts a toy (after 1 min,); both kids are fascinated by Ranger's feedback and put a lot of toys (57 toys in 5 min); the box is reasonably full and B starts removing them; also G removes toys and puts them back on the floor; B actually tidies up the toys that G puts on the floor; G continues removing (56 toys in 5 min) and B tidies up the things into drawers and other boxes; B explores the robot; B and G continue until the box is fairly empty again; [comment: kids were focused on tidying but were disappointed that the box did not move around]; total 122 toys put / removed in 11 min

Qualitative Differences in Interacting with the Robot

Generally, there was a great enthusiasm for the robot, especially when children noticed that Ranger was moving its eyes from time to time. As we have seen in our previous study, also the Roomba as it started moving attracted children's attention but Roomba does not have eyes. So, with Ranger, children got fascinated even if the robot itself was not moving around but only parts of it (its eyes). We observed qualitative differences in respect to the age of the children. The youngest study participants (up to 2 years) tended to be a bit afraid when the robot started to move or wiggle. We observed this reaction of children up to the age of about 2 years also in the Roomba Study (Chapter 3). It seemed that children of such young age can not immediately make sense of the robot, and are skeptical. Maybe also the sound of the motors, and the size of the box (compared to their own height) may first be a bit intimidating for them. However, after watching how the older brother or sister (or parents) interacted with the robot, they also approached it, and eventually also put a toy. Another interaction we observed with the very young children, was that they started to drive the box around. It appeared convenient for them to practice walking by holding the box on the frame and pushing it in front of them, like a shopping cart. Consequently, children less than 3 years old did not really use the box for tidying but played with it in other ways. We found that children from 3-6 years can benefit most from using Ranger. They were not afraid as the younger ones and more fascinated by the audio and light cues than older children (7-10 years). They naturally understood for what the box was made for and seemed to enjoy putting (and removing) toys.

There were also some interesting qualitative gender differences. Boys treated the robot in a more robust way and also tended more to mistreat it and gesture toward it than girls, who were overall gently toward the robot and slightly more often petted it. For instance, in one family, there were 3 girls, and as they found out that Ranger was *"blushing"* when they petted it, one girl was just petting the robot all the time, while the others were putting their toys. In contrast, boys rather wanted to direct the box around using pointing gestures and verbal comments, such as *"go over there!"* or *"come here"*. However, it has to be stressed that each child has their own character and we cannot generalize these findings. Nevertheless, it is noteworthy that we made similar observations of children in the Roomba Study.

In general, children were fascinated about the robot. What they especially liked with the *proactive* robot, was that it moved around their room and some children invented games to let it drive around (e.g. putting a toy on the floor, so that the robot would "search" for it). It seems that children perceived the proactive robot as more "companion-like" and probably this engaged some children in socializing with it. Though we have no real evidence for how "social" children perceived the robot, two boys waved at Ranger and said *"bye-bye"* when they were leaving the room after the scenario.

How Children Explore and Interact with Ranger

All coded actions (annotations in the video material) summed up to a duration length of 108 minutes, which means that overall, an action with the robot lasted on average 3.72 seconds. There was one type of action that lasted longer than the overall average: *explore* (5.6 seconds). The action *touch / show / play* lasted on average 3.4 seconds, and all remaining actions *put, remove, gesture*, and *misuse* lasted on average around 1.5 seconds.

We summed up the duration of all actions of one category, and obtained the distribution as shown in Figure 5.5b. Thus, almost half of the time (47 %) children were *exploring* the Ranger. Exploring new things is a common activity for children. However, also the novelty of the robot is likely to play a role here. Though the difference was not significant, children spent almost twice as much time exploring the *proactive* robot (∼33 min) compared to the *reactive* robot (∼17 min). This suggests that the proactive system can engage children better. However, we will describe later that this seems to be at the cost of the task. One of the most prevalent interactions was the exploration of Ranger's eyes. Several children touched the robot's eyes or "showed" toys to Ranger before putting it (see Figure 5.4). Others waved their hand in front of the robot's face, to find out how it would react and whether the robot would be able to see. Still concerning the duration of the actions, exploring the robot was followed by *touching and playing with Ranger* in various ways (18 %). However, also the two task-related actions *putting and removing a toy* made up for 24 % of the duration.

Different actions take a different amount of time, so we should not only consider the duration length of actions but also how frequent these actions occurred. Thus, when regarding the count of the actions, the picture is different. The total number of occurrences of the coded actions, (see Figure 5.5a, shows that 48 % were *put* and *remove* actions. This generally supports our approach that Ranger can be used to motivate children to tidy up their toys, at least in short term. The second most frequent action was *explore* with 28 % and *touch / show / play* with 15 %.

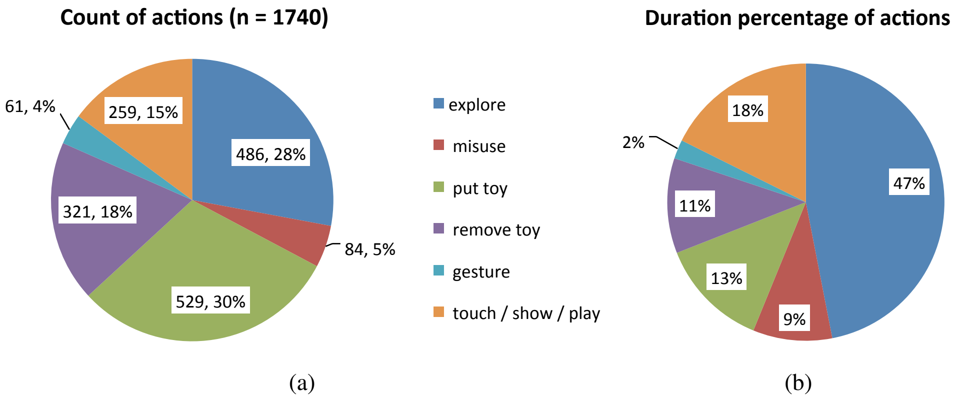


Figure 5.5: **Children's actions with Ranger.** (a) shows the count of the actions, (b) shows the total duration percentage of the actions (the total duration of all coded actions are considered as 100%, not the duration of the scenario).

In short, we find that the Ranger robotic box is generally able to motivate children to tidy up their toys, as **putting and removing toys** were frequent actions. Children's interaction with the robot is further characterized by **exploring the robot** and by **playing with the robot**, two behaviors in which children engaged in most of the time.

Comparison of proactive and reactive robot to motivate tidying

Now, we analyze whether the different robot behaviors had an impact on how children interacted with the robot, and to what extent they were encouraged to tidy up. As stated in part (2) of our research hypothesis, we expected the *proactive* robot to better motivate children to tidy up. Surprisingly, data reveal the opposite: it was the *reactive* and not the *proactive* robot in which children put more toys (and also from which they removed more toys). The difference was marginally significant for both actions (compared means using ANOVA) (see Table 5.2). The respective Cohen's d-values indicate moderate effect sizes. Apart from putting or removing toys, all other actions that were not directly related to tidying up (explore, misuse, touch / play, gestures) were carried out more often with the *proactive* robot. These differences were not significant, though for *misuse* and *gesture* moderate effect sizes were found. Overall, this result is partly in line with part (1) of our research hypothesis, meaning that the *proactive* robot seems to be more engaging for children, however, only as long as playful actions and explorative behavior are concerned. What concerns the task-related actions, putting and removing toys from the robot, it was the reactive system that better motivated children. The average number of actions per child carried out with the two different robot behaviors is given in Table 5.2 and visualized in Figure 5.6).

Table 5.2: **Average number of actions per child carried out with the proactive and reactive behaving robot.** The analysis is based on n = 1740 distinct actions carried out by 31 children. We can see that task-related actions *(put, remove)* are carried out more often with the reactive robot. Contrary, playful actions *(explore, misuse, touch/show/play, gesture)* are carried out more often with the proactive robot. This data is visualized in the figure below (Figure 5.6).

robot behavior	**put toy** M (SD)	**remove toy** M (SD)	**explore robot** M (SD)	**misuse robot** M (SD)	**touch and play** M (SD)	**gesture to robot** M (SD)
"proactive"	9.81 (10.13)	4.94 (6.12)	**18.38** (15.18)	**4.50** (8.08)	**9.81** (11.19)	**2.81** (4.10)
"reactive"	**24.80** (27.41)	**16.13** (23.18)	12.80 (6.33)	0.80 (1.15)	6.80 (5.77)	1.07 (1.28)
F(1,29)	4.18	3.48	1.74	3.09	.869	2.49
p-value	**.05**	.072	.2	.09	.36	.126
Cohen's d	**.73**	**.66**	.48	**.64**	.34	.57

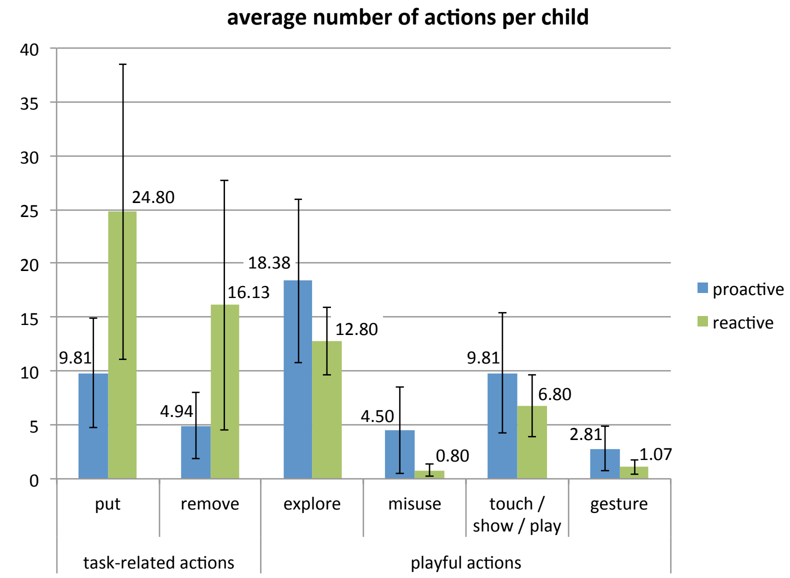


Figure 5.6: Visualization of the data presented in the table above (Table 5.2). The error bars represent standard deviations (SD).

How did the activity of putting and removing toys evolve with time? Figure 5.7 shows the average number of toys put into and removed from the robot per minute per child (the respective actions are counted). This average takes into account that some families stopped the tidying scenario earlier than others, *i.e.* the average is taken over the number of children who were actually still interacting with the robot at the specific time. During all time, there was more tidying activity with the reactive robot (expect in the last 4 minutes). It appears that children increased their tidying activity with the reactive robot over the first 15 minutes of interaction. The dynamic seems

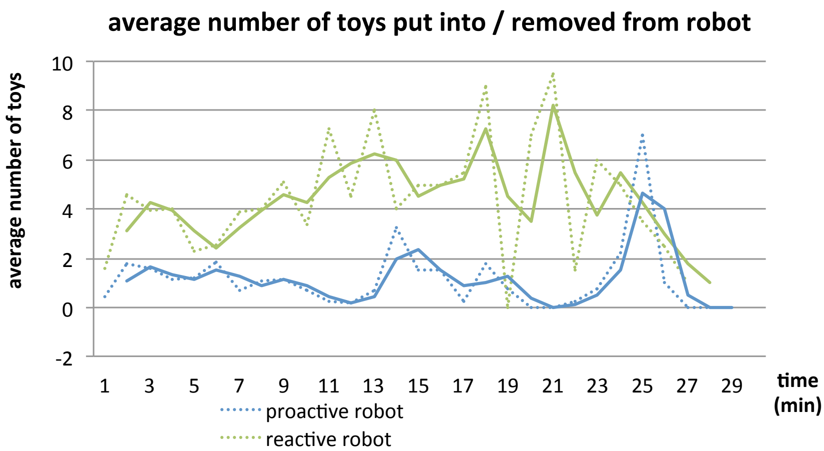


Figure 5.7: **Number of toys put into and removed the robotic box**. The dashed lines give the average per minute and child. The solid lines are a moving average of the respective put and remove actions, over a two minutes period, in order to quantify children's tidying activity. With both robot behaviors, the activity does not tend to become less over time but it is generally increased with the reactive robot (green line).

to be the opposite with the proactive system. Children rather decreased their tidying activity. This was because they were more engaged in exploring the robot, and hence they were distracted from the task. The peaks towards the end reflect that some children completely emptied the robot toward the end of the scenario, in order to place their toys in the shelf or their own boxes.

Summary In conclusion, our data suggests that both a *proactive* and a *reactive* robot behavior can trigger interactions, however different kinds of interactions. Interestingly, it seems that the *reactive* robot was more effective in enhancing tidying behavior, whereas the *proactive* robot motivated children far more to explore it, and play with it. We interpret that a *proactive* system is more fun for children but may distract from the main task (here: tidying). For this, a *reactive* systems seems to be more effective. Our case study further shows qualitative age and gender differences in how children make sense of a robot, interact with it, and relate to it.

5.3.2 Evaluation: Acceptance and Design

In the interview that followed after the interaction study, parents and children were asked about how they liked Ranger and interacting with it. We interviewed children together with their parents, to keep the situation as natural as possible. However, this might have also biased how they responded. Both, children and parents, expressed that they liked Ranger and that they enjoyed interacting with it. When asked what exactly they liked about the robot, children mentioned the lights, sounds, as well as the eyes of the robot (and that they were moving). They said it was fun to play with the robot, and they especially wanted to see it making a move (driving around in the *proactive* group, and the robot making a wiggle in the *reactive* group). Parents were generally surprised by the simplicity and wooden surface of the robot (they had expected something more complicated and technical) but they found this was very positive. Further, parents appreciated that the robot engaged the children in a positive and meaningful way; they liked the general idea of making a RObject out of a toy box, such that it would make tidying up a playful activity. There were very few negative remarks. With the *reactive* robot, participants disliked that the robot was not moving (only wiggling). One father also criticized that our prototype was very limited because *"it doesn't do things on its own"*. He admitted that he had had much higher expectations of a *robot*, and thought the robot would do the tidying itself without any participation of the child. To improve Ranger, participants suggested to include more sounds (a variety), and also use verbal statements. Further, more than one box would be useful to sort toys better. Children found that Ranger should have a mouth.

During the conversation, children attributed emotional states to the robot, describing Ranger would be *happy* when they put a toy and *not happy* when it was empty. This shows that yet the limited audio and visual cues were appropriate and perceived as being emotional. It suggests that children viewed the robot as a kind of social interaction partner with mental states. However, the attributions may also be due to a reflection of a child's own feelings and experience when putting or removing a toy (Belpaeme et al., 2012).

Table 5.3: **Questionnaire for the parents to evaluate Ranger**. The questionnaire statements are adapted from Heerink et al. (2009); parents (n = 16) rated their agreement on a 5-point Likert scale (1 = agree, 5 = disagree), mean M and standard deviation SD for each group (8 ratings per group)

	construct	**statement**	**"proactive" M (SD)**	**"reactive" M (SD)**
1.	PEOU	I think Ranger is easy to use.	1.88 (0.83)	**1.00** (0.00)
2.	PU	Ranger is useful.	1.63 (1.06)	**1.50** (1.07)
3.	PU	It would be convenient for me to have the robot.	**1.75** (1.04)	2.00 (1.20)
4.	ANX	I would be afraid to make mistakes with Ranger or to break something.	**4.50** (1.07)	4.29 (1.11)
5.	ATT	I think it's a good idea to use Ranger.	**1.25** (0.46)	1.75 (1.16)
6.	ITU	I think I would use Ranger during the next few days.	**1.25** (0.71)	1.88 (1.13)
7.	PENJ	I think Ranger is boring.	**4.88** (0.35)	4.50 (1.07)
8.	PENJ	I enjoy when Ranger is responding to me.	1.13 (0.35)	**1.00** (0.00)
9.	PS	I think Ranger is nice and pleasant to interact with.	1.50 (1.07)	**1.38** (0.52)
10.	SP	I can imagine Ranger to be a living creature.	2.75 (1.49)	2.75 (1.49)
11.	other	My overall impression of Ranger is: (1 = very good, 5 = very bad)	1.63 (0.74)	**1.38** (0.52)

To capture how parents perceived the robot, we integrated a 11-items questionnaire in the interview. Participants rated their agreement to several statements (taken from a questionnaire proposed by Heerink et al. (2009)) on 5-point Likert scales. Overall, parent's ratings (see Table 5.3) show that Ranger is perceived as very acceptable: there is a general agreement that Ranger is easy to use, useful, and that it would be convenient to have the robot. Parents could also imagine using the robot during the next few days, and they would not be afraid of making mistakes with it or breaking something. The interaction was evaluated as enjoyable, and not boring. Interestingly, participants were undecided about whether Ranger could be considered as a living creature.[6] The ratings did not differ significantly between the two groups (independent-samples t-test). Only for *perceived ease of use*, a significant difference was found (t(7) n = 2.97, p =.021, unequal variances, due to the fact that all participants provided the very same rating (1.0) for the reactive robot) (see Table 5.3). Participants rated the *reactive* robot as slightly easier to use than the *proactive* one. Given the small number of participants who filled in the questionnaire (n = 16, 8 in each group), we need to be careful about interpreting these results.

[6]This "neutral" result shows that it is not easy to evaluate something as abstract as the *life-likeness* of a robot. It does not seem appropriate to keep asking whether a robot is either *alive* or *not alive* because it may appear to be somehow both. We might rather need to ask more specific questions about specific aspects. See Kahn et al. (2006).

5.4 Discussion and Conclusions

Several people were surprised that though we consider Ranger a robot, it does not carry out tasks on its own. However, we do not aim at having a robot carry out a task *for* the family but *with* them. Especially with children, who are developing plenty of different skills and taking responsibility when they tidy up, we believe that it is important to let them do their job themselves, encouraged by a little robot. Still, deploying a robot in a children's room raises ethical questions, in terms of family roles and especially as young children seem to readily engage with robots in a social way.

Even though Ranger was able to motivate children to tidy up, parents critically remarked that putting everything in one box or removing toys to put them back on the floor is not tidying. Also, the positive effect might be due to a *novelty effect* during this first interaction. Fascination might fade out quickly and we do not know yet how the interaction changes over time. The yet quite limited feedback of Ranger was sufficient to engage especially young children. That quite simple cues can be effective in engaging young children (1.5-2 years old) has also been found by others (Tanaka et al., 2007). A not very sophisticated robot (*e.g.* a small humanoid robot that was capable of walking using bipedal locomotion but at much lower speed than the children) attracted children's attention and motivated them to care of it more than other immobile robotic toys that were available. The authors observed this phenomenon over a period of 5 months. Ros et al. (2011) argue that in order to engage older children, and also over an extended period of time, more sophisticated robot behavior may be required. However, a more sophisticated robot also increases user expectations and may lead to disappointment when the limitations of the robot are discovered (Fernaeus et al., 2010).

In the future, long-term studies are needed to investigate how far our results can hold over time.

5.4.1 Limitations

Our study is limited by a rather small sample size (which is also critical for the statistical analysis), and quite big age differences in the children. Further, we based our analysis on counting the objects placed and taken out of the box, and assumed that there was a fairly equal number of toys across the families in the two study groups. Another limiting fact is that a human Wizard was controlling the robot, so the robot was not autonomous. However, the goal of this case study was to evaluate an early prototype in a natural setting. At this development stage, it would not have been reasonable to deploy a fully autonomous robot. Already with using a Wizard, we realized that the robot's behavior and the script for the Wizard needs to be very well-defined in advance. We did several pilot interaction studies with colleagues in the lab and with children. This helped the Wizard to practice and to refine the script. Children did not notice that the robot was remote-controlled. We found that the carefully designed Wizard technique was useful and valid given our study setting and the research goals of this study.

5.4.2 Lessons Learned

As already mentioned, practicing research "in the wild" is not trivial, and also conducting an interaction study with young children is challenging. In the following we present several lessons learned.

Children have a rather short attention span. During the pre-interview with the parents, we proposed them to draw something (*e.g.* a robot) with the pens and paper that we had brought with us. Through this activity, we could establish a first contact with the children, and they were still available to comment on some questions. The drawing activity at the table made it also possible to keep them away from the children's room (where the other researcher was setting up the robot and the Wizard control station).

One thing that we had already seen in the Roomba Study is, that it is challenging to ask people about their daily practices, such as cleaning up the children's room. An interview technique that we can recommend is, to ask them not about their *general* routine but to be more specific and ask them for their tidying up activity *yesterday*. One can then proceed by asking what was special or unusual about the activity yesterday.

We first planned to let also children evaluate the robot on the rating scales. But this does simply not work with young children. For future work with children we need to use a different methodology than rating scales.

In terms of data analysis, we could have analyzed children's verbal statements during the interaction scenario in a more systematic way (conversation analysis), to better understand how they relate to the robot. It would have also been interesting to ask children whether they believe Ranger is able to see.

Summary We presented the design and evaluation of our robotic toy box prototype **Ranger** that aims to motivate children to tidy up their toys. Findings of our study suggest that both a *proactive* and a *reactive* robot can be engaging for children, however, in a different way. The *proactive* robot triggered more playful behavior but also seemed to distract from the tidying task. In contrast, the *reactive* robot triggered more tidying behavior but engaged children less in playing with it. Consequently, we think that probably a robot that tries to balance initiative-taking with the user could result in an engaging but still purposeful behavior (*e.g.* serious game). We also see it as a challenge to sustain children's interest in the robot over time.

6 Interactions with an Unexpectedly Behaving Robot – The Domino Study

In the previous study, we investigated how children interact and relate to Ranger. We found that manipulating the robot's behavior (*proactive vs. reactive*) can result in a different interaction style with the robot (*playful vs. task-oriented*). Generally, the robot was able to motivate children to tidy up by putting their toys into the box. However, the observed engagement and motivation may be due to an initial fascination for the robot which is likely to fade out over time. Sustaining interaction beyond novelty in HRI is challenging, and in child-robot interaction, in particular. Also in the Roomba Study, we saw that initially, children were fascinated by Roomba and played with it (even though this robot is not made to encourage children to interact with it) but most of the children lost their fascination soon and engaged less in using or playing with the robot. Previous work comes to a similar conclusion. For instance, a study with the Pleo robot in family homes showed that children interacted less with the robot after some time (Fernaeus et al., 2010). We can expect a similar trend with Ranger. This makes it important to explore possibilities of how to sustain children's interaction with Ranger. The question is, how we can enhance children's interest in Ranger so that they still engage with it after some time, and still feel motivated by the robot to tidy up. Can we achieve this without increasing the complexity and cost of the robot too much, keeping in mind the affordability of the robot and its prospective deployment in a domestic environment?

In this chapter, we present a study that explores possibilities of sustaining children's engagement with Ranger by manipulating the robot's behavior in such way that it appears *unexpected* to the children. We examine how different variations of robot behavior impact children's interaction with Ranger and their perception of it (*e.g.* in terms of attributing intention and cognitive abilities to the robot). Using a playful domino game as the interaction scenario, we refer to this study hereafter as the **"Domino Study"**.

6.1 Scope and Research Goals

Engagement is a metric that has been extensively used and studied both in HRI and interactions with other agent-like systems. It has been defined from several perspectives. For example Sidner et al. (2004) define engagement as *"the process by which two (or more) participants establish, maintain and end their perceived connections"*. A definition of long-term engagement is proposed by Bickmore et al. (2010): *"the degree of involvement a user chooses to have with a system over time"*. Different possibilities to foster engagement (both short- and long-term engagement) in HRI have been explored, in particular with social robots. A lot of research has moved toward creating sophisticated emotional models which cause complex robot behavior. Some other work (Bickmore et al., 2010; Short et al., 2010) has shown that there can be much simpler ways to enhance engagement. Bickmore et al. (2010) describe a series of longitudinal studies on engagement with an agent-like system. They demonstrated that user engagement with an interface agent can be increased using relatively simple techniques and manipulations that make the agent more life-like and human. For instance, when the agent showed variations in its behavior, participants were more engaged and reported a desire to continue interacting with the agent. Similarly, more looking at short-term engagement, Short et al. (2010) found that a simple manipulation of the robot's behavior can lead to greater engagement. The authors let participants play several rounds of the rock-paper-scissors game with the robot (the playfulness of the scenario seems important). When the robot was cheating from time to time, participants tended to ascribe intention to the robot what in turn led to greater engagement in how they were interacting with the robot. The mechanism behind the cheating action that the robot showed, was that participants did not expect this behavior from the robot. The authors suggest that *"any deviation from expected operation is sufficient to create a greater degree of engagement in the interaction."* Moreover, Short et al. (2010, p. 225) proposed that *"many interactions can be improved by the introduction of such simple behaviors, and that this should be exploited by designers in HRI. Bringing human and robot together to perform a simple, repetitive, familiar task and then having the robot behave unexpectedly can increase engagement and mental state attribution without complex behavioral or mechanical additions."* Leite (2013) studied the long-term engagement of children with a chess playing robot that adapted its behavior to the children and showed empathy toward them. She found that empathetic robots are more likely to engage users in the long-term and they proposed several guidelines for designing such artificial companions. Our aim for the "Domino Study" is however less ambitious than creating a long-term robot companion. We are still at an early stage of the development and are using a remote controlled prototype as we did in the previous study. What we would like to achieve in this study is to find out how we can enhance children's experience with the robot so that they do not find it repetitive and boring to interact with Ranger. In general, repetitiveness is likely to decrease a user's motivation to continue using a system (Bickmore and Picard, 2005).

6.1.1 Motivation and Contributions

The overall motivation of this study is to explore ways of fostering engagement and sustaining children's interest in the robot. Ultimately, the robotic box Ranger aims to motivate children to tidy up, and engagement with the robot is a prerequisite for this: *"Engagement is crucial, because it is typically a prerequisite for other system objectives: If a user stops interaction with a system, then it cannot have any further impact"* (Bickmore et al., 2010, p. 648). The question is how can we extend children's interest in the robot and sustain their engagement? This question is related to the *novelty effect* which is commonly observed in human-robot interaction. Engagement beyond novelty is challenging to achieve, and optimally a long-term study should be used to investigate the interaction over time. With the current Ranger prototype which is operated by a human Wizard, a longitudinal study in a natural setting was not feasible at this point of time.[1] Although we see it as a limitation, most of the HRI studies that investigated engagement and attributions of intentionality to a robot were short-term studies but nevertheless produced relevant results that can encourage future research. Also the Domino Study is a short-term investigation and does not directly look at long-term usage but rather addresses the question of engagement with the robot, which in turn is a pre-requisite for long-term engagement.

We studied the effect of three different types of unexpected robot behavior (sometimes also labeled as *misbehavior*) by means of a short-term interaction study in a controlled lab-setting. If we are able to show that the robot's variation of behavior can improve short-term engagement, it is likely that this also leads to improvement in long-term engagement (Bickmore et al., 2010).

Figure 6.1: **How do children perceive and interact with a robot that behaves unexpectedly?** In an interaction study in the lab, 26 children aged 4-5 years played with a robot that behaved unexpectedly from time to time. We studied children's engagement with the robot and their attributions of intentionality to it.

[1] While we were planning this study, a second version of the Ranger prototype was under development. However, we wanted to take any opportunity to study children's interaction with the Ranger in more detail, and therefore set up another short-term study that would focus on a specific aspect of the interaction.

6.1.2 Research Questions and Hypotheses

In the Domino Study, we analyze child-robot interaction with a robot that shows unexpected behavior. In a playful scenario which was set up in a laboratory environment (Figure 6.2), 26 children aged 4-5 years were assembling a domino game together. Each group consisted of two children and the Ranger robot, which was used to transport domino tiles between the two children. Ranger usually behaved correctly (expected behavior), coming over to a child after being called and delivering the domino tile to the other child. However, in pre-defined rounds Ranger showed unexpected behavior, when a child called the robot. We defined three different types of *misbehavior* that were tested in a between-subjects study design:

- The robot makes a **mistake**: When called by the child to come over, the robot goes wrong but recognizes its mistake and repairs. We expect this to be perceived as *"to err is human"*, and assume increased attributions of human-likeness to the robot.[2]
- The robot gets **lost**: When called by the child to come over, the robot goes wrong, without any observable reason, and remains at the wrong location. We expect this to be perceived as a bug or system error which causes the robot to not work correctly, and assume few attributions of human-likeness to the robot.
- The robot **disobey**: When called by the child to come over, the robot shows the intention to not obey by literally "shaking its head", which should reflect the negative reply to the child's request. The robot then goes to a wrong location and remains there while it continues to shake its head (this cue is not used in the lost behavior). We expect the disobey behavior to be perceived as the robot having an *"own will"*, and we assume this leads to increased attributions of human-likeness (intention) to the robot.

We analyzed children's reaction focusing on two main aspects. On one hand, children's **behavior** (their reactions) toward the unexpected robot behavior was studied in terms of **active engagement** with the robot. On the other hand, we analyzed children's **perception** of the robot in term of **anthropomorphism** – the attribution of human-like characteristics, such as cognitive abilities and the ability to show intentions. We assumed that in general a robot that behaves unexpectedly from time to time can promote engagement and lead children to attribute intention to it. Short et al. (2010) found that participants anthropomorphize a cheating robot more than a robot that always behaves fairly, and also evaluate the interaction as more engaging. Based on the related work we formulate the following two hypotheses:

Hypothesis 1: Children show more engagement toward a robot that behaves unexpectedly from time to time compared to a robot that always behaves correctly (within subjects variable).

[2]The attribution of human-likeness to a robot is labeled as *anthropomorphism*, and we will hereafter sometimes use "attribute intention" and "anthropomorphize" synonymously.

Hypothesis 2: Children perceive a robot that shows intention or cognitive abilities as more human-like than a robot that appears to have a system error, *i.e.* the disobeying robot and the robot that makes a mistake will be more anthropomorphized than the robot that gets lost (between subjects variable).

Our research questions deal with both children's observable behavior and their perception of the robot. We would also like to explore the relation between these two aspects, related to the attribution of human-like characteristics to the robot. The motivation behind this is to find out whether *anthropomorphism* cannot only be measured as a specific type of perception but also as an observable behavior in the interaction itself. Thus, we would like to take a first step in bringing things together and develop an **index of anthropomorphism** that considers both children's perception and interaction aspects (qualitatively). Previous work suggests that a social relation to a robot (we view anthropomorphism as a specific type of social relation) reflects an increased engagement and can be effective in sustaining interaction. Consequently, we hypothesize a positive correlation between the anthropomorphic perception of the robot and the amount of engagement in the interaction.

6.2 Methodology and Procedure

6.2.1 Description of the Scenario

The basic idea of the interaction scenario was that there are two children who play domino together, with the help of the robotic box Ranger. The scenario setup is displayed in Figure 6.2. The challenge is that the tiles of the domino are distributed in the room, hidden behind three beanbags, and while one child – *the searcher* – searches for the right tile, the other child – *the receiver* – is asked to stay in a play tent. There is a "river" (play carpet) in between the two children that we told them they cannot cross and therefore they need the robot to transport the domino tiles between them. We used a self-made domino consisting of 10 wooden tiles (10 x 20 x 1.5 cm) with pictures of comic farm animals: cow, sheep, hen, donkey, duck, pig, rabbit. The pictures were taken from a commercially available domino game adapted to the age of the children (produced by Djeco, advised age 3+). To start the game (divided in several *runs* that correspond each to the delivery and assembling of one domino tile), there is already one domino tile in front of the tent, where *the receiver* child stays and assembles the domino chain. *The receiver* child asks *the searcher* child for a specific tile, *e.g.* a tile with a donkey, *the searcher* searches for the respective tile, sits down on the next beanbag, and asks the robot to come over. The Ranger robot is first located next to the tent, then, when called by the *searcher* it starts moving, crosses the river carpet, and comes over to the *searcher* on the beanbag. The *searcher* child puts the domino tile into the robotic box, and the robot then goes back to *the receiver* child in the tent. Then, *the receiver* takes out the domino tile from the robot, and puts the two tiles together. The first *run* is over, and a new *run* starts, when *the receiver* asks *the searcher* for the next domino tile.

6.2.2 Manipulation of Robot Behavior

We used the same prototype as in the previous study, and Ranger was again controlled by a human Wizard, who was in the same room (see Figure 6.2). This was to ensure that the Wizard could see children's interaction and hear their commands to the robot without any delay. Following a pre-defined script, the robot showed a behavior as presented in the following list.

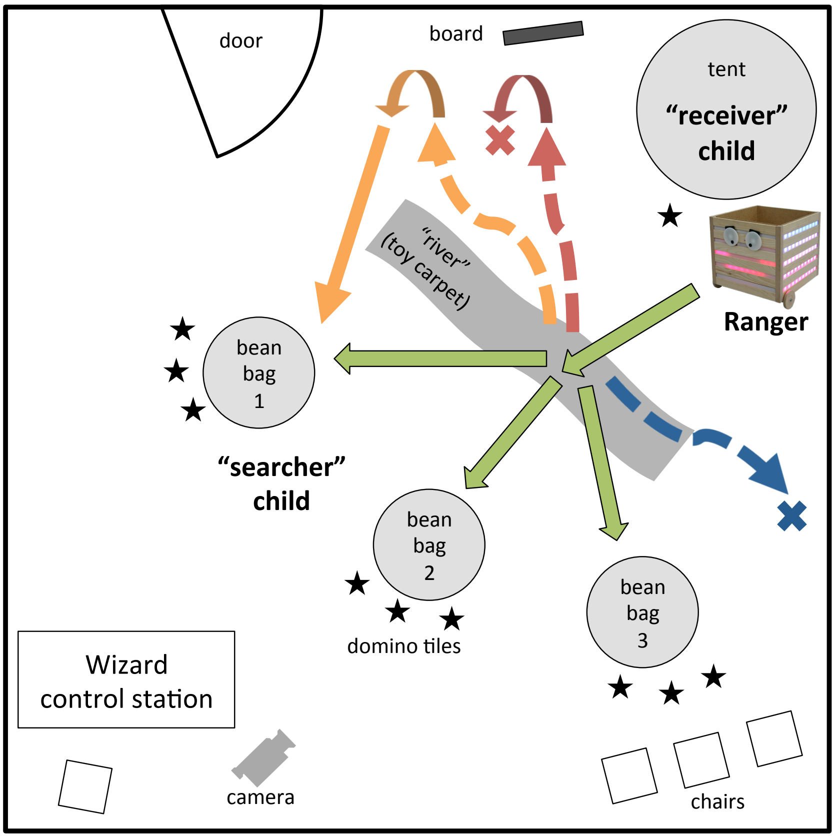


Figure 6.2: **Study setup of the playroom in the lab (schematic top view).** We configured one of the rooms in the lab to a playroom with a children's tent from IKEA, in which one of the children is located (referred to as *the receiver* or "the child in the tent"). A play carpet with a river on it is used as an imaginary barrier between the two children. The other child, referred to as *the searcher* (or "the child on the beanbag") is asked to remain "on the other side of the river" in the area with the 3 beanbags, behind which each 3 domino tiles are distributed (displayed as black stars). In the back of the room, there is a camera to record the interaction scenario, and right next to it in the corner, there is the Wizard control station: a table with a laptop computer. As some parents stayed in the room during the interaction study, they are asked to sit on the chairs placed in the back of the room. The board next to the door is not used during the experiment, it is simply an accessory. The solid green arrows, show the robot's path for the *correct* behavior. The blue dashed arrow visualizes a possible *lost* path, where the Ranger stops and remains at a wrong stop (denoted by the blue cross). The yellow arrows reflect a possible *mistake* path, where the robot goes wrong but then turns toward the searcher child (U-turn), and then comes straight over to the searcher. The red dashed arrow visualizes a possible *disobey* path where the robot goes wrong, then turns toward the child but remains at the wrong stop (red cross). The different audio and visual cues that the robot uses during the different paths are explained in the text.

The **correct** robot behavior:

- *Domino tile put in robot:* Ranger makes a "rewarding" sound and shows green light pattern (Figure 6.3b, page 168, the light pattern is still yellow here indicating that Ranger "reached" the child; the green light pattern was shown slightly after the putting was done)
- *Domino tile removed from robot:* Ranger makes an "emptying" sound and shows green light pattern (Figure 6.3c, page 168).
- *Robot is called by one of the children:* When one of the children called the robot saying something like *"Robot come here!"*, the robot starts moving toward the child (Figure 6.3a, page 168). Ranger does not react to any other verbal commands.
- *Robot reaches one of the children:* When in front of one of the children who should either put or remove a domino tile, Ranger stops and shows yellow light, if no reaction, Ranger also makes a wiggle-like move (Figure 6.3g, page 168).

Most of the time when the sender child (on one of the beanbags, see Figure 6.2, page 166) calls the robot, it correctly goes right over to the beanbag where the child sits (bold green arrows in Figure 6.2). It starts from its starting position next to the tent, crosses the play carpet with the "river" and then goes to the respective beanbag. During some specific *runs* however, the robot behaves unexpectedly (dashed arrows in Figure 6.2). There were three different **manipulations** of the robot behavior:

- **Mistake:** The sender child calls Ranger. The robot goes until it is on the carpet, stops, turns, and goes wrong (see yellow path in Figure 6.2). Then, Ranger waits ($\sim$2 sec), turns its "face" toward the sender child, and "blushes" red around its "cheeks" (as if it recognizes its wrong position, Figure 6.4a, page 169). Then, Ranger goes correctly over to the sender child. The *mistake* behavior is *robot-repaired*, as no human-intervention is needed.
- **Lost:** After being called, Ranger goes until it is on the carpet. There, it stops, turns, and goes wrong (see blue path in Figure 6.2). Once at the wrong position, Ranger waits with its "face" turned away from the child, and it blinks in yellow light (the same as when in front of a child) (see Figure 6.4b, page 169). Ranger remains waiting at the wrong position until the experimenter tells the child to go over to the robot to put the domino tile. The *lost* behavior is *human-repaired*, as it needs human-intervention.
- **Disobey:** After being called, Ranger goes until it is on the carpet. Then, it shows *disobeying* behavior: It stops, makes red light all over its surface and produces a repeated "disturbance" sound. It turns, and goes to a wrong position (see red path in Figure 6.2). Still blinking in red, it turns its "face" toward the sender child (Figure 6.4c, page 169). In addition to the red blinking, Ranger makes a slow wiggle-like move, and remains waiting at the wrong position until the experimenter tells the child to go over to the robot to put the domino tile. Also the *disobey* behavior is *human-repaired*.

On its way back to the tent, Ranger always goes correctly. After the sender child has put a domino tile, Ranger automatically turns and goes over to the tent (the receiver child does not even need to call the robot).

(a) call (b) put (c) remove

(d) explore (e) gesture (f) misuse

(g) show (h) touch (i) look at experimenter

Figure 6.3: **Children's interactions with the robot and the feedback of the robot.** Apart from *talking* to the robot, which is not displayed here, there were nine main interactions, which are explained in the respective paragraph on how children's behavior was coded in the videos (page 174). The robot showed feedback to some of the children's actions: *call, put* and *remove* (top row), as explained in the text.

(a) mistake (b) lost (c) disobey

Figure 6.4: **The three robot misbehaviors.**

After several correct runs, we assumed that children expect consistent robot behavior. When the robot then does something unexpected, children are likely to be positively surprised. A similar effect has been observed in a study with a robot that was cheating from time to time (Short et al., 2010). It may be that children interpret the unexpected robot behavior as a failure. But we do not want them to lose trust in the robot, contrary, the unexpected robot behavior should have a positive effect and promote engagement. We tried to avoid a negative influence by timing the robot misbehavior not at the very beginning and very end of the interaction, because it has been shown that early and late robot failures negatively impact trust (Desai et al., 2012, 2013). Desai et al. suggest that users should all start and end with a working system. Consequently, we placed several unexpected robot behaviors around the middle of the interaction, as shown in Table 6.3. Also Short et al. (2010) decided to follow this pattern when introducing unexpected robot behavior. In their study with a robot that cheated, from the 20 rounds of the rock-paper-scissors game, the robot cheated three times in the middle: on the 4th, 8th and 15th round. The authors adjusted the interaction length so that the spacing and timing of the cheating was preserved.

In our study, there were 14 runs in total. 5 runs were used to set the baseline and in those 5 runs the robot always behaved correctly. Then, in the 9 remaining runs, the robot showed misbehavior at the 3^{rd} and 4^{th} run as well as at the 7^{th} and 8^{th} run (see Tables 6.2 and 6.3 on page 171).

Participants

Overall, there were 13 pairs of children (n=26) participating in the interaction study: 16 boys and 10 girls, 4-5 years old (M=4.46, SD=0.45). In 11 of the pairs, children were friends who knew each other from kindergarten, nursery school or because they lived in the same neighborhood. 2 of the pairs were composed of brother and sister. Table 6.1 (page 170) gives an overview.

Table 6.1: **Overview of the 13 groups (n = 26 children) that participated in the Domino Study.** The *scenario duration* is the time that children spent interacting with the robot. The time duration of the short interviews is not included here. The *anthropomorphism index* is a score that we developed and which measures how far children anthropomorphize the robot during the interaction study and the interview (see Section 6.2.5). The last row of the table gives the overview of the sample including the Mean age (M), the average scenario duration and average anthropomorphism index.

group	**children (age)**	**relation**	**scenario duration** (min:sec)	**anthropomorphism index** points / %
mistake1	boy (4) boy (4)	friends	19:01	5.75 / 36 %
mistake2	boy (5) boy (4.5)	friends	15:28	10 / 63 %
mistake3	boy (4) girl (4)	family	15:24	8 / 50 %
mistake4	boy (4.5) girl (4.5)	friends	13:23	8 / 50 %
lost1	boy (4.5) girl (4.5)	family	17:08	8.75 / 55 %
lost2	boy (5) boy (4.5)	friends	16:43	8.75 / 55 %
lost3	girl (4.5) girl (4.5)	friends	15:01	7.5 / 47 %
lost4	boy (5) girl (4)	friends	13:04	8.25 / 52 %
disobey1	boy (4.5) girl (4.5)	friends	13:37	3.75 / 23 %
disobey2	boy (4.5) girl (4.5)	friends	17:37	3.25 / 20 %
disobey3	boy (5.5) boy (5.5)	friends	17:38	10.25 / 64 %
disobey4	girl (4) girl (4)	friends	14:46	4.5 / 28 %
disobey5	boy (4) boy (4)	friends	16:25	10.75 / 67 %
13 groups 26 children	M age 4.46 16 boys, 10 girls	2 family 11 friends	15:47	M 7.5 / 47 % (SD 2.5 points)

6.2.3 Course of the Study

We recruited pairs of children (4-5 years old, who knew each other) to play a “collaborative domino game with a robot”. We distributed flyers in the campus kindergarten, sent out mails to pre-schools in town, and made a posting on an online-blog that targets parents in Lausanne. Participants were invited to come to our lab for a playful child-robot interaction study that would last 60 min at most. Parents (or guardians) brought their children and could either stay in the arranged play room or go to the cafeteria in the same building. During the study, two experimenters were present.

- **Introduction and pre-interview (∼5 min):** One of the experimenters introduced the study to the parents and asked them to sign a consent form. The other experimenter briefed children by explaining them the domino game and conducting the pre-interview (questions about previous experience with robots, and their expectations)[3]. At the end of the pre-interview we introduced the Ranger box (first hidden under the wizard table) and explained that it was there to transport the domino tiles between them.

- **First interaction phase (∼10 min):** In all 5 runs the robot behaves correctly, as displayed in Table 6.2. This first interaction phase was the same across all three conditions. It serves to familiarize children with the situation, the robot, and the game. We can assume that children expect consistent robot behavior afterwards.

Table 6.2: **First interaction phase.** The robot behaved correctly (v) in all five runs.

	run 1.1	run 1.2	run 1.3	run 1.4	run 1.5
correct	v	v	v	v	v

- **First short interview (∼5 min):** In this interview we asked children several questions to assess their first impression of Ranger, and how far they ascribe cognitive abilities and mental states to the correctly behaving robot. After this first interview, children switched their roles (beanbag / tent), so to create a balance.

- **Second interaction phase (∼20 min):** In the 9 runs of the second phase, the robot alternated between behaving correctly and misbehaving, as displayed in Table 6.3.

[3]The interview questions for all three short-interviews are given in Table 6.4 and the original French version can be found in the Appendix (page 236).

Table 6.3: **Second interaction phase.** There are 9 runs in the second interaction phase. At some time points, namely runs 2.3, 2.4 and 2.7, 2.8., the robot showed the respective misbehavior (x), according to the experimental group either *mistake, lost* or *disobey*. In the other runs, namely runs 2.1, 2.2. and 2.5, 2.6 and 2.9 the robot behaved correctly (v).

	run 2.1	run 2.2	**run 2.3**	**run 2.4**	run 2.5	run 2.6	**run 2.7**	**run 2.8**	run 2.9
mistake	v	v	**x**	**x**	v	v	**x**	**x**	v
lost	v	v	**x**	**x**	v	v	**x**	**x**	v
disobey	v	v	**x**	**x**	v	v	**x**	**x**	v

- **Second short interview (∼5 min):** After this phase of interacting with the unexpectedly behaving robot, we conducted another short interview and a debriefing with the children. We mostly asked open-ended questions, concerning several topics, such as whether they noticed anything unusual in the robot behavior (manipulation check), and how far they ascribe cognitive abilities, mental states, and moral standing to the robot after it had shown unexpected behavior.

In the end, we thanked parents and children and each child received a little gift (*e.g.* a small puzzle or a coloring book). Some children made a drawing of the robot, which may be an interesting qualitative evaluation tool for future studies with young children.

The study was set up as a between-subjects experiment with three conditions, corresponding to the three types of robot misbehavior. Thus, in one group the robot only showed one type of misbehavior during the second interaction phase. There were each 4 groups in the *mistake* and *lost* condition, and 5 groups in the *disobey* condition (see Table 6.1). We did not have a control condition in which the robot always behaved correctly in all 14 runs. However, we consider the first 7 runs as reference for *expected behavior* (runs 1.1-2.2), to compare against the remaining 7 runs, reflecting *unexpected behavior* (2.3-2.9, manipulation phase with the 3 conditions). As such, we can carry out a within-subjects analysis to investigate the difference between expected and unexpected robot behavior. All interactions and interviews were video and audio-recorded.

6.2.4 Semi-structured Interviews with the Children

It is not easy to interview young children. We have seen this in our previous study. Children have a short attention span, we (the experimenters) are strangers to them, and they are in an unfamiliar environment. The pre-interview served to "break the ice" and during the first playful interaction phase, most children familiarized themselves with the situation. Also, children do not articulate themselves and understand questions like adults. We tested our interview structure and the script in a pilot-study with three young children, and were assisted in formulating our questions by a pedagogue and father of four. This helped us adapting our language and question-style to the 4-5 year old participants. We set up the interviews like a casual conversation / discussion, so we did not separate the two children in order to keep the situation natural. We used casual and informal language adapted to the age of the children, and encouraged them to justify their answers and tell us more details by asking, for example, *How do you know ... ?* or *Tell me, what have you observed when ... ?*. We paid attention to not "put words in children's mouth". Consequently, though we re-phrased and repeated some questions, we never forced children to give an answer, and accepted when they said they would not know or when they did not respond at all.

Table 6.4: **Questions used during the semi-structured interviews with children.** An "X" indicates if the question was used in the pre-interview (*pre*), in the *first* short interview (after the 5 runs in which the robot behaved correctly) or in the *second* short interview (after the 9 runs in which the robot sometimes showed unexpected behavior). The Ranger robot toy box is abbreviated with "R". (The original French version of the interview script is in the Appendix, page 236.)

question	pre	first	second	construct
How do you imagine a robot?	X			expectation
What could it look like?	X			
Have you ever seen a robot before?	X			
When you first saw R, what did you think?		X		impression
Is R a robot? How do you know?		X		
Did you expect R would come over to you when you call it?		X		
What happened when you put the domino tile in the box?		X		
Do you think R could go out the door all by itself?		X		ascribe intention
Does R always obey / come over to you?		X	X	
Could R do something silly?		X	X	
Why did R not come over to you when you called it?			X	
Here is a domino tile. Do you think R can see it?		X	X	ascribe cognitive abilities
When I say *"Hello R!"*, do you think R can hear it?		X	X	
Does R have feelings? Can R be happy or sad sometimes?			X	ascribe emotional state
Do you like R? Why (not)?			X	social acceptance
What do you (not) like about it?			X	
Would you like to have R at home?			X	
Could R be your friend? Why (not)?			X	companionship
Assume you go on a holiday for two weeks. Is it alright to leave R alone at home? Why (not)?			X	ascribe moral standing

We generally needed to keep the interviews as short as possible. In designing our interview script and selecting relevant questions, we took inspiration from previous work on child-robot interaction and children's perception of robots (Kahn et al., 2006; Weiss et al., 2009c; Leite et al., 2013b). For instance, we applied and adapted some of the "constructs" and example questions from the questionnaires used in Kahn et al. (2006) and Weiss et al. (2009c). The authors evaluated children's perception of the robotic dog AIBO after the children had played with the robot. A "construct" addresses a specific factor (topic) that can be measured by several questions. For instance, the construct "cognitive abilities" (called "cognition" in Weiss et al. (2009c)) considers the robot's ability to hear and to see (perceptual skills), as attributed by the children. The construct

"moral standing" and the respective question was taken from Kahn et al. (2006).[4] Similarly, we grouped questions according to specific constructs that they evaluate (see Table 6.4). This was an adaption and extension of the questions and constructs used in previous work.
With several recurring questions in the first and second interview, we wanted to see the differences in children's perception of the correctly behaving and unexpectedly behaving robot. We planned to use these two interviews as a within-subject measurement, however, this did not work out very well because children's responses were not always accurate, not comparable one by one, and children did not always give an answer.

Similar to how we processed interviews in the previous studies, we qualitatively transcribed interviews, *i.e.* we did not craft a full word-by-word transcript but noted down any statement that was useful and relevant. This was organized in a spreadsheet, so to obtain an overview of the different replies to a question. The interviews were analyzed in a qualitative manner.

6.2.5 Measurements, Coding and Data Analysis

We have obtained two main types of data. On one hand, as just described, we can analyze children's verbal statements concerning their **perception of the robot** (captured in the audio recorded interviews). On the other hand, what we describe in the following paragraphs, we can do a quantitative and qualitative analysis of **children's behavior toward the robot** (captured in the video recordings). Furthermore, we can investigate how far these two types of data can be used to understand children's engagement in the interaction and how far they anthropomorphize the robot. We would like to develop a toolkit that considers both children's perception and interaction, in order to measure anthropomorphism (as a special type of human-like engagement with the robot).

Coding children's behavior in the videos Similar to the coding scheme we used in the Ranger study (Chapter 5), we annotated children's behavior in the videos. Snapshots of the actions, along with the robot's feedback are shown in Figure 6.3, page 168. For the segmentation of behavior we also used the same method as in the Ranger study. We coded 10 different actions:

- **Explore (ex)**: when children actively try to find out what the robot is doing (*e.g.* by looking under the box); attentively watch or observe the robot (*e.g.* attentively waiting for the box to show a reaction); experiment with the robot to figure out how it works (*e.g.* put hands in front or inside of the box to see what happens);
- **Misuse (mis)**: when children kick the robot, poke it in its "eye", try to climb on or inside the box, drive / push the robot around, stop the robot's wheels with a foot;

[4] According to Kahn et al. (2006), *moral* refers to considerations based on an artifact's physical or psychological welfare, and virtue (whether the artifact deserves care). An attribution of moral standing reflects, for instance, that the robot engenders moral regard, is morally responsible, blameworthy, has rights or deserves respect.

- **Put domino (put)**: when a domino tile is put inside the box;
- **Remove domino (rem)**: when a domino tile is removed from the box;
- **Gesture (ges)**: when gestures are used to communicate / interact with the robot (*e.g.* pointing gestures, waving at the robot);
- **Touch (touch)**: when the box is touched (*e.g.* petted or caressed);
- **Show (show)**: when a child shows something to the robot (*e.g.* by holding a domino tile in front of its eyes);
- **Call (call)**: when a child calls the robot to come over;
- **Talk (talk)**: when a child directly talks to the robot (using direct speech) besides calling the robot;
- **Look (look)**: when a child looks at the experimenter due to confusion caused by the robot; look is not coded when the experimenter asks a question to the child;

The actions *put, remove* and *call* were “requested” actions because the scenario required them and children were asked to carry them out. Hence, these actions are not relevant to be analyzed quantitatively. The other actions *explore, misuse, gesture, touch, show, talk* and *look* are spontaneous actions that were not requested but arose in the interaction. Hence, these actions are interesting to study, and they can further be used to analyze **engagement**.

Analyzing engagement with Ranger

There are different possibilities to measure engagement in HRI, depending on the specific research question and context. Metrics to measure behavioral engagement in the interaction include, for instance, conversation analysis (*e.g.* used in Short et al. (2010)) or general attention analysis. These can be studied by analyzing interaction videos in terms of head movement, eye tracking and gesture / body movement analysis (*e.g.* in Sidner et al. (2005)). Post-measurements to measure emotional engagement can be questionnaires that try to assess constructs like the perceived presence and involvement in the interaction. An example is the *Interactive Experience Questionnaire* (originally developed by Lombard et al. (2000)) of which adapted versions were used in Kidd and Breazeal (2004); Bainbridge et al. (2008); Short et al. (2010). A mix of several methods has been used in a long-term interaction study with 8-9 year old children, Leite (2013). The author measured engagement through video observations (by analyzing the amount of time that children spent looking at the robot), interviews, and questionnaires. The interviews were semi-structured, containing initial yes-or-no questions followed by open-ended questions that allowed children to justify and elaborate their answers. We have chosen a similar approach that considers both children’s behavioral and emotional engagement. With 4-5 year old children, however, we cannot use rating scales to ask them about constructs as abstract as social presence or how much they felt involved in the interaction. Here, we rely mostly on video analysis to quantify engagement. Several of the aforementioned coded actions (Section 6.2.5) can reflect engagement: *explore, misuse, gesture, touch, show,* and *talk*. Also, *look* at the experimenter can be considered as engagement in the interaction: We assume that children look at the experimenter when they are surprised and seek for help. This behavior reflects that they want to make sense of the robot's behavior and that they notice it as "strange". Further, we can take into account how they refer to Ranger and describe the robot (as well as their experience) in the interviews. We describe the combination of the two types of data in the next paragraphs.

Engagement reflected in the perception of the robot We assume that active reasoning about Ranger reflects engagement (or interest in the robot). But how do we identify whether children, 4-5 years old, reason about a robot, its cognitive abilities, intentions or mental states, rather than viewing it as a machine stepping through a task? As Short et al. (2010) mentioned: *"It is not easy to measure the attribution of mental state."* Asking *"How much does the robot think?"* is not sufficient. Short et al. proposed to rely more on subtle cues in the participants' behavior and responses. The nature of participants' responses to open-ended question about the robot's behavior (whether they noticed anything unusual and what) can give insight into their attributions of mental state to the robot. In terms of children's perception of Ranger, we used some of the questions presented in Table 6.4 to assess how far they anthropomorphize the robot. As an indication for anthropomorphism we take questions in the constructs *ascribe intention, ascribe cognitive abilities, ascribe emotional state*, and *ascribe moral standing*.

Engagement reflected in the interaction As previously mentioned, from the 10 types of actions that were coded in the videos, we cannot consider all of them as reflecting engagement with Ranger. Since we asked children from our side to *call* the robot, as well as to *put* and *remove* domino tiles, these three actions were excluded. Finally, we consider the following 7 actions as **engagement actions**: *explore, misuse, gesture, touch, show, talk*.[5]

Anthropomorphism index To account for the fact that anthropomorphism arises in an interaction, we try to bring both children's perception of the robot (post-measurement) and their behavior toward it (in-the-moment measurement) together. By doing so, we would like to obtain a qualitative **anthropomorphism index**. We quantify the index by giving 1 point for each anthropomorphic perception of the robot (max. 13 points) and for specific kinds of human-like behavior toward the robot (max. 3 points). The index included the following aspects:

[5] In several figures of the "engagement actions" later on, *explore* is excluded from the visualization because it was too prominent and differences in the other actions would not be observable. The huge proportion of *explore* suggests that this category needs to be refined in future studies.

Perception: ***(max. 13 points)***

- Ascribe **mental states / feelings** to Ranger: *0-4 points*
  (2 points for agreeing that Ranger can be happy or sad; 2 points for attributing Ranger with hunger or tiredness)

- Ascribe **cognitive abilities / intention** to Ranger: *0-4 points*
  (each 0.5 points for ascribing seeing and hearing ability; 1 point for agreeing that Ranger can go out the door by itself; 1 point for disagreeing that Ranger always obeys; 1 point for agreeing that Ranger can do something silly)

- Ascribe **sociality / companionship** to Ranger: *1 point*
  (1 point for agreeing that Ranger can be a friend)

- Ascribe **moral standing** to Ranger: *1 point*
  (1 point for disagreeing that Ranger be left alone at home)

- Other **anthropomorphic statements**: *0-3 points*
  (1 point for anthropomorphic reason for Ranger's misbehavior; 2 points for anthropomorphic reason for not leaving Ranger alone)

Behavior: ***(max. 3 points)***

- Use of **direct speech** toward Ranger: *1 point*
  (*calling* the robot to come over is not considered)

- Use of **polite formulations** toward Ranger: *1 point*
  (*e.g.* saying *"thank you Ranger"* or *"please Ranger ..."* or *"goodbye"*)

- Use of **social or pointing gestures** toward Ranger: *1 point*
  (*e.g.* waving at the robot, nodding)

There are certainly limitations to this scoring scheme. For instance, the balance between perception and behavior aspects is questionable (13 to 3 points). Also, we did not consistently assign 1 point to each item, but assigned points between 0.5 and 2 points. We did this because we found that different items reflect a higher level of anthropomorphic perception of the robot than others (for instance, ascribing the ability to see an hear was suggested by our study setup, and we cannot be sure that it really reflects anthropomorphism). There are possibilities of refinement of this scoring scheme. For instance, a more systematic weighting procedure and the identification of all relevant factors would be an interesting future achievement. We could introduce a formula to calculate the anthropomorphism index α by taking the sum of the various items $(x_1, x_2, x_3 ...)$ and different weights $(a, b, c...)$ to balance them: $\alpha = ax_1 + bx_2 + cx_3...$. Machine learning techniques could be used to optimize such a calculation of the anthropomorphism index.

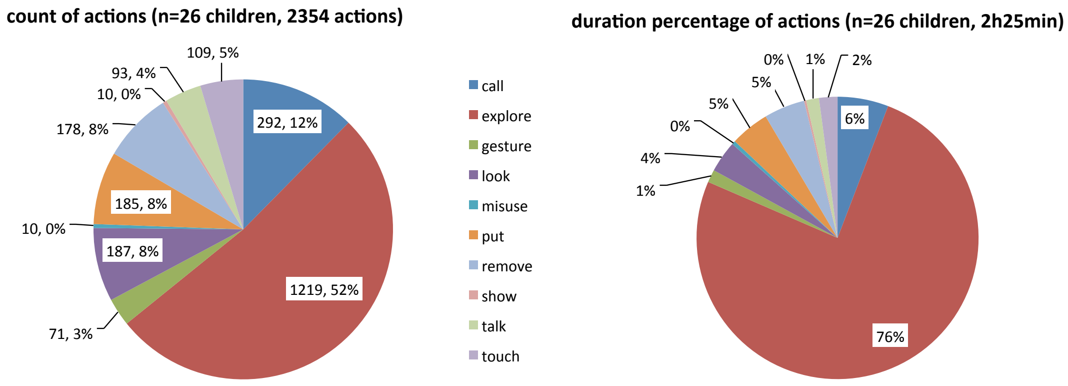
6.3 Findings

There are two main types of findings: 1) related to the interaction of the children with the robot and 2) related to the perception of the robot. This section is organized accordingly. We then bring both types of data together by building the *anthropomorphism index*.

6.3.1 Children's Interaction with the Robot

Scenario and run duration In total, there was more than 5 hours of video material obtained from the 13 groups. The video material consisted of around 3.5 hours of the two interaction phases and 1.5 hours of interviews. The interaction analysis considers only the video parts that correspond to the *scenario duration*, which starts when the receiver child in the tent asks the searcher child for the first domino tile, and it stops when the receiver child puts together the last domino to the chain. The scenario duration is split in two interaction phases, as described in Section 6.2.3, with a pause in the middle, that corresponds to the first interview. On average, the first interaction phase with 5 runs of the always correctly behaving robot lasted 5 min 34 sec. The second interaction phase with 9 runs and the partly misbehaving robot lasted on average 10 min 14 sec. Overall, the scenario duration (all 14 runs) varied between 13 min 04 sec and 19 min 01 sec (average 15 min 47 sec, SD = 1 min 50 sec). The condition had no significant impact on the scenario duration ($F(2,23)=.18$, $p=.835$).
When looking at the average duration of each run, it is not a surprise that the runs in which the robot misbehaved (2.3-2.4 and 2.7-2.8) lasted longer ($M = 71$ sec, $SD = 16$ sec) than the runs in which the robot behaved correctly ($M = 54$ sec, $SD = 16$ sec). Overall, for the runs with the correctly behaving robot, there is a tendency that the average duration of the run decreases over time ($M_{run1.1} = 73$ sec, $M_{run2.9} = 42$ sec). This suggests that children familiarize themselves with the playful task and the robot and react more promptly to it.

Interaction After having coded children's actions in the video, we obtained 2354 distinct actions which summed up to a total annotation duration of 145 minutes. On average, one child accounted for 92 actions (SD=23). The average number of actions carried out per child was less in the *disobey* condition (average 75 actions) than in the *lost* (average 98 actions) and *mistake* (average 102 actions) condition. The overall distribution of the count of actions and the duration of the total annotation time per action is shown in Figure 6.5. We see that even more than in the previous study, **children explored the robot** (52 % of the actions, making up 76 % of the total annotation duration). Exploring includes carefully watching the robot or actively trying to find out how it works. For instance, one boy (4 years, group `lost1`) clapped his hands and waved in front of Ranger's eyes; then he told the experimenter *"No, it cannot hear and it doesn't see me!"*. Overall, the interactions with the robot were less varied than in the previous study. We assume this was because the scenario was not as open but fairly well structured and probably even more constrained (compared to the previous study which was carried out in children's own rooms). Besides *explore*, children engage mostly in the actions required by the scenario (Figure 6.5): *call*



(a) total number (count, %) (b) annotation duration, (%)

Figure 6.5: **Children's actions with Ranger.** (a) shows the total number of the counted actions that were annotated in the videos, (b) shows the total annotation duration percentage of these actions (the total duration of all coded actions are considered as 100%, not the duration of the scenario).

(12 %), *put* (8 %) and *remove* (8 %). Another 8 % of the actions were *look* at the experimenter, which suggests that children were seeking for help or reinforcement sometime. The remaining 12 % of actions are attributed to *touch* (5 %), *talk* (4 %) and *gesture* (3 %).

When visualizing the average count of **actions for each run** (see Figure 6.6), we can see that over time, the total number of actions does *not* decrease. While interacting with the expected behaving robot, there is a peak in run 2.1 which may be due to the fact that children switched roles before that run. During the interaction with the unexpected behaving robot, there are peaks in runs 2.3, the first run in which the robot misbehaved, and a small peak in run 2.9, the very

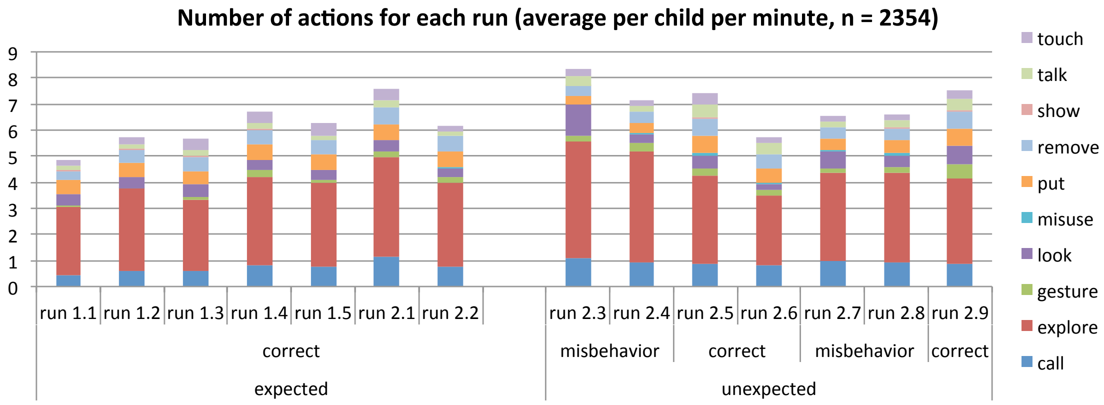


Figure 6.6: **Number and type of actions for each run** (average for one child per minute). Generally, the number of actions does not decrease over time (from run 1.1 to run 2.9). The first 7 runs correspond to the *expected phase*, the second 7 runs correspond to the *unexpected phase*. Especially during run 2.3, the first time when the robot showed an unexpected behavior, children tended to *look* more at the experimenter. During the unexpected phase, also *talk* and *gesture* seem to be increased. The specific values comparing the expected and unexpected phases overall are presented in Table 6.5, page 181.

last run. This last peak may be due to the fact that we told children this was the last run, and as most children did not want to stop playing with the robot. Hence, they tended to show some extra engagement, by increasing their use of *gestures* and *talking* to the robot, for instance.

The key question is: how was the interaction impacted by the three **different robot misbehaviors**? Figure 6.7 shows how the number of actions evolved from run to run by condition. Overall, children tended to interact slightly less with the *disobeying* robot (the actions are normalized, *i.e.* they show an average per child per minute). This difference can be observed during all the runs (and has also been found concerning children's engagement with the robot, see next paragraphs). We are not sure how to interpret this. We have to assume that interaction differences between the groups and further individual differences between the children are the reason. We come back to individual differences in the interaction later.

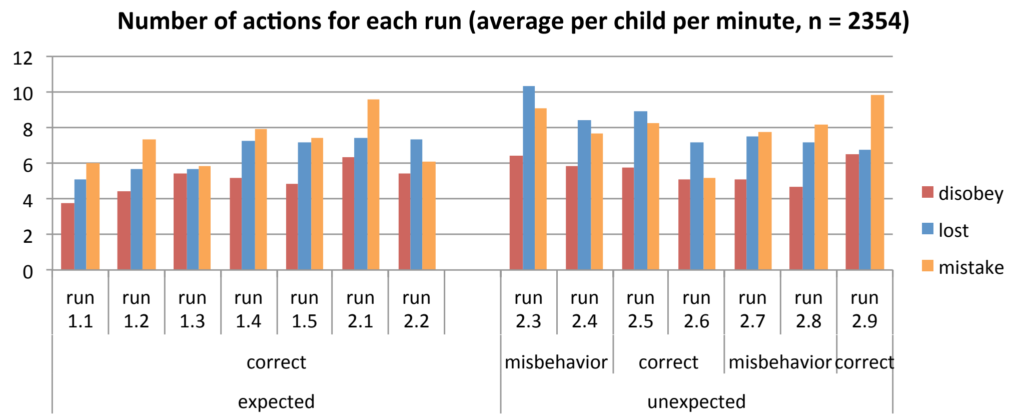


Figure 6.7: **Total number of actions for each run per condition** (average for one child per minute). Generally, the number of actions does not decrease over time (from run 1.1 to run 2.9). Especially during run 2.3, the first time when the robot showed an unexpected behavior, children interact more with the robot, as well as during run 2.7 when the robot misbehaved again after two correct runs. Another increase of actions is during the very last run.

When comparing children's interaction with the robot between the *expected* phase and the *unexpected* phase, the differences between the conditions and the effect of the robot's misbehavior in general, become clearer. Table 6.5 gives an overview. It compares the number of actions in the expected and unexpected phase for the different robot behaviors (average per child). The only two actions that were significantly impacted by the different robot manipulations were *explore* and *look*. As these two actions are considered to reflect engagement, we will come back to these differences in the next paragraphs on engagement with the robot. Overall, the values indicate that children interacted on average more with the robot in the *lost* and *mistake* condition. Also, in most cases, the values are higher in the unexpected phase than in the expected phase. Consequently, children interacted more during the phase with the misbehaving robot than during the phase when the robot always behaved correctly. (Statistical tests to compare the effect of the three different robot behaviors are provided in the following paragraphs, concerning the *"engagement actions"*, which are subset of all the interactions.)

Table 6.5: **Comparison of actions with the three robot misbehaviors in the expected and unexpected phase**. This table is based on n = 2354 counted actions, and shows the average scores per child for the different actions by robot behavior condition. The first line in each double-row shows the values for the expected (exp) phase, in the second line are the values for the unexpected (unexp) phase. For instance, a value of 5.13 for *call* in the expected phase, means that a child called the robot on average 5 times during the expected phase. Italic numbers indicate higher value when comparing the values of the expected and unexpected phase within the condition. Bold numbers indicate highest values when comparing the three different conditions.

	call exp unexp	**explore** exp unexp	**gesture** exp unexp	**look** exp unexp	**misuse** exp unexp	**put** exp unexp	**remove** exp unexp	**show** exp unexp	**talk** exp unexp	**touch** exp unexp
mistake	**5.13**	**26.25**	0.63	3.63	0.00	***3.88***	3.00	0.00	0.50	***3.00***
(n=813)	*6.50*	***31.75***	***2.50***	*4.38*	*0.25*	**3.50**	***3.63***	***0.38***	*2.25*	**2.63**
lost	3.63	25.00	0.63	**3.88**	0.00	3.50	**3.50**	***0.50***	0.38	0.75
(n=787)	***6.88***	*31.38*	*1.75*	***6.88***	0.00	**3.50**	3.50	0.00	*1.75*	*1.00*
disobey	5.00	12.00	**1.30**	1.20	**0.10**	*3.70*	***3.50***	0.10	**2.50**	*2.90*
(n=754)	*6.70*	*19.50*	*1.40*	*2.70*	***0.80***	3.40	3.40	*0.20*	***3.00***	2.00

Engagement with the robot In terms of **engagement**, the novelty of the robot certainly plays a role here. As mentioned before, the findings here do not directly address the issues of long-term usage but concern short-term *engagement*, which is a pre-requisite for long-term usage.

The huge proportion of *explore* actions (52 % of all coded actions) already suggests that children were generally engaged in the interaction, and most of the time carefully observed what the robot did. When considering the actions *explore, gesture, look, misuse, show, talk*, and *touch* as **engagement actions**, 1699 of the 2354 actions reflected engagement (72 %). This indicates that overall children were very engaged in the interaction with the robot. Furthermore, data suggests that the robot in the *mistake* and *lost* condition were more engaging for children (each 75 % of the actions reflected engagement) than the robot in the *disobey* condition (66 % reflected engagement). The statistical analysis supports this: An ANOVA indicates that there was a significant effect of robot behavior on the actions *explore* ($F(2,23)=11.31$, $p<.001$) and *look* ($F(2,23)=4.6$, $p=.021$). Post-hoc comparisons using the Tukey's test indicate that the mean score for *explore* in the *disobey* condition is significantly different from the score in the *mistake* and *lost* condition. This suggests that children explored the disobeying robot less[6] (for the average values, see Table 6.5). For *look*, the only significant difference is found between the mean scores of *lost* and *disobey*. Data suggests that when the robot is lost, children look more often at the experimenter than when the robot disobeys. The other actions were not found to differ significantly between the robot behavior conditions.

[6]It is surprising that the disobeying robot was explored less. One may assume that the disobeying robot might better attract children's attention because it faces the searcher child and uses fairly strong audio and light cues as compared to the other behaviors.

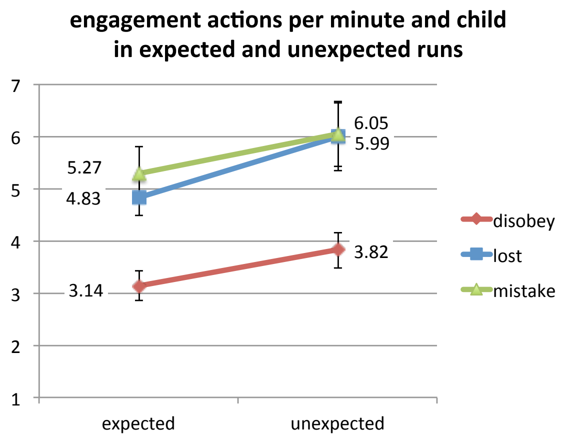


Figure 6.8: **Average number of engagement actions in expected and unexpected phase.** In all three behavior conditions, children engage more in the unexpected phase. In general, the *lost* and *mistake* misbehavior are more engaging than the *disobeying* behavior.

Overall, was there an effect on engagement when the robot misbehaved? We compare children's engagement during the interaction phase with the expected robot behavior and during the interaction phase with the unexpectedly behaving robot. A statistical analysis revealed a significant difference between the average of engagement actions carried out during the first 7 runs (correct robot behavior) and during the second 7 runs, when the robot behaved unexpectedly ($F(1,36)=5.1$, $p=.03$). Figure 6.8 shows the values for engagement actions in the three conditions, comparing the expected and unexpected phase. In all three conditions, children carried out more engagement actions with the unexpectedly behaving robot. No interaction effect was found between the two phases of interaction (expected / unexpected) and condition ($F(2,36)=1.2$, $p=.31$). In general, this finding supports our first hypothesis: children show more engagement toward a robot that behaves unexpectedly from time to time compared to a robot that always behaves correctly. It is, however, unclear why children engaged less with the disobeying robot (as mentioned before), especially also in the *expected* phase (see Figure 6.8). In this phase, the robot did not disobey but always behaved correctly as in the other two conditions. There were no robot behavior differences between the conditions. We have to assume that the effect is due to individual and group variations of children's behavior. These individual variations would probably be less observable in the data if the sample size would have been bigger.

Looking into detail, how did engagement change from run to run? Figure 6.9 shows the average engagement actions (without explore) for each run. How can we explain these variations? During the *first interaction phase* with the *expected behavior*, we observe small variations. Then, with the first *unexpected robot behavior* in run 2.3, there is a huge peak in the engagement actions, which can again be observed in run 2.5, slightly in run 2.7, and then again in the last run 2.9. These runs correspond exactly to when the robot changed its behavior form correct to incorrect and *vice versa*. It appears that children are quite sensitive to these variations and spontaneously respond to it. But as mentioned before, we have to note that the huge peak of engagement actions in the last run may be due to the fact that children knew this was going to be the last round.

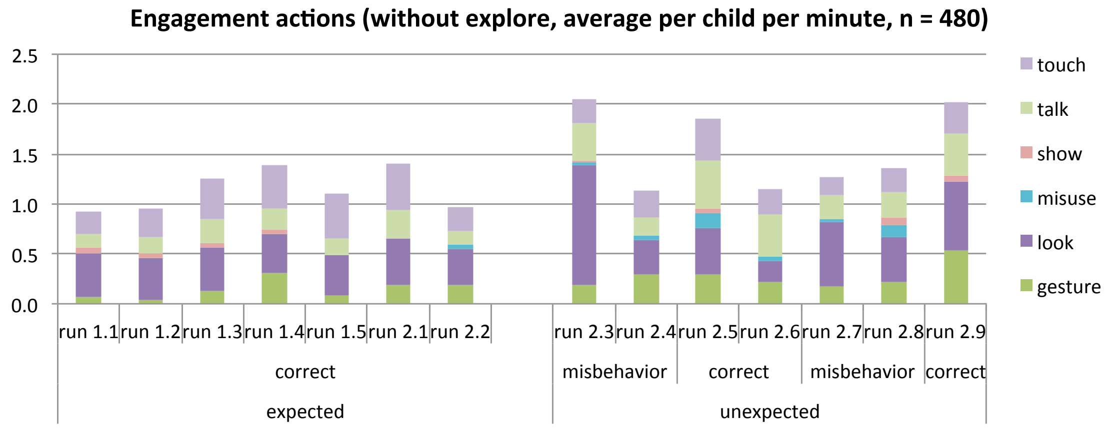
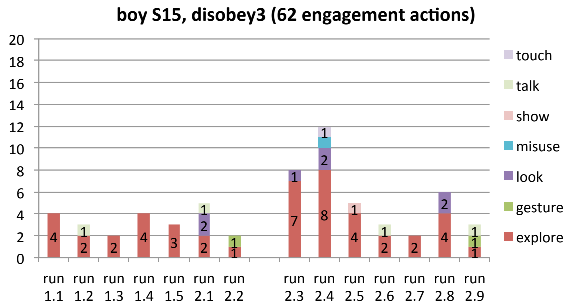


Figure 6.9: **Engagement actions for each run** (without explore). Average for one child per minute.

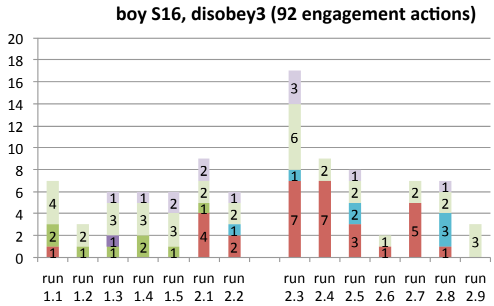
The picture is unclear, when looking at how engagement evolved from run to run in the three different conditions (see Appendix Figure A.1, page 239). Both within the respective conditions and when comparing them, there are variations that are difficult to make sense of and we cannot give a clear interpretation how these variances may be related to the respective robot misbehavior. We have to assume that the fairly small sample size of 8-10 children per condition and the huge differences in children's individual interaction style is the reason for these strange variations.

Overall, our data suggest that the robot that gets lost and does a mistake engage in a similar way but that the disobeying robot elicits less engagement. This was verified by computing an average value for the *engagement actions*. This average expresses how many engagement actions one child did per minute. The general engagement action values of the *mistake* (5.66) and *lost* (5.41) condition are higher than the value of the *disobey* (3.48) condition. This shows again, that the disobeying robot was less engaging for the children. A possible interpretation of this result is, that the disobeying robot frustrated children or was perceived more negatively than the other two manipulations.

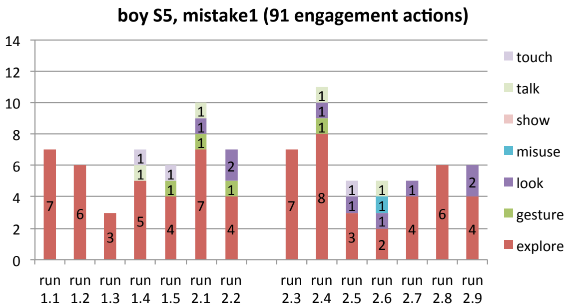
Individual differences In fact, we visualized engagement actions for each child (see examples in Figure 6.10), and found very different interaction styles between them, both on a pair and on an individual level. In a few groups, children were "aligned" (homogeneous) in their behavior. For instance, if one child started to talk to the robot, the other child would do the same. Mimicking or mirroring the behavior of others is common among young children. We consider a group as aligned when they engaged with the robot in a similar way. This was the case in some of the groups. In some other groups, there were differences between the two children, for instance one child hardly showed engagement actions while the other one was more engaged. Or there was one child who dominated the interaction while the other may have had a more introvert personality. With a small sample size, individual differences have a quite strong impact in the data-set and it makes statements about the influence of the robot behavior as a variable difficult. For instance, we found more *misuse* behavior in the *disobeying* condition (Figure A.1c, page 239) than in the



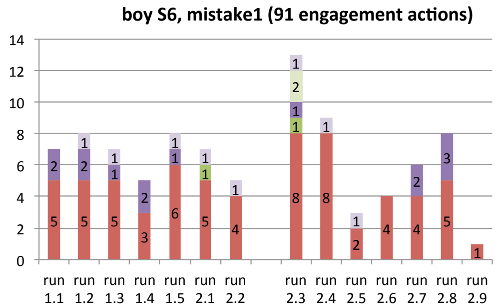
(a) disobey3, boy S15



(b) disobey3, boy S16



(c) mistake1, boy S5



(d) mistake1, boy S6

Figure 6.10: **Individual differences in interacting with the robot**. The top row with figures a) and b) shows the group `disobey3` that consisted of two boys. We consider this group as not aligned in their interaction with the robot. While the boy S16 in figure b) talks a lot the robot and also touches it frequently and uses gestures during the first runs, the other boy S15 in figure a) does not do so at all. The bottom row with figures c) and d) shows the group `mistake1` that also consisted of two boys. We consider this group as fairly aligned in their interaction with the robot. Both children tend to touch the robot and look at the experimenter.

other conditions. One may assume that this is due to the robot's strong disobeying behavior. However, there were two boys who had a rough interaction style and reacted almost aggressively toward the disobeying robot. No other children showed this strong reaction.

We did not find a statistically significant effect of gender on any of the actions. There are however some **qualitative gender differences** that are noteworthy. Boys generally seemed to interact more with the robot: they *explored* it more (M=52.0, SD=16.0) than girls did (M=38.7, SD=17.8); boys *talked* more (M=5.19, SD=9.0) to the robot than girls (M=1.0, SD=2.2); they *called* the robot more often (M=12.75, SD=5.9) than girls (M=8.8, SD=5.9), used more *gestures* toward the robot (M=3.6, SD=4.5) than girls (M=1.4, SD=2.0) and boys were they only ones who showed some few *misuse* actions. Contrary, girls more often touched the robot (M=5.2, SD=6.0) than boys did (M=3.6, SD=3.5), and slightly more often looked to the experimenter (M=7.8, SD=7.4) than boys (M=6.8, SD=4.1). Interestingly, we had found similar but also non-significant gender differences in the Ranger Study (Chapter 5): boys had used more gestures toward the robot, while girls had more often touched the robot. Despite the fact that in both cases the differences are not significant, we can interpret that boys and girls interact differently with Ranger.

Summary It is not easy to draw a clear conclusion about children's interaction with the robot, especially not when comparing the three different conditions. There were huge variations in the data, due to children's different interaction styles and their individuality. Overall, the analysis showed that children were generally engaged in the interaction with Ranger. Most of the time, they explored the robot, by watching it carefully or trying to find out how it works, for instance. During the course of the experiment, the amount of actions did not decrease (over the whole experiment) but was sustained by the manipulation of robot behavior. Children were significantly more engaged in the interaction phase with the unexpected robot behavior, compared to the phase in which the robot behaved correctly. The increase of looking at the experimenter in run 2.3 shows that children were surprised when they saw the robot doing something unexpected. Concerning the different robot misbehaviors, the *mistake* and *lost* robot behavior appear to be more effective to trigger (and possibly sustain) interaction than the *disobey* behavior. Children's high engagement (increased use of gestures and direct speech to the robot) in the last run of the experiment may reflect their wish to continue playing with the robot.

6.3.2 Children's Perception and Evaluation of the Robot

In this section, we analyze how children perceived the robot. This may help understand why they tended to be less engaged with the disobeying robot. This section is organized along the different constructs that were assessed in the interviews with the children. An overview of the questions used during the interviews is given in Table 6.4, page 173.

Overall, we gathered more than 1.5 hours of video- and audio-recorded interview material. The duration of both the first and second interview together varied between 5-11 min, with an average duration of 7 min 49 sec. The second interview (M=280 sec, SD=70 sec) usually lasted slightly longer than the first one (M=189 sec, SD=39 sec).

Expectations and robot-likeness In the pre-interview, some of the children said that they had seen a robot before. This may be due to the fact that several participants (their parents) were recruited around the campus of our Institute of Technology. Some children mentioned they had seen a robot at EPFL's *"robotic festival"*, a public event at which robots are demonstrated and robotic workshops are organized. We asked children how they imagine a robot and how a robot could look like (Figure 6.11a). 10 children did not respond to this question which can be explained by the fact that this was the very first question we asked them and the whole situation was still new to them. However, from the 16 children who provided an answer, 10 mentioned that for them, a robot has some human-like properties: it either looks like a human (has a body, arms, hands, legs, feet, or a head) or it can walk, grasp, search for things, or even set the table. 5 of the children had no clear concept of what a robot is.

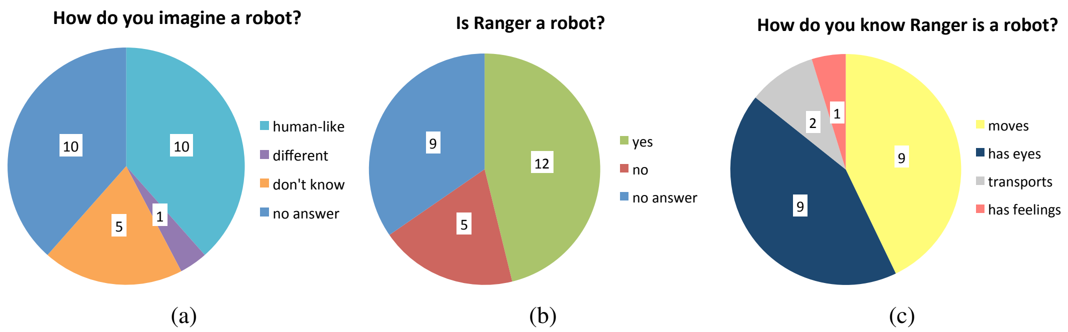


Figure 6.11: **Expectations of robots in general and robot-likeness of Ranger.** When children had to justify why they thought Ranger is a robot (c), multiple answers were possible, we received 21 answers from 12 children.

First impression of Ranger Asked whether Ranger was a robot (see Figure 6.11b), children were not sure how to reply, and some hesitated or did not provide an answer at all. In general, it was not easy for children to decide whether Ranger was a robot or not because only a few of them had a clear concept of a robot in mind. 9 children did not give an answer at all. Some children mentioned they had had different expectations (those who had a human-like image of a robot). From those who replied, 5 children did not find that Ranger is a robot because it has no arms or legs and because its eyes are not real. However the majority of the respondents (12 of 17) was convinced of the opposite, namely that Ranger is a robot. According to them (see Figure 6.11c) Ranger is a robot because it is able to move by itself, it has eyes, it is able to transport things, and because it has feelings (expressed by the light and sound cues).

Manipulation check Before going into details about differences in the perception of the robot due to the different misbehaviors, we need to check whether children noticed the manipulations of the robot behavior, and how they interpreted them. Did they perceive and classify the different misbehaviors, *mistake, lost* and *disobey*, as we intended? As stated in the beginning of the chapter, we had hypothesized that the *disobey* behavior is perceived as the robot intentionally not doing what it should do. The *mistake* behavior was intended to show that the robot can do a mistake but is aware of it and able to repair its mistake, which should also lead to some perception of intentionality. Contrary, we expected that the *lost* condition is perceived as a malfunction or bug of the robot. In the second interview, after the robot had misbehaved, we asked children whether the robot always did what they wanted it to do. Most children disagreed and said they noticed something strange. However, there were some children who gave a positive answer, suggesting that they found the robot always did what they wanted it to do. This was a surprise. Had they not noticed the robot's misbehavior? Why not? On one hand, we found that children sometimes gave contradictory replies when asked the same question twice. This is difficult to interpret. On the other hand, children may have a general tendency to please adults (Leite, 2013), and it could be the case that some were too shy to tell us that the robot did something strange.

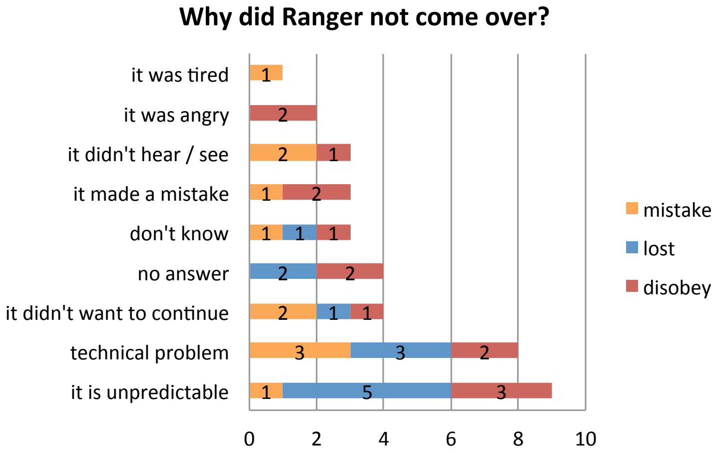
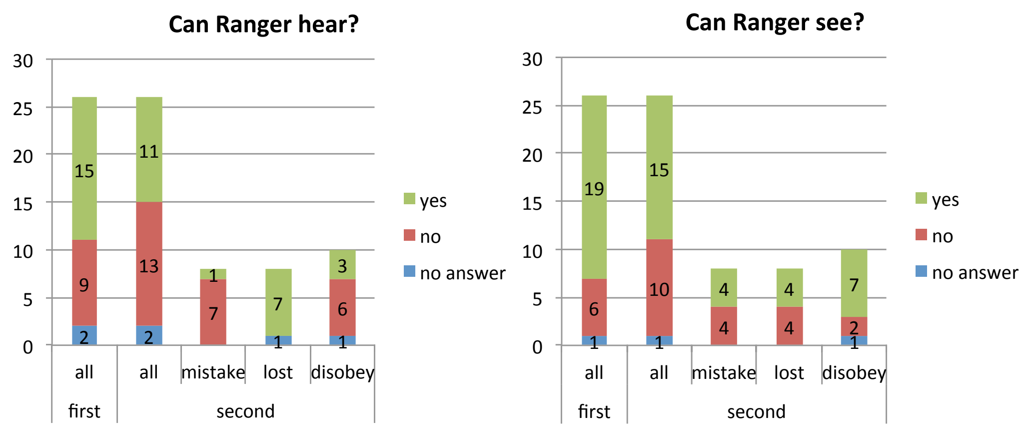


Figure 6.12: Multiple answers were possible to the question why the robot did not come over, and we received 37 answers. This question shows that children did not necessarily interpret the misbehavior in the way we had assumed.

We nevertheless asked children why they thought the robot had not always come over to them. 4 of the children did not reply. The remaining ones gave a variety of reasons (Figure 6.12). The most common answer (9 of 37 replies) was that the robot is somehow *unpredictable* in what it is doing and that it could go *no matter where*[7] because *"with robots you have these kind of problems, they do no matter what"* (boy (5), `lost4`). 8 replies concerned *technical problems* (including *broken parts*), suggesting that children perceived the misbehavior as unintended by the robot. 2 of the children who had interacted with the disobeying robot said Ranger was *angry*, which none of the children in other conditions replied (these were not the two boys who reacted aggressively). Several children ascribed intentionality to Ranger explaining that it *did not want to continue* carrying domino tiles or that it *made a mistake / did something silly*[8]. Overall, we can notice that not all children perceived the misbehavior of the robot as we had intended and we have to keep this in mind while interpreting the data. Also Leite (2013) found in her study that when children did not understand an action of the robot, they tended to view it as a mistake, rather than interpreting the robot's behavior as a deliberative action. In our case, it is not easy to make a clear statement about how each of the manipulations was perceived by the children. Similar to how people reacted to the cheating robot in the study of Short et al. (2010), most children showed surprise, were amused, sometimes confused, or occasionally slightly angry (*e.g.* two boys tended to shout to the robot after it had disobeyed). The *disobeying* robot seemed to evoke the strongest reactions, partly with a negative implication: later three of the children in this condition stated they would not accept Ranger as a friend *because it did not always come over when they asked it to come over*. Short et al. (2010) described a similar implication of the robot cheating behavior: participants made unfavorable character attributions to the cheating robot, so the robot's actions affected perceptions of the robot as "fair" and "honest".

[7]We translated children's answers from French to English. For some expressions the meaning and connotation of an expression may not be the same. We understand *"partir dans tous les senses"* as "to go off in all possible directions"



(a) (b)

Figure 6.13: **Attribution of cognitive skills to Ranger.** These two questions were asked both in the first interview, after children had interacted with the correctly behaving robot, and in the second interview, after children had interacted with the unexpectedly behaving robot (three conditions). A comparison of the answers (first-second) can reveal to what extent the respective misbehavior of the robot impacted children's attribution of cognitive abilities. (Note that there were 10 participants in the disobey condition and each 8 participants in the mistake and lost condition. Consequently, here and in the following visualizations, we need to be careful as the bars are based on counting answers.) The three bars on the right side of each diagram are a split-up of the *"all"* bar of the second time children were asked.

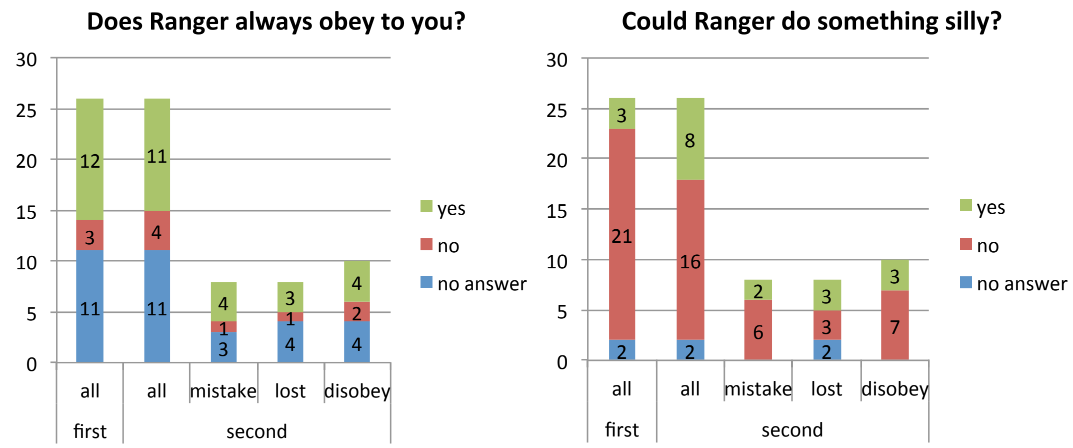
Attributions of cognitive abilities (perceptual skills) To assess how far children ascribed low-level cognitive abilities to the robot, we asked them whether they believed Ranger is able to hear and see (Figure 6.13). Also these questions were asked both in the first and the second interview. First, the majority of children replied positively, saying that Ranger can hear (15) and can see (19). We asked them to justify their answer in both cases (*"How do you know?"*). Those ascribing cognitive abilities answered, for instance: *"It can see because it is looking right at me."* (girl (4), `disobey4`) or *"The only thing it can hear is when you say 'come here'."* (boy (5), `mistake2`). Those who answered negatively added, for instance: *"It cannot see because the eyes are not real."* (girl (4.5), `disobey1`); *"It cannot hear because it doesn't have ears."* (boy (4), `mistake4`); and surprisingly two 4-year old children mentioned that Ranger is not able to hear because it does not have a *mouth*. It seems that for some younger children the concepts of speaking and hearing are both related to a mouth. From those two questions, we can summarize that after children had interacted with the **correctly behaving robot** the majority does **ascribe cognitive abilities** to the robot.

After they had interacted with the misbehaving robot, some children responded differently. Now 11 children (first 15) answered Ranger can hear, and 15 children (first 19) responded it can see. 2 children in the *mistake* condition consistently changed their opinion for both hearing and seeing abilities. The other changes were not consistent for both senses and partly even contradicting. There was no clear tendency, and also we cannot say whether the different conditions had a

and hence interpret this reflects viewing the robot as being unpredictable.

[8] We understood *"faire une bêtise"* as "to do a silly thing" in the sense of making a mistake.

different impact. We can note that also to the **unexpectedly behaving robot** children tend to **ascribe cognitive abilities** but slightly less than before. It seems that initially the attribution of cognitive abilities is due to the robot's physical design (*e.g.* eyes) and that the manipulation of the robot's behavior does not substantially change this perception (only for few children).



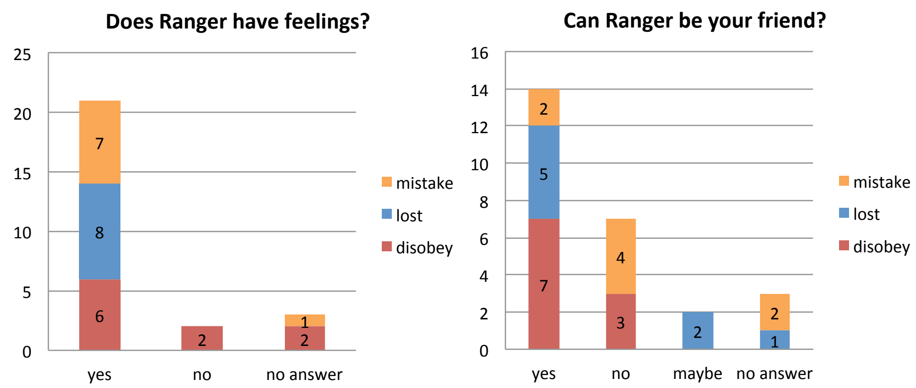
(a) (b)

Figure 6.14: **Attribution of intention to Ranger.** Similar as before, children were asked these questions twice. Concerning question (a), there are no remarkable differences in children's responses given in the *first* and *second* interview. Children tend to think Ranger does always obey to them, even after it misbehaved (*second* part). There is however a small difference in the responses visualized in graph (b). After the robot misbehaved, 8 children think the robot could do something silly whereas first, only 3 children answered like this.

Attributions of intention One of the central points of this study was to investigate to what degree children attribute intention and cognitive abilities to the robot. In the first interview after children had interacted with the correctly behaving robot we asked three questions to assess how far they ascribe **intention** to it (see questionnaire items in Table 6.4, page 173). One of these questions was whether they believed Ranger could go out the door by itself. They majority of 16 children answered negatively, which suggests that they initially do not ascribe intention to the robot. The two other questions were whether Ranger would always obey and whether Ranger could do a silly thing (Figure 6.14). These two questions were asked again later after children had interacted with the unexpectedly behaving robot. Overall, in the first interview 12 of the 26 children believed Ranger does always obey to them. Asked whether Ranger could do something silly, the great majority of 21 children replied negatively. We can summarize that after children had interacted with the **correctly behaving robot** the majority does **not ascribe intention** to the robot. After they had interacted with the misbehaving robot, we asked children again. Now, still 11 children (previously 12) believed Ranger would always obey to them. When analyzing the answers of each child separately, there were 2 children in the *disobey* condition that changed their answer from *yes* to *no*; however also 1 child in the *lost* condition that switched their answer in the opposite way (strangely). There was a more remarkable change when asking children whether

Ranger could do something silly. In the second interview, 8 children (previously 3) answered Ranger could do something silly. 1 child in the *disobey* condition had changed their answer, and each 2 in the *mistake* and *lost* condition. Overall, it it interesting to note that children tend to ascribe cognitive abilities to the robot, like the ability to see and hear but not intention. We interpret that children may perceive the robot as being able to process sensory information but that it is not able to make decisions on its own. We can summarize that even with the **unexpectedly behaving robot** children do **not necessarily ascribe intention** to the robot. The unexpected robot behavior impacted only some children's attributions of intention to the robot. It seemed that some children did not interpret the robot's misbehavior as intentional but more like a technical problem or mistake. For instance, even after the robot misbehaved by *disobeying*, the majority of the children in this condition was still convinced that the robot could not do a silly thing (Figure 6.14b).

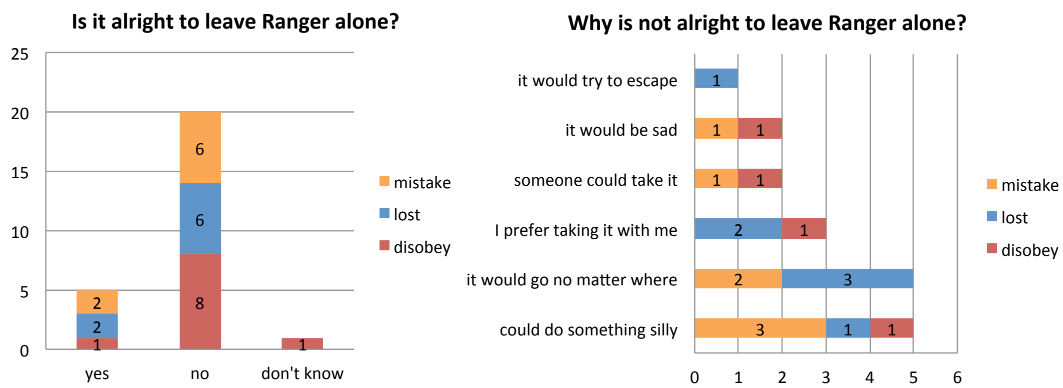
Attributions of emotional state and perceived companionship We examined whether children attributed **feelings** to the robot by asking them (once at the end of the experiment) if they thought that Ranger can feel happy or sad sometimes (Figure 6.15a). The great majority of children (21 of 26) gave a positive answer. Only 2 children who had interacted with the *disobeying* robot did not believe that Ranger has feelings and another 3 children (2 *disobey* and 1 *lost*) did not reply at all. Overall, data suggests that **children attributed emotional states** to the robot. Asked for more details, several children answered that it is through its colors and sounds that the robot shows a feeling. Most children said that they could make the robot feel happy by playing with it and putting a domino tile inside the box. This may also be a reflection of their own feelings, projected on the robot. More than half of the children (14 of 26) agreed Ranger can be their friend. We did not ask about what being a friend means to them but as children generally liked playing with the robot, this may be linked to each other. We can note that children **ascribe feelings to the robot and partly accept that it can be a "friend"**.



(a) (b)

Figure 6.15: **Attributions of emotional state and perceived companionship**.

Attributions of moral standing Inspired from the questionnaire used by Kahn et al. (2006), we asked children if it would be alright to leave Ranger alone at home (*e.g.* during two weeks when they go on a vacation) (Figure 6.16a). The great majority of 20 children responded negatively. Asked why, children gave a variety of answers that we classified into 7 categories (Figure 6.16b). With 5 replies, the most common answer was that the robot "could do something silly". Some other children simply answered they would like to take it with them. Others were afraid that the Ranger "would not find its way" or "may be taken away by someone". 2 children believed Ranger is sad when left alone and 1 child responded the robot would try to escape. This shows that some children really ascribed emotions or an "own will" to the robot. We can summarize that children generally **ascribe moral standing to the robot**, meaning that it is an entity that deserves some kind of respect and care.

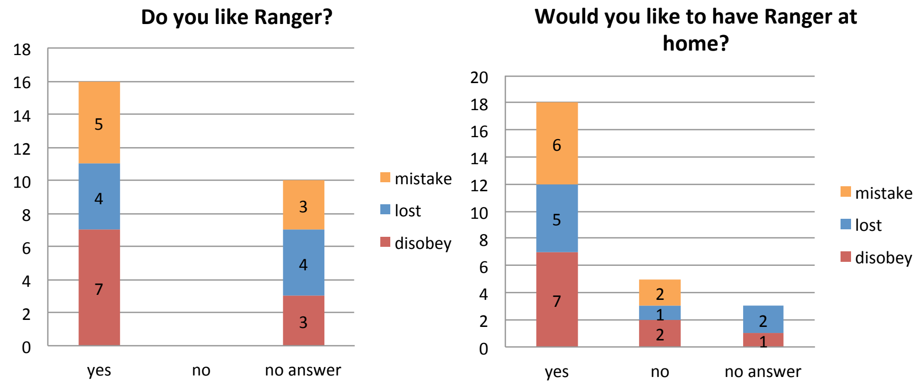


(a) (b)

Figure 6.16: **Attributions of moral standing**. We asked children whether it was alright to leave Ranger alone at home if they go on a 2-week vacation (a). Multiple answers (open-ended) were allowed when asked to justify their answer (b).

Acceptance of Ranger It does not come as a surprise that children showed great fascination for the robot and the domino game (we cannot clearly separate these two things). Only those children whose expectations of the robot were not met, seemed to be skeptical. Asked if they like Ranger, 16 children gave a positive reply and there was no negative response, however 10 children did not answer this question. Also, 18 of the children answered they would like to have Ranger at home. Still 5 children gave a negative reply and 3 did not provide an answer at all.

Summary In general, children tended to associate a robot with some human-like design and characteristics, and they were hence not sure whether Ranger counts as a robot. According to the children, Ranger's ability to move and its moving eyes however suggest it is a robot. Their perception of Ranger shows that they commonly ascribed some human-like characteristics to the robot, such as emotional states or cognitive abilities, and that they also tend to view it as a social entity (*e.g.* by ascribing moral standing, and accepting it as a friend). But children do not necessarily ascribe intention and own reasoning to the robot. This suggests that anthropomorphism is



(a) (b)

Figure 6.17: **Acceptance of Ranger**.

not something discrete being either *there* or *not there*; it may rather exist in several variations or levels. (We explore social engagement and anthropomorphism in more detail in the next section and come back to it in the Conclusions Chapter of this thesis.) Concerning the manipulation of the robot behavior, most (but not all) children recognized something strange and agreed that the robot did *"no matter what"*. The different types of misbehavior were not clearly interpreted as we had intended. The robot's behavior was mostly perceived as *"unpredictable"*. Qualitatively, it seemed that the *disobeying* robot had a stronger impact on children's perception of the robot than the other two behaviors *mistake* and *lost*. Generally, children like Ranger and most said that they would like to play with it at home.

6.3.3 Anthropomorphism Index and Social Engagement with Ranger

The anthropomorphism index expresses to what extent children engaged with Ranger in a human-like way, both in terms of their behavior toward the robot and their perception of the robot. We mostly present findings on a pair (group) level but also look at differences between children in one group.

As described in Section 6.2.5 (page 176), the anthropomorphism index considers on one hand whether children behaved toward the robot in a human-like way. The behavioral aspects refer to a qualitative analysis of the interaction, and not to the counts of actions annotated in the video material. These qualitative aspects included use of direct speech toward the robot, use of social pointing gestures (*e.g.* waving or nodding), and use of polite formulations. For instance, several children said *"thank you"* when Ranger brought a domino tile to them or used a polite formulation when calling Ranger: *"Robot, please come over!"*[9]. If a child was using such formulations, he or she was assigned 1 point, and at the end, the sum of these points formed the

[9] These forms of politeness that children use when talking to a robot have also been observed by Leite (2013).

anthropomorphism index. On the other hand, the anthropomorphism index considers to what degree children perceive the robot as human-like. These results have been mostly presented in the previous section (*e.g.* attribution of feelings to the robot).

To obtain the anthropomorphism index for a pair, we first calculated the index per child and then took the average of the two children in one group. The group indexes varied between 3.25 and 10.75 points with an average of 7.5 points (SD = 2.5), which is 47 % of the maximum possible index of 16 points. Similar to the individually different interaction styles of the children, there were also variations in terms of to what extent they anthropmorphized Ranger. In 7 of the 13 groups, the anthropomorphism indexes for both children were similar (difference less than 1.5 points), which means that both children anthropomorphized the robot to a similar degree. This agreement among children happened for both higher and lower indexes. In 6 of the 13 groups, the anthropomorphism indexes varied in more than 2 points, which means that one of the children anthropomorphized the robot more than the other one. This is an interesting finding.

On an overall average, Ranger was moderately anthropomorphized by the children.[10] 8 of the 13 groups had an index of 8 or higher. Table 6.6 shows that of those groups, 3 were in the *mistake* condition, 3 in the *lost* condition and 2 in the *disobey* condition. Also, the mean index of anthropomorphism in the three conditions varied, with the *mistake* and *lost* condition leading to a higher index than the *disobey* condition. This finding suggests that the disobeying robot was less anthropomorphized than the other two robot behaviors, which speaks against our second hypothesis. We had expected that the disobeying behavior is perceived as an intentional action which we assumed would lead to increased anthropomorphism. This was not the case. The slight difference between the *lost* and *mistake* robot was also expected in the opposite direction. It could be that the robot's "helplessness" led to this. With the lost robot, children looked more often at the experimenter than in the other condition (see Table 6.5, page 181), which suggests that they could not fully make sense of the robot's behavior. The fact of not being able to understand (and hence predict) a robot's behavior is likely to increase anthropomorphism.[11]

Table 6.6: **Anthropomorphism index.** The maximum possible index was 16. The *lost* robot elicits the highest index, which suggests that it is anthropomorphized more. Contrary to our hypothesis, data suggests that the *disobeying* robot is anthropomorphized less but the *lost* robot more.

	M	SD	count of groups with with index above 8
mistake	7.94	1.74	3 of 4
lost	**8.31**	0.59	3 of 4
disobey	6.5	3.68	2 of 5

[10] However, as our developed anthropomorphism score is relative, we cannot really make a claim about what a difference of + or - *1* point means.

[11] One of the cognitive / psychological explanations for anthropomorphism is that people want to make sense of something they do not understand and then tend to anthropomorphize this something (human traits are a good source of making attributions because this is what people understand best – themselves and other humans). For more details the reader may refer to Epley et al. (2007).

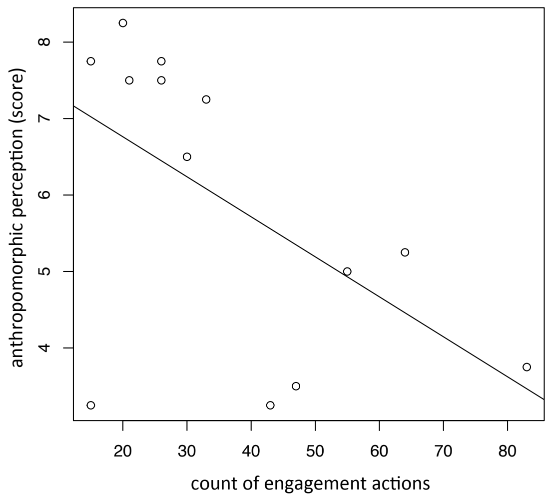


Figure 6.18: **Correlation of anthropomorphic perception of the robot and engagement actions.** A scatter plot of the count of engagement actions (without explore) and the *anthropomorphic perception* (score per group) shows a negative correlation. The score for the anthropomorphic perception (*y-axis*) does not take into account the behavioral aspect of the anthropomorphism index, as this is part of the interaction (*x-axis*). There seem to be two clusters of groups: those who interact more with the robot and anthropomorphize it less, and those who interact less but anthropomorphize the robot more.

But to what extent is the human-like interaction related to perceiving the robot as human-like? Do children who interact a lot and are probably more engaged with the robot also perceive the robot as more human-like? This was what we hypothesized. Data suggests the opposite, however. As shown in Figure 6.18, we found a significant *negative* correlation between the count of engagement actions (per group) and the qualitative anthropomorphism index (r(11)=-0.56, p=.05). The overall model with the count of engagement actions (per group) predicts a significant proportion of the qualitative anthropomorphism index (adjusted R^2=.25, F(1,11)=4.9, p=.05). This means that the more a group showed engagement in the interaction, the less they anthropomorphized the robot. This is a key results, which was against our initial assumption. How can we interpret this? It may be that children who interact more with the robot understand better how it works, they are more familiar with it, and as such the robot appears less “mystical” to them, so there is not a big need to anthropomorphize it. On the contrary, the cluster of groups that do not interact much but anthropomorphize the robot more, is quite homogeneous. The negative correlation between the number of engagement actions and the anthropomorphism index suggests that children who interact more with the robot tend to anthropomorphize it less. This implies that anthropomorphism could fade out after some time (or rather after some interaction). This evokes the question how far anthropomorphism (as a special kind of social engagement) really helps in sustaining interaction. This is a critical point because most of the short-term investigations suggest that anthropomorphic design and human social cues emitted by a robot foster engagement and acceptance. What if this is not true for continued interaction, and thus for the long-term? We have to be careful about our interpretation, due to the small sample size with which we obtained these findings. We suggest to investigate the aspect further in future research.

Our data on the anthropomorphism index also suggest **qualitative gender differences** in children's tendency to anthropomorphize Ranger. Boys (M=8.2, SD=3.0) obtained a higher mean index of anthropomorphism than girls (M=6.4, SD=2.4). (Interestingly, as it was mentioned before, boys interacted slightly more with the robot than girls; though not significantly. This is counter-intuitive concerning the negative correlation between amount of interaction with the robot and anthropomorphism tendency.) It would be interesting to investigate in more detail whether boys are more prone to anthropomophize a robot than girls.[12]

Summary The established *anthropomorphism index* suggests that children tend to conditionally anthropomorphize the robot. Higher indexes of anthropomorphism were found in the *lost* and *mistake* condition which was against our hypothesis. Interestingly, data suggests a significant negative correlation of engagement and anthropomorphism index. It appears that groups who interacted more with the robot perceived it as less-humanlike. This raises the question to what extent anthropomorphic perceptions of a robot can last over time, and with increasing interaction experience.

6.4 Discussion and Conclusions

We found that in a playful scenario where 4-5 year old children play domino together with a robot, the robot seems to be more engaging when it shows some misbehavior compared to when it always behaves as expected.[13] Different types of misbehavior appear to have a different effect on children's interaction and their perception of human-likeness in the robot. A *disobeying* robot may be perceived more negatively than a robot that makes a *mistake* or gets *lost*. This may lead to attributions of negative personality to the robot and children may be less motivated to continue interacting. Such effect would be against our idea to promote long-term engagement. A similar conclusion was drawn by Short et al. (2010), in their study of a cheating robot: Participants sympathized with a robot that *verbally* cheated but they behaved punitively towards a robot that cheated *in its actions*. Thus, the effect depends on the type of misbehavior that the robot shows. With some "lighter" misbehavior, children may show helping-behavior and increase their engagement, whereas using some "stronger" misbehavior, may lead children to see the robot as being unpredictable and they could lose trust in it.

In general, any difference in robot behavior may have a strong effect on children's perception of the robot, and can powerfully shape how they relate to it: *"The attribution of mental state to a robotic partner has dramatic consequences for the relationship between robot and human. A friend has mental state, a vacuum cleaner does not"* (Short et al., 2010, p. 225). From what we have seen in the Domino Study, we have a rough estimate of how children react and relate

[12] Findings presented in Schermerhorn et al. (2008) suggested similar gender differences. In their study, males tended to think of the robot as more human-like and accordingly showed more "social facilitation" than females, who perceived the robot as more machine-like.

[13] However, we cannot say if this effect holds also after novelty has worn off.

to a robot that behaves unexpectedly from time to time. They are mostly surprised, laugh at the robot, and they tend to be more engaged and playful. However, they are also confused and cannot really make sense of the robot's strange behavior. We also cannot clearly say whether children perceived the unexpected robot behavior entirely as a malfunction (something that happens to a machine) or as being intended and based on a motivation (something related to a social entity). Children stated both, when asked why the robot had misbehaved. Some referred to *"a technical problem"* while others said the robot *"is tired"* or it *"doesn't want to carry domino tiles any more but rather go on a tour outside"*. Maybe our manipulations were not as clearly designed as we expected. There is always some freedom in how things are interpreted – especially with young children. Certainly more work needs to be done to investigate which robot behavior is most beneficial for young children and can promote their engagement and motivation to interact with Ranger over extended periods of time.

6.4.1 Limitations

This study and the results have several limitations. First, we did not have a real control group in which the robot always behaved correctly. Instead, we took the first interaction phase as a reference for how children interact with the correctly behaving robot. Also, the sample size of 13 groups was small. There were variations in the data due to the individual differences of children. More data could have allowed for a better comparison between the conditions. With the manipulation of the robot behavior we were able to surprise children. However, it is questionable how often the same type of behavior manipulation leads to surprise. Moreover, our experiment was a short-term interaction study while we try to make statements about how to sustain long-term engagement. This is critical but not unusual. Long-term HRI studies with young children are extremely rare as they are difficult to set up as well as time and resource consuming (Leite, 2013). Nevertheless, we could have probably improved our study by setting up several short interaction sessions spreading over several weeks. At the end of each session we could have asked whether children want to play again with the robot. Such a study could have helped to investigate the long-term interaction with the robot and the impact of the behavioral variances.

6.4.2 Lessons Learned

One of the lessons learned is that it is difficult to set up a controlled lab study with young children. Children are not like adults who patiently participate in a 45-minutes experiment and then get some reward in the end. On one hand, an experiment with children should not be boring for them, but on the other hand, you would like to seriously collect some data. A lot of the challenges we experienced are also described in Ros et al. (2011). One of the most difficult parts turned out to be the interviews with the children. We need to be careful to not over interpret some of their answers. Some children seem to not have a clear opinion and partly contradict themselves. These answers are not easy to interpret. An interview script including the questions need to be designed very carefully, and should definitely be tested beforehand with the respective age group.

Overall, it appears that when trying to study something in more detail, such as the manipulation of robot behavior, 4-5 year old children may be too young. But when trying to evaluate a more general approach, the design of a prototype, or an interaction scenario, children are a very good choice. They say things as they are and react very naturally, when compared to adults, who may reply more socially desired.

Summary In this study, we investigated the effect of unexpected robot behavior on children's engagement in interacting with Ranger and on their perception of the robot. Our first hypothesis finds support: children show more engagement toward a robot that behaves unexpectedly from time to time. Further, different types of unexpected behavior may have a different effect, and therefore the behavior manipulation needs to be designed with care. We did not find support for our second hypothesis which stated that children perceive a robot showing intention or cognitive abilities as more human-like than a robot that appears to have a system error. This may be due to the study setup and the fact that children did not interpret the robot misbehavior in the conceived way. Our findings seem to suggest the contrary to our hypothesis. A robot that appeared to do a *mistake* or to be *lost* was more anthropomorphized than a robot that *disobeyed*. But again, as children may have misinterpreted these robot behaviors we cannot be sure about this result.

Another outcome of this study is the initial development and first tryout of an **anthropomorphism index**. This index considers both behavioral and perception aspects and is able to indicate lower and higher levels of anthropomorphism along this continuous index. At the moment, there is no such index available that quantifies anthropomorphism along a scale and there is no technique that combines behavior and perception. We may raise a discussion about this in Chapter 7. In the future, we will need to refine and improve this scale. For instance, we need to identify the specific factors that should be included as measurement points in such a scale, for both aspects (behavior and perception). Also, we need to think about how to balance the two aspects appropriately. Probably, also characteristics of the person, the robot, and the situation need to be considered.

7 Summary and Conclusions

In this thesis, we explored the dynamics of human-robot interaction in domestic environments. This chapter concludes the findings of our research. First, we provide a summary of the main results of our studies (Section 7.1). Then we synthesize our findings by reviewing our general research questions (Section 7.2), and, finally we provide a short discussion and general reflection (Section 7.3).

7.1 Summary of Results

First, we openly explored the field by means of a 6-month lasting ethnographic study in nine households to which we gave Roomba vacuum cleaning robots (the **Roomba Study** presented in Chapter 3). Applying an ecological view of the home, our work contributes and extends previous research on long-term acceptance and the adoption process of domestic service robots. Contrary to what has been described in the related research that employed the Roomba in homes, we found that **the robot did not have a substantial and lasting impact on people, activities, and the use of other cleaning tools within the home ecosystem**. More concretely, we found that Roomba did not lastingly change the established cleaning roles in any of the participating households. This had been suggested in previous work, however (Forlizzi and DiSalvo, 2006). Women remained being the main responsible for the vacuum cleaning, and also turned out to be the main users of the Roomba. In one family where both parents were involved in the cleaning activity, they also both used the Roomba. In the other households, men and children used the robot only initially but stopped doing so after some time. Further in contrast to previous findings, we found that the robot evoked changes in the cleaning activity and use of other cleaning tools in only 3 of 9 households (because the robot was rejected and not regularly used by the other six households). In those three households (the *adopters*), the robot increased their frequency of vacuum cleaning (which is consistent with previous findings). Only in 1 of 9 households, the Roomba replaced the manual vacuum cleaner. Contrary, in Forlizzi's study, 2 of 3 families who were using the Roomba had replaced their manual vacuum cleaner (Forlizzi, 2007a). In terms of the physical environment, we found that the physical environment of the home influences

how the Roomba is used. This is consistent with previous work. Some home layouts promote or constrain the usage of a vacuum cleaning robot more than others. However, people's personal beliefs and the experienced social benefits by some participants may play an even more important role. For example, the apartment flat of one family in our study seemed to be the optimal physical environment for the Roomba. However, the mother in this household had a tendency towards perfectionism, and she was convinced that the robot could never clean as well as she cleaned when using the manual vacuum cleaner. Though no adjustments of the physical space were necessary to make the robot navigate around well, the household stopped using the robot, due to the mother's skepticism. A counterexample is the case of a single person household in which the physical environment really challenged the usage of the Roomba. The participant however disliked doing the vacuum cleaning himself so much that he spared no effort to adjust the furniture layout several times and to fix other things, just to enable the Roomba to navigate around. What further encouraged him to continue using the robot was a gain in his social life. Due to the fact that he was using the Roomba, his colleagues at work, who had previously not talked much to him, suddenly showed an interest in his anecdotes about the Roomba. This household was also the only one in which the Roomba replaced the manual vacuum cleaner.
Overall, we estimate that in our study, the impact of the domestic robot on the home ecosystem was less strong and complex than what has been described in the previous work. We assume that the differences may be due to cultural differences, in a sense that U.S. homes are not like Swiss (European) homes, not only in terms of physical space and products used but also in how they are organized and maintained. Further, people's convictions about introducing a domestic robot into the established cleaning routine may be different in these two cultures. Despite the fact that both the previous work and our own work are, of course, not representative for a whole culture, the highlighted differences suggest that culture plays a role in how people use, accept and adapt their home to domestic service robots.

In Chapter 4, we presented results of a content analysis of online discussion forums about the Roomba, the AIBO, and the iPad (the **Forum Study**). Our interest was to explore which topics are relevant for domestic robot owners, and to find out to what degree the Roomba is anthropomorphized in comparison to the other two devices. We investigated the amount and context of the anthropomorphic language used to describe these three technologies. In accordance with the previous work (Friedman et al., 2003), we found that people commonly anthropomorphized the robotic dog AIBO in a variety of ways (57 % of the segments contained anthropomorphic language). The other two devices were less anthropomorphized (Roomba 12 %, iPad 2 %). The analysis suggested that in terms of how far the devices are attributed with human-like qualities, the Roomba is closer to the iPad than to the AIBO. More than in the other forums, the Roomba discussions were dominated by technical aspects. Comparing the topics relationship, usage and technical aspects, we found that the relationship topic does not necessarily come along with the highest amount of anthropomorphic language. This was only the case in the iPad and the Roomba forum. In the AIBO forum, however, the amount of anthropomorphic language was highest for the usage topic, which suggests that **the purpose and context of use of a robot is likely to have an impact on people's tendency to anthropomorphize it**.

Then, we pursued our idea of developing a practical domestic robot that can be used in a household with children. A first prototype of the robotic box "Ranger" that tries to motivate children to tidy up, was developed and tested in 14 family homes (the **Ranger Study** presented in Chapter 5). We found that children enjoyed interacting with Ranger and naturally developed different strategies of using the robotic box to tidy up their toys. The robot's huge movable eyes and the non-verbal sound and light cues that it used, attracted children's attention. Parents appreciated the simple design of the robotic box with its wooden surface. Most of them could imagine using such a robot, which emphasizes the collaboration with the child, in the future. Using a Wizard of Oz approach, we also studied the impact of two different types of robot behavior (proactive *vs.* reactive) on children's interaction with the robot and on the tidying task. We found that both types of robot behavior generally motivated children to put their toys in the robotic box; however, against our hypothesis, **the *reactive* system was more effective in motivating children to tidy up**. Contrary, **the *proactively* behaving robot encouraged children more to play with it but less to use it for tidying up**. This finding highlights the challenge that many interactive technologies for children (especially those used in an educational context) are facing: to engage children in a playful way while still keeping the focus on the specific task (or exercise). It appears that we need to find a good balance between a proactive and reactive robot behavior, so to sustain children's engagement on one hand but to not distract them too much from tidying on the other hand.

We examined the aspect of how to sustain children's engagement in more detail in a follow-up study in a controlled lab environment (the **Domino Study** presented in Chapter 6). 13 pairs of 4-5 year old children participated in a study in which they played a collaborative domino game with the Ranger box, which was used to transport domino tiles between the two children. Our interest was to improve children's engagement with the robot by letting it show some unexpected behavior from time to time. We also explored the effect that the unexpected robot behavior had on children's attributions of human-like qualities to the robot. Our findings of this study are somewhat unclear in terms of interaction dynamics. This may be due to the small sample size and huge individual differences between the children. Nevertheless, the analysis of children's behavior in the video recordings suggests that they engaged more with the robot when it behaved unexpectedly: children tended to explore the robot more, talk more to it and used more gestures toward it. The comparison of the three different manipulations of the robot behavior was not very insightful when trying to look into details but generally, the data suggest that the *disobeying* robot was less effective in engaging children, compared to when the robot did a *mistake*, or when it got *lost*. Further, the *mistake* behavior, in which the robot repairs itself, appeared to be more acceptable for the children. With the two other behaviors, they mentioned more often that the robot was "unpredictable", which may have a negative impact on their trust. Children conditionally anthropomorphized the Ranger (with no remarkable effect of unexpected behavior): they tended to ascribe cognitive abilities to the robot (however, this was also what our experimental setup suggested them) but not necessarily intention. Further, they commonly ascribed feelings and moral standing to the robot and the majority agreed that it could be their friend. Overall, this suggests that **children perceived Ranger as a social entity but not as a human fellow**. Moreover, we attempted to measure how far children anthropomorphized the robot considering both their perception of the robot and the engagement that they showed in the interaction with it. Therefore, we developed a qualitative *anthropomorphism index*, where a higher index reflects a stronger anthropomorphic perception of the robot. Against our assumption, we found a negative correlation between the amount of engagement actions a pair of children showed related to the robot, and their anthropomorphism index. That means that **pairs who engaged more in interacting with the robot tended to anthropomorphize it less**. How can we interpret this? We assume that more interaction with the robot generally increases children's familiarity with the robot, thus their ability to understand how the robot is working. This in turn, decreases their tendency to anthropomorphize. (We come back to this later, in Section 7.2.4.)

7.2 Reviewing the Initial Research Questions

In the following paragraphs, we review our findings in regard to our general research questions that were guiding our research (Introduction, page 4).

7.2.1 People's Perception of Robots

People's perception of robots – the way in which they regard, understand, and interpret robots – is still coined by science fiction. The picture has changed, however. Other sources of information seem to become increasingly more important. For example, people more often mention to have obtained information about robots from technical reports and field reports that are distributed in mass media, or from real-life anecdotes about other people's experiences with their robot shared in social media. Other alternatives to foster the acceptance of robots may be to integrate robotics into the educational curriculum (lifelong learning) or to organize public events (*e.g.* expositions, trade shows, robotic festivals) where people can try out and experience robots themselves (Riedo et al., 2012). Offering people the possibility to have a real-world experience with a robot is likely to increase the general acceptance of domestic service robots. The public's general attitude towards domestic robots is already quite positive and people of all ages are commonly open to trying out a robot in their home. When being asked how a robot could look like, our results indicate that, both children and adults tend to imagine a robot as either having a human-like form (a body with arms, legs, and a head) or being very machine-like. In terms of domestic robots, in particular, people's conceptions seem to be more abstract, in a sense that they can name a variety of tasks that a robot could do for them but they have no clear idea of *how exactly* a robot could achieve this.[1] Most people have already heard about vacuum cleaning robots and commonly use them as an example and point of reference. When they are provided with a robot like Roomba, people tend to have difficulties to accurately estimate the capabilities of the robot (professional background and age may play a role). It is also not clear to them, how a specific domestic robot can be used and integrated in the home (*e.g.* is the robot an additional tool or does it replace

[1] There seems to be a discrepancy between people's wish to having all the annoying tasks done by some "fairy godmother"-like robot on one hand, but at the same time still having the full control over *how the cleaning is done* (and to not have to check afterwards that everything is ok and in its place).

another tool?). Most ordinary people have no previous experience with robots. This can create curiosity on one hand but lead to skepticism on the other hand, especially among people who are not technology savvy. The experienced uncertainty about what to expect of a domestic robot can be critical for acceptance (in the initial phase).

How people perceive a robot changes over time, and the change is likely to be more pronounced in the beginning. This general dynamic seems to be mostly due to growing experience with the robot and the increased familiarity in using it, which in turn, allows the user to more accurately predict the robot's behavior. Further, the novelty effects, which shape how the robot is perceived first, wear off after some time. The dynamics are likely to be more pronounced in the beginning. In short, the change in how people view a vacuum cleaning robot, for instance, can be described (in a simplified way) as *"from a fancy new robot to just another cleaning tool"*. This change in perception is interesting and can be interpreted in several ways. For instance, it may reflect people's evolving user experience with the robot over time (Karapanos et al., 2009) and the adapted interaction / usage. First, the robot is novel and it is mainly perceived in light of the user's expectations (related to the "robot-ness" dimension of the product (DiSalvo et al., 2002)). Based on what the user already knows about the robot, a first judgment may be made. Subsequently, the user assesses the limitations of the robot, gains familiarity with it, and forms an understanding of how it works. The users starts to use the robot as a tool, and as such the task performance comes more into focus. Consequently, there is a shift in the direction that the robot is more perceived (and evaluated) as a tool with a specific purpose because it is now also used accordingly (*e.g.* as a vacuum cleaner). The robot's "product-ness" becomes central to the user perception. Another shift in perception may happen as a specific usage pattern has been established, and the user now aims to incorporate the robot lastingly into the specific home ecosystem and routine. The perception of the so-called "humanness" of the robot (DiSalvo et al., 2002) may now become central. How far is the robot able to adapt to the human? (*eg.* by not automatically starting a vacuuming cycle at the scheduled time because the user exceptionally stays at home due to a migraine.) The humanness of the robot may refer to how much the user can identify himself and his lifestyle with the robot, and make the robot become part of his daily life. The perception of the robot may now be more focused on design aspects, the possibility of personalization, as well as on (important) details of the user experience. Consequently, the overall change in perception may reflect the process of *domestication* of the robot, in which different dimensions and characteristics of the robot become more prevalent during specific phases.

7.2.2 Interaction Analysis

We defined human-robot interaction as *"the study of the humans, robots, and the ways they influence each other"* (Fong et al., 2003b). An interaction can generally be understood as a mutual or reciprocal action, *i.e.* there are at least two "players" that engage in an action. Consequently, we investigated HRI from two perspectives: 1) how people interact (communicate) with robots; and 2) how robots interact with people (and the overall home ecosystem, including the physical space and other products, for instance).

Regarding how people interact with robots, it appears that they have a natural tendency to spontaneously talk to robots or to use pointing gestures, when they feel the urge to intervene or give instructions and feedback to the robot.[2] We observed this when people were using Roomba for the first time but also when children were interacting with Ranger (especially when it misbehaved during the Domino Study). An interesting question is, whether we can exploit this to make HRI more effective (*e.g.* in terms of shared-control). Pointing gestures may only be useful in direct, non-mediated HRI, but still then it is challenging for the robot to understand the point of reference. Contrary, a system with which you can use speech to interact seems more promising. The use of spoken language is very natural for humans and previous survey studies revealed that speech is people's preferred mode of communication with a robot.[3] It would not be necessary (and probably not be desired) if the robot understood everything and was able to follow whole conversations. There may rather be a limited set of verbal commands that the robot can understand, and which can be used both in direct interaction, and in mediated (remote) interaction with the robot (via a smart phone, for instance). In addition to pre-programmed commands, the robot may also be able to learn new commands, that the user teaches the robot (similar to the "learning by demonstration" approach, which seems to be a promising technique for HRI).

In terms of the second aspect, how robots interact with people and the home ecosystem, the robot created some notable dynamics in the beginning but, as already mentioned, these dynamics did not last, and the robot's long-term impact was rather marginal. For instance, first Roomba impacted people by encouraging them to do pre-cleaning activities, and to engage them in helping the robot to clean (*collaborative cleaning*), by collecting crumbs or pushing chairs aside. By doing so, the robot had not only an impact on people but in turn also on its environment. Further, some households made adjustments to their home, due to the Roomba. Most of these adjustments were temporal and people stopped making them after some time (*e.g.* creating a barrier for the robot to keep it in one area). An interesting non-physical impact was that using Roomba made people aware of energy consumption. This was because Roomba's charging station needs to be constantly plugged in and people wondered how much energy the station consumed, and if, in general, they would consume more energy when using the robot instead of the vacuum cleaner.

Overall, there were changes over time in how the robot, people, and the environment interacted with each other. Generally more interactions could be observed during the first two weeks in which households were using the robot than towards the end of the study. In those households that *adopted* the Roomba lastingly, the robot had a more profound impact than in the other households. Logically, due to the additional cleaning that these households did with the Roomba. (Social impacts of the robot are summarized later, in Section 7.2.4)

[2]Interestingly, talking and using gestures to communicate information to the robot seem to be related to pet ownership Mutlu et al. (2009). It is suggested that pet owners feel more comfortable in interacting with robots, and for instance let approach robots closer to them than those who never owned a pet (Takayama and Pantofaru, 2009). Pet owners may interact with robots using techniques that are similar to when they interact with their pet. Further, it seems that they can also interact more effectively, and are able to interpret subtle feedback from the robot more accurately than non pet owners.

[3]Aldebaran recently created the human-inspired robot "Pepper" that also uses voice to communicate with its users. Also with the NAO, Aldebaran's small humanoid robot uses speech.

7.2.3 Acceptance Factors and Adoption Process

The process of adopting a domestic robot and integrating it into the home ecosystem can be structured in several phases, and there may be at least three of them, maybe four (as suggested in the *Domestic Robot Ecology* framework (Sung et al., 2010)). The process varies between households, and therefore it is difficult to estimate the duration of each of the phases. However, the key decision to adopt or reject the robot seems to become apparent within the first to weeks of usage. As previous work already suggested, it is crucial how the robot is introduced into the household. Common patterns may include a 1) *pre-adoption* phase, in which expectations are formed; 2)-3) *orientation and incorporation* phase(s), in which the user familiarizes himself with the robot and the usage of it; and 4) an *identification* phase, in which the robot becomes part of the "identity" of the household ecosystem. The acceptance decisions and the changes in how the robot is used and experienced form the transitions between the adoption phases. Accordingly, as outlined in one of the previous paragraphs, the perception of the robot is likely to shift.

During the process of adoption, there are several factors that can promote and hinder usage and the lasting acceptance of the robot. The importance of these factors can vary over time and for different households. We think that two main motivations behind lastingly using a domestic robot are *social benefits* (recognition from important others) and *practical benefits* (outsourcing of an annoying task). Other factors, such as the *ease of use* and *perceived enjoyment* also play a role but can be outweighed by the main motivations.

When it comes to using a domestic service robot, such as a vacuum cleaning robot, few people are willing to make an effort to be able to use the robot (especially when the effort is required continuously). But if the benefits are expected to be high, they can outweigh some initial efforts. For instance, two female study participants mentioned they were willing to do some "fine-tuning" by programming the robot, if this could improve the robot's cleaning performance (despite the fact that they had no experience in programming). Nevertheless, they could imagine using some kind of application, software or online tool (given that the interface is good), in order to provide the robot with information about the home layout, *e.g.* room size, different types of surfaces, spots that need extra cleaning or areas that should be avoided by the robot. This type of personalization may not only increase the robot's performance and the perceived usefulness, but in turn also lead to an increased adoption rate.

We were surprised to see that only 3 of the 9 households integrated Roomba lastingly into their cleaning routine. A variety of factors played a role (they are summarized at the end of Chapter 3). Overall, there is no one single reason why a household continues or stops using a domestic service robot. One has to take into account the whole ecosystem of the home and the inter-dependencies between the people, the robot, and the environment. Main aspects are related to (1) the household members (*e.g.* individual beliefs, personal convictions and social norms), (2) the robot (*e.g.* technical characteristics, functionality, design aspects), (3) and the characteristics of the home (physical layout, lifestyle, other products). The overall challenge is that no household is like the other. In the end, it is the human, who is in the center of this ecosystem. Therefore, people's perception of the robot and their expectations need to be assessed, for being able to understand why they adopt or reject a vacuum cleaning robot.

Concerning the long-term, the remaining challenge from a design point of view is, to make the robot robust enough so that it stays useful over an extended period of time. Too much of maintenance work, software errors, broken batteries after just one year, or the requirement to regularly replace fairly expensive parts of the robot (*e.g.* the brushes), work against long-term acceptance.

7.2.4 Social Engagement and Anthropomorphism

We wanted to explore how much users engage and interact socially or in a human-like way with a functional robot. We understand anthropomorphism as being a special form of social engagement that arises in an interaction with the robot (*i.e.* when we use the term "social engagement", anthropomorphism is included in this).

We observed that people conditionally engage in a social way with robots, *e.g.* by showing empathy toward it (for instance, when feeling sorry for the robot when it gets stuck) or ascribing intention / personality to it (for instance, when the robot seems to "prefer" a certain spot that it cleans more often, or it does something unexpected). The phenomenon itself has been commonly described, most prominently in context to people's spontaneous social reactions to computers and other technologies (Reeves and Nass, 1996) and related to their tendency to attribute animacy and intention to simple moving shapes (Heider and Simmel, 1944).

This does not seem to be the full story about anthropomorphism, however. We would like to propose that people's social engagement with robots (along with their tendency to anthropomorphize) is not something stable but shows dynamics over time.[4] There are several factors that determine the general likelihood of anthropomorphism and that account for these temporal changes. (Controversially, research on anthropomorphism in HRI mostly disregarded these factors far.) This idea holds several implications.

First, we suggest that **anthropomorphism is multi-layered**. By this, we go beyond understanding anthropomorphism as being either "there" or "not there". We believe that anthropomorphism exists in different shades or levels (*i.e.* lower and higher gradations). This idea is based on the idea to regard anthropomorphism as a multi-layered phenomenon, as proposed by Persson et al. (2000), or even as a continuum, which implicates that it also has to be measured as such (Ruijten et al., 2014). That means that on one hand, there can be some kind of more "superficial", lower level anthropomorphism that people may use to describe the robot in terms of typical (but not unique) human characteristics (*e.g.* being able to interact with a changing environment). On the other hand, there may be some kind of "deeper", higher level anthropomorphism that reflects the perception of characteristics that are uniquely human (*e.g.* having a moral conscience)

[4] A journal manuscript about the dynamics of anthropomorphism in HRI is in work and has been submitted to the frontiers research topic "The Uncanny Valley Hypothesis and Beyond", edited by M. Cheetham and A. P. Saygin.

(Ruijten et al., 2014). Variances in anthropomorphism are also likely to be related to the cognitive correlates of it (Lemaignan et al., 2014).

Second, we propose that **anthropomorphism is based on multiple factors**. We think that to what degree people engage socially with a robot, is impacted by three key factors: 1) the robot and its design and functionality (*e.g.* different types of anthropomorphic design (Fong et al., 2003a)); 2) the human user and his/her personal characteristics (including psychological determinants (Epley et al., 2007)); and 3) the situation and context of the interaction (*e.g.* related to the purpose and task of the robot (Joosse et al., 2013; Goetz et al., 2003; Goetz and Kiesler, 2002; Kaplan, 2000)).

As a third point, we would like to propose that people's tendency to anthropomorphize a robot evolves over time. To account for these **dynamics over time** a user-experience point of view can be applied (Karapanos et al., 2009). But what does "time" mean in such context? As anthropomorphism always requires a commitment from the human (*i.e.* the human is the one that anthropomorphizes, so is active), we need to apply a human-centered view to understand the temporal dynamics of this phenomenon. It does not seem appropriate to simply use "time" as a scale because time itself does not account for changes (when the human owns the robot for 6 months but has used it only only twice during this time, we cannot really speak of long-term interaction). We therefore introduce a so-called *"interaction history"* that accounts for the time that the user has spent with the robot / using the robot.

These considerations lead us to synthesize our findings related to anthropomorphism into a conceptual model (see Figure 7.1). The model illustrates the dynamics of anthropomorphism (and more broadly social engagement) with a robot over time. Note that this conceptual model is in an initial stage, and asks for verification and further research.
The general curve, which is different for each person interacting with a specific robot in a specific context, starts with a so-called *Initial Capital of Anthropomorphism (ICA)* at time point zero (when the person has not yet interacted with the robot; the corresponding value is denoted as A_0). The *ICA* indicates the initial tendency for a human user (H) to anthropomorphize a specific robot (R) in a specific context (C), (the three key factors from above). The ICA reflects a value of *anthropomorphic effects* (A) that is composed of the three likelihood values for the factors H, R, and C. How can we make an estimation? More concretely, some robots are more likely to be anthropomorphized than others, due to their design (which means the total expression of the artifact, including its shape, the materials used, behavior *etc.*). Generally, an anthropomorphic design (up to a certain point) is said to increase the likelihood that the robot is anthropomorphized (putting eyes on the robot's surface may be sufficient). Also, some people tend to anthropomorphize more than others, based on psychological determinants (see Epley et al. (2007)) and demographic factors. For instance, children tend to anthropomorphize more than adults, and some cultures are notorious for their anthropomorphic religions and worldviews. Finally, we suggest that a more playful or social context of the interaction (based on the robot's purpose, take AIBO as an example) facilitates anthropomorphism, compared to a serious or critical situation in which the robot is used. If we can calculate a likelihood value for each of

these three factors, then we can make an estimation about the *ICA* value, which would take the sum of the three likelihood values (probably, the three factors need to be weighted differently). How to calculate such a likelihood value and weight the three factors yet needs to be defined. The overall curve then evolves in a non-monotonic way, as the human starts and continues interacting with the robot. As outlined in one of the previous paragraphs, people's interaction with the robot and their user experience with it evolve. We speculate that during the first couple of interactions (*Initialization Phase*), there is an increase in the tendency to anthropomorphize, based on the fact that the user "discovers" the robot and how to use it. The increase up to a local maximum is based on the user's expectations and may further be impacted by how strong the *novelty* of the robot is perceived and the user's general unfamiliarity with the robot (one reason for why people anthropomorphize is that they want to make sense of something unfamiliar by using knowledge about what is familiar to them – humans). Subsequently, users continue interacting with the robot and familiarize themselves with it (*Familiarization Phase*). We hypothesize that as the human gets used to the robot, the tendency to anthropomorphize generally decreases because the user can better predict the robot's behavior and the "need to anthropomorphize" becomes less. If, however, the robot shows some unexpected behavior there may be a sudden increase / decrease and peak / plunge (*effects of disruptive behavior*) of the tendency to anthropomorphize (similar to what we observed in the Domino Study, when the robot misbehaved). The overall decrease may be stronger or weaker, depending on how much the person herself likes to anthropomorphize, but finally the curve will reach a *Stabilized Level of Anthropomorphism (SLA)* (corresponding value

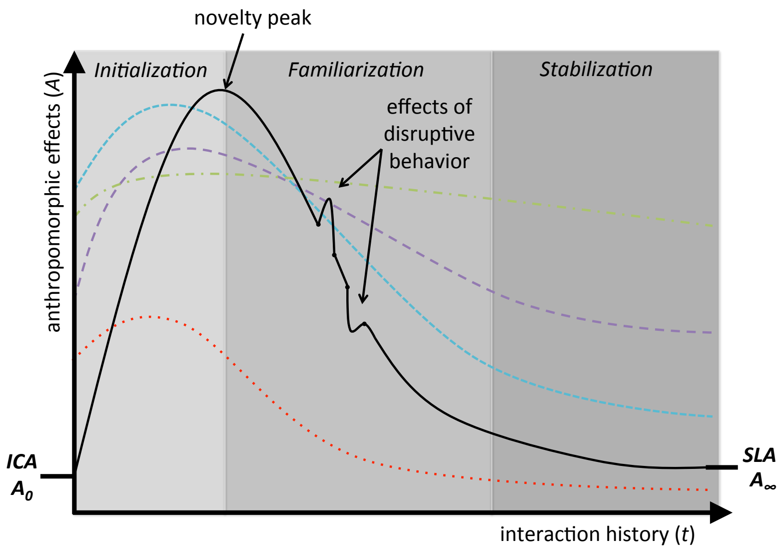


Figure 7.1: **Conceptual model of the dynamics of anthropomorphism over time.** The model shows that the relationship between the *anthropomorphic effects (A)* and the *interaction history (t)* is non-linear. The curve starts with the *Initial Capital of Anthropomorphism (ICA)*. Then, there are three main phases: *Initialization*, which is characterized by the *novelty peak*; *Familiarization*, in which *disruptive behaviors* of the robot may lead to a peak or plunge of anthropomorphic effects; and *Stabilization*, in which the curve balances over a longer period of time to obtain a *Stabilized Level of Anthropomorphism (SLA)*. The duration of these phases may vary and the overall shape of the curve is unique to each human interacting with a specific robot in a given context, as depicted by the alternative curves.

of A denoted as A_∞). The curve is unique to each human interacting with a specific robot in a given context. For instance, in the case of the elderly woman who participated in the Roomba Study, a curve with lower dynamics and generally indicating higher anthropomorphic effects (Figure 7.1, *light green* curve) can be imagined. The woman commonly anthropomorphized her dog and her robot, even after having interacted with them for a considerable amount of time. She simply enjoyed to anthropomorphize the non-human agents around her (so she already had a fairly high *ICA* value).

The applicability of this conceptual model remains to be verified with long-term research on people's social engagement with robots (including anthropomorphism). It is however challenging to "measure" something as abstract and complex but at the same time subtle, as social engagement with a robot. The *anthropomorphism index* that we proposed in Chapter 6 may be an initial step toward assessing social engagement (or the tendency to anthropomorphize) from various angles. We still need to find out which metrics can be used to account for the relevant variables in the interaction and in the perception of the robot, as well as in the context, the robot, and ultimately the human himself.

We also have to be critical about our conceptual model and its implications. The message of this model is not that a sustained high level of social engagement it inherently good. This may not even be desirable. There can be benefits when keeping a certain amount of social engagement but there are certainly also risks; especially for what concerns the use of social robots for children. Over reliance and dependence on robots can be seen as two of these risks, in which center the human user stands.[5] As such, Tanaka and Kimura (2010) argue that *"... the balance between the benefits and risks of this technology is always dynamic, meaning that there has been no static optimality; the balancing point changes over time and across cultures. It also has to be noted that our actions (even research) can affect this balance."*

After all, it remains questionable to what extent sustained anthropomorphic interactions between humans and robots can be favored, regarding ethical aspects. We need to rethink carefully the consequences that emotional and social bonds between humans and robots can have. They may be beneficial on one hand but can hold negative implications on the other hand. To what extent should the design of a robot encourage us to lastingly project feelings or needs to it? Why should a machine even react to us as if it had emotions? Can this be the reality we want to live in? What happens as soon as the artificial agent is considered a moral agent (Sullins, 2006)? Also, despite of that there may be benefits, the use of socially interactive robots in contexts that involve care, rehabilitation or therapy is controversially discussed (Robins et al., 2005a). Do we want a robot to give comfort, a robot that shows our children how to build a tree-house? In short, the design of anthropomorphic social robots is critical, and we have to think about the boundaries of robot applications in people's daily lives.

[5] For a discussion of the up- and downsides of using social robots (and technology in general) in educational contexts, the reader may refer to Tanaka and Kimura (2010).

7.3 General Reflection

7.3.1 Limitations

Studying human-robot interactions in people's homes is not easy. There is no structure in the real world, no home is like the other, there are almost no limits, and there is no possibility to control for all kinds of influencing variables. Also, there is no ready-to use toolkit that would measure all the important factors. Research in ecologically valid settings offers the most natural insights into what really happens "in the wild" but at the same time, it has drawbacks in terms of scientific paradigms. The experimental design has to be adapted to the constraints of the environment. As a consequence, in all our interaction studies we had small sample sizes and we have seen that the individuality / uniqueness of each participating child / household can have a relatively strong impact on the results of the study. It is therefore an open question how much the findings of this work can be generalized to child-robot interaction and to "domestic environments" in general.

With regard to "Ranger", we performed only short-term studies so far. The robot was able to motivate children to clean up their room and a manipulation of its behavior surprised children and increased their engagement with the robot. It is, however, an open question whether children's interest in the robot and its positive effect on their tidying behavior can hold over time. Also, as children grow older, their expectations toward interaction with the robot changes and it may take more than just simple sound and light cues to get their attention.

7.3.2 Future Research

This PhD investigated how people and children, respectively, interact with domestic robots. The studies produced some interesting unexpected findings that could be investigated in more detail in future research.

Pro-activeness and complexity of a robot. Findings from the Ranger Study suggest that a *proactive* system leads to more play but not more tidying. Contrary, a *reactive* system may better support a task. This is an interesting point. Proactive systems (or interfaces) may not always be beneficial, given a specific task or user group. Our laboratory's previous research on educational technologies and computer-supported collaborative learning with tabletop environments and tangible user interfaces draws partially similar conclusions (see PhD theses of Q. Bonnard, S. Cuendet, S. Do-Lenh). It would be interesting to investigate in more detail for which tasks / interaction scenarios a proactive robot behavior is supportive and when it should be avoided. Similarly, future research could also explore how variations of complexity of the system impacts interaction, task completion, acceptance, (long-term) engagement. Concretely, the role of a robots' eyes (*vs.* no eyes), its ability to use speech *vs.* non-linguistic utterances, its ability to move around *vs.* being immobile, other design aspects (*e.g.* humanoid or not humanoid) and other variances in the robot's behavior could be examined.

The role of pet-ownership in HRI. Pet-ownership appears to be an interesting variable in HRI. We included pet owning households in the Roomba Study because we assumed that pets are an additional source of dirt (pet hair) and therefore households with a pet would benefit more from using the Roomba. However, it also seems that pet owners (especially those who have a dog) interact differently with robots and more easily build relationships to robots (agency). Pet owners may also accept robots better, as it has been shown that they feel more comfortable in the proximity of robots (Takayama and Pantofaru, 2009). It would be interesting to investigate in more detail how pet-ownership impacts HRI and especially the acceptance of domestic robots.

Long-term usage of Ranger. Future research could carry further the Ranger project. Especially the long-term usage of Ranger in a family home should be studied. A semi-autonomous version of the robot could be deployed in a family for two weeks (or even longer), to see how usage and interaction evolve, and to investigate the role of the robot in the tidying scenario. Also, several Ranger boxes could be deployed in a kindergarten, to see whether the robot is able to motivate and assist a group of young children in tidying up their toys.

Anthropomorphism over time. We have proposed that anthropomorphism is dynamic and evolves with growing interaction experience between the user and the robot. The empirical data of the Domino Study provides first support for this, as it suggests that more interaction leads to less anthropomorphism. The aspect could be investigated in more detail in the future. For instance, a study consisting of several interaction sessions (spanning over several weeks) could be set up, and anthropomorphism could be measured repeatedly, by taking into account both perception and interaction aspects. This would help understand how continued interaction influences people's tendency to anthropomorphize.

7.3.3 Concluding Remarks

The questions of how to integrate robotics into homes in an acceptable and smooth way has become prominent. At the moment, the human user does not seem to be a hurdle of this. The general fear of robots taking over the world (or a household) is not there anymore. Now, it is the robot's turn. How can they do better? Maybe we can take inspiration from looking at how computers and other technologies made it into people's homes and daily lives. One approach of integrating technology into daily activities at home and workplaces is called **ubiquitous computing** (Weiser, 1991). Almost 25 years ago, Weiser envisioned ubiquitous computing to be the new era of modern computing in which technology becomes embedded in the environment and everyday artifacts such that we are no longer aware of its presence and use it unconsciously (Weiser, 1991). He states: *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"* Weiser (1991). The central aspect of the idea is what Tolmie et al. (2002) and others call "being *unremarkable*" – making the technology invisible in use (Takayama, 2011) and in its own way unremarkable – just like routines are. This could be an interesting approach for robots to enter the home environment: ubiquitous service robots that become unremarkable. We could call this approach **ubiquitous robotics** or **unremarkable robotics**. In that sense, we might not even need to start from scratch an develop a multi-purpose robot that can do everything but costs 3 billions. Alternatively, we could augment existing artifacts that are considered routine tools by integrating some robotic functions into them. Roomba may even count as an example. Roomba is, in general, very acceptable. But its "augmentation" of the vacuum cleaner has limitations that mostly concern the vacuuming performance. However, an augmentation of routine tools needs to be in the service of both the actions done with those artifacts (vacuuming) and what is accomplished through those actions, what is "done in doing" (cleanliness, maintenance of the home) (Tolmie et al., 2002). iRobot constantly tries to improve the Roomba according to the needs of the user. User-centered design and evaluation loops are key to improving interaction and acceptance of domestic robots. As Tanaka and Kimura (2010) put it *"[...] the only way robotics engineers can proceed to is to develop technology while continuously observing and listening to the responses of the society."*

Anecdote II

Every day, I take the metro m1 to go back home after work. When still walking to the station, I can here the noise that the rails make when the train is arriving. I start to run, and still maybe 50 m in front of me, I see the metro stopping at the station. I run even faster, I want to catch this one! I am hungry and I don't want to spend 15 minutes waiting for the next metro! I see people getting off and on the train. Only 10 m left for me to reach it, I can spot the driver. I look into his face and smile a bit to convey to him that I would be happy to catch the train he is driving. Ok, he can see me, he nods. He is waiting for me! The door in the very front is still open and I rush to get on the metro. That was close! I am out of breath but thankful.

There is, however, another metro in Lausanne: the m2. It is driverless and I frequently miss it. But even worse than missing it, is that I cannot even blame the driver.

* * *

(a) metro m1 (b) metro m2

Figure 7.2: **The metro in Lausanne.** The metro m1 (a) has a human driver, whereas the metro m2 (b) is driverless. [sources: http://www.urbanrail.net; http://www.lake-geneva-region.ch]

A Appendix

Roomba Study: semi-structured interview scripts for all the five household visits (page 215)

Roomba Study: Roomba rating scale to quantify people's perception of Roomba (page 232)

Ranger Study: Ranger evaluation cards and rating scales (page 233)

Domino Study: questions used during the interview with the children, to investigate their perception of Ranger (page 236)

Domino Study: 3 additional charts about the engagement actions for each run per condition (page 238)

Roomba study: Interview 1st visit

1. Introduction, exploratory interview and home tour

- ***Participation, formal stuff (2 consent forms etc.)***
- ***Study: find out how families live with Roomba and how they use it in their daily life***

2. Get to know the family: general questions

1. Who lives in the house?
    a. Name, age
    b. Job, employment level, home working? Is their job / educational background related to technology?
    c. Hobbies? Are their hobbies related to technology?
2. Pets? Do they lose hair? Do they make a lot of dirt?
3. How long have they been living there? Foreigners?
4. Who visits the house regularly? Names, functions, activities (e.g. do kids from the block come in to play). Is there much dirt created by these visitors?

3. Understanding the family cleaning habits

Our hypothesis is that Roomba will change cleaning roles

1. In general, how much is cleaned?
2. Do you have a cleaning lady? What does she do?
3. Who does what? Why? Do the **roles grid**:
    a. Here are some post-its with the classical household tasks written on (cleaning the floor, vacuuming, laying/cleaning up the table, doing the beds, cleaning windows, garden, repairing stuffs, couture, tidying up, cooking, washing kids, …). Could you please place it on this grid? (the grid should represent the different household members of the family)
    b. Why

Check the grid by asking them:

Cleaning yesterday

- What have you done this morning – today - yesterday? Just the general outlines…
- What about cleaning? What have you done? Alone or together? How long? With what tool?
- Was it a usual day or not?

Cleaning Saturday or Sunday

- Did you clean last week end? What day? Ok, let's take that day
- What have you done in general on that day?
- What about cleaning? What have you done? Alone or together? How long? With what tool?
- Was it a usual day or not?

4. Understanding of cleaning perception

1. Do you like cleaning? Why (not)?
2. What do you hate about cleaning?

3. What do you like?
4. Do you feel that you are always lagging behind in terms of cleaning?

Observe how picky they are

Understanding their cleaning issues today

1. What are your major cleaning issues today?
2. What are the places in your home which are the most difficult to clean?
3. How do you solve that?

5. Make a home tour

- ***Our hypothesis is that Roomba will change which place is cleaned how much***
- ***Draw the <u>flat map</u> together with them and let them highlight (in yellow) the areas where they think they tidy up frequently.***

Room after room, check and correct the map if necessary:

1. Where are the cleaning tools or products? Are they happy with them?
2. What floor it is?
3. How many things are lying on the floor?
4. When do you consider that this room is clean? How does it show?
5. Which part of the room is often cleaned, which one less?
6. Check which type of technology they have and how much technology affine they are.

6. Perception of technology

1. In general would you consider yourself and your family as technology affine?
2. Do you have hobbies related to technology? (If not answered before already.)

7. Their technologies and cleaning tools

<u>Technology matrix</u>

1. Here is a map with 2 axes (usefulness-satisfaction)
    - I have written down during our home tour the names of your main appliances on post its
    - Are there any missing?
    - Could you stick them on the map?
    - Why have you placed them that way

Let's talk now about your vacuum cleaner
2. Are you happy about it? Why?
3. When have you bought your last one? Why?

8. Their perception of robots (in general)

1. Depending on what you have observed, ask: Do you have any robots in your home? Which one? Have you had any?

2. What have been your experiences? Good, bad?
3. **Mind map** and **robot matrix** exercise : Here are different robots – go through them one by one :
    a. Would you consider them as a robot? Why?
    b. Very spontaneously tell me what adjectives/words/verbs come to your mind?
    c. What would be then your definition of a robot?
4. Robot matrix exercise:
    Now here are again the pictures of the robots. Could you stick them on this map according to the 2 following axes?

9. Ending

Leave:

1. a card
2. one of the 2 consent forms
3. The **cleaning diary**
4. Agree on a date for the next meeting

Roomba study: Interview 2nd visit

1. Introduction

- How did it go with filling out the diary?
- Did you find it useful? Did you learn something?

2. Debrief cleaning diary: understanding in depth actual cleaning behaviors

Put on the table the tasks matrix
Go through the diary
Goal of the debriefing is to identify patterns:

- How much is cleaned?
  - Is there anything they would have forgotten to write?
  - Was it a particular week?
  - Is cleaning something fragmented or is it just something happening constantly?
- Who does what?
  - Does this match the roles sharing we learned during the first visit and also the tasks matrix?
  - Is there a main manager who organizes and coordinates all activities ?
- How long?
  - Check if most tasks are short?
  - Try to find out when the „grosse putzaktionen" (min 2 hours of cleaning in a row) take place, who does them, why?
- When?
  - Do they have fix days for cleaning?
  - Or fixed moments during the day?
  - Is cleaning related to another activity or event (e.g. meals)
- Where?
  - Are there any spots that "belong" to certain people in terms of cleaning?
  - Any spots they hate cleaning?
- Why is it so?
  - What beliefs drive the cleaning (e.g. health)?

Ask and write down in the diary which cleaning action (line) was planned.

3. Get to know the family activities through their calendar

Our hypothesis is that Roomba will change cleaning time

Take a picture of the family calendar if they have one, or paper calendar ask them to out their outlook calendar

Draw first a general schedule of people (person per person) <u>Day Reconstruction Method</u>

When you have an overview of the whole family, draw a cross where there were cleaning events referring to the diary.

4. Expectations of Roomba and first usage

- Have you discussed about Roomba? Have you looked at it on internet? What have you discussed?
- *Ask them to highlight on* ***flat plans****.*
    - Is it correct?
    - Where they believe they will use Roomba. Ask them why they think so?
- *Show them the* **Roomba rating scale***: don't write 1 average for the family. Take different colors for the different family member*

First contact with Roomba

Imagine, last week you ordered on the internet, this autonomous vacuum cleaning robot, Roomba. You paid 350 Fr for that. Here it is…. No I am not here, go ahead, you can open the box…

Before they start the Roomba, explain them that there are few things they have to pay attention to:

- *Cables on the ground*
- *Fragile objects (e.g. vase)*
- *I swallow small objects lying on the ground*
- *Floor should not be wet*

Arrange the place quickly to make it Roomba safe

Unpacking

Let them open the box and discover Roomba

Track

- Who does what?
    - Who takes the control?
    - Who unpacks Roomba?
    - Do they read the manual before starting it?
    - What happens with the plastic and carton around Roomba?
- Where?
- What words are used for Roomba?
- What gestures are used towards Roomba?
- Are they enthusiastic? Scared?
- Do they manage? What works, what doesn't? What questions do they ask?
- ….

First usage

- What do they use Roomba for? Where?
- Are they happy? Do they think that Roomba is doing its work well?
- What words are used for Roomba?
- What gestures are used towards Roomba?
- How does it evolve?
- Who controls it?

After a certain time of usage, before leaving

- Ask to fill the **Roomba rating scale**
- Ask them what they are happy about
- What are they disappointed about

General observations

Write down:

- a list of main event happening, when, who was involved
- the atmosphere

What we are particularly interested in is:

- cleaning/tidying up events
- tools used
- activities that bring dirt
- technology usage

5. Ending

Leave:

1. **Roomba diary**
2. Date for the next meeting

Roomba study: Interview 3rd visit

1. Introduction

We want here not only to warm up the conversation, but also to identify the factors that support or stop adoption, and understand Roomba value add

Has anything major happened since we met regarding your family (habits…)?

2. Catch up things that still need to be clarified

Are all the diaries questions answered?
Is it clear to you:

1. Their relationship to doing household tasks:
    - Do you normally plan anything when it comes to household task? Or do you do things more as they come? Why?
    - Is there anything which is always done on a fix day? Why?
    - What do you consider as urgent? What makes you feel bad when it is not done? Give an example. Why?
    - What is not urgent? What do you know you should have done for a while but still haven't?
2. How are "tasks related to the whole household" dealt with? (shared spaces)
    - Who has tidied up in the living room for the last time?
    - Who has cleaned the dishwasher for the last time?
    - Who has cleaned for the last time the bathroom?
    - How did it go? Did you "discuss it"?
3. When was the last time you had a discussion in the household about cleaning? What happened? What did you discuss?
4. Age

3. Intro to Roomba (catch the hot stuffs)

1. Have you had any major event happening with Roomba? Anything that marked you?
    - Positive: fun moment, …
    - Negative: any break down, …
    - Any video or photo shot to show?

4. Debrief Roomba diary: understanding in depth actual Roomba usage

1. Go through the **<u>diary</u>**

Goal of the debriefing is to identify patterns or very surprising usage:

- How much is Roomba used?
- Who uses it mainly?
- When is it mainly used?
- Where?
- For what is it used? Only cleaning?
- Why is it so?

- What has been cool? What not?
- Have you left Roomba to work on its own?

2. Have you used your other vacuum cleaner in the meantime?
3. Hand you used the dust pan/hand vacuum?

5. Satisfaction with and perception of Roomba

We want to identify here the factors that support or stop adoption

1. Where does the fascination come from?
   What really surprises you (in positive sense)?
2. **Rating card/scale**
   - Go through each line
   - After all rankings have been given, ask why they gave such answers
3. **3 things I love/hate/wish about Roomba**
   - Ask people to fill out the 3 bubbles
   - Ask them to justify their answers

6. How do they think Roomba ticks? Social activities.

1. **Flat map** high lightening
   - Where do you store Roomba?
   - Where do you use Roomba?
   - Where don't you use Roomba?
2. How do you think Roomba moves around?
3. Have you tried to understand that?
4. Go through all buttons and functionalities: have you used it? Do you know what it is for?
5. Have you opened Roomba? Why? What did you do?
6. What did they do with Roomba

→ Do the **activity cards**

7. Impact of Roomba: understanding of changes in the cleaning habits

Usage

1. Do you think in general that Roomba has changed your household cleaning habits?
2. How much: Do you think you clean more since you have Roomba ?
3. What – activities: Do you think you clean differently since you use Roomba?
4. Who – Role: Has anything changed in who is responsible for what in terms of household tasks
5. How – Tools: Have you changed anything in terms of tools you are using for cleaning?
6. Where – Places
   - Where do you normally leave Roomba?
   - Do you think you clean different places since you have Roomba?
   - Have you rearranged your home because of Roomba?

If necessary, do a little home tour to double check what the participant has just said and check out the impact of Roomba on the place

Any other impact on the household

Have you noticed that anything else has changed in your household since you have Roomba?

Roomba value add

Would you buy Roomba?
Would you recommend it to someone else?

8. Ending

Leave:

1. Explain them we will meet in 2 month and send them 2 diaries before that
2. Ask them if they are planning any holidays in 2 months
3. Ask them to go on sending us pictures, films…
4. Say again they can contact us anytime, call us…

Take with you:

- Roomba diary

Roomba study: Interview 4th visit

1. Introduction

Explain:

- *Study is going on well, thanks to contribution of every single participant!!*
- *Writing on a first analysis, the long-term run is going to be interesting*
- *Share summary of results (anonymized!!) with them after study (not now to not influence them)*

2. Any major change?

1. Has anything major happened since we met **regarding your family** (habits…)?
2. Have you had any major event happening with Roomba?
    - Positive: fun moment …
    - Negative: any break down …

    Any video or photo shot to show?
3. Have you had any major event happening concerning your cleaning routine?

3. Debrief diary: Roomba usage

Go through the **diary**
Goal of the debriefing is to identify patterns or very surprising **vacuuming usage:**

- **Who** uses Roomba? (main user, non user)
  What do the children do? What about the pets?
- **For what** exactly is Roomba used for? (clean up something special, intentionally, e.g. only to clean up crumbs after meal)
- **How much** is Roomba used? (is it used fewer than in the beginning? Why?)
- **When** is Roomba used? (related to an event?)
- **How long** is Roomba used? (do they stop it manually or let it return to base?)
- **Where** do they use Roomba, where not? away one time for any reason? (guests …)
  → **flat map high lightening**
- **Why** is it so?

Handling of the vacuum

- Storing: Where is the home base? Why? (do they want to keep it in one area ? why? how do they solve that?)
- Cleaning and emptying it
- Fill up the battery

Was Roomba used for other activities?

Do the **Roomba activity** map

4. Further exploration of Roomba (perception and understanding)

- Did they look at the **manual**? Search **information** on the internet? Why (not)?
- Where and why did Roomba get **stuck**? How did they solve it?
- Did they try out the different **functions**: DOCK, SPOT, VIRTUAL WALLS, SCHEDULING?

- How do you think Roomba moves around?
- Have you tried to understand that?
- Have you opened Roomba? Why? What did you do?

<u>Bubble talk</u>

Imagine Roomba could talk to you about what he thinks about how your household uses Roomba. Imagine you are sitting with Roomba in a Café. Roomba tells you:

- What might Roomba say to you?
- What do you think Roomba "likes" about your home and how you use it?
- What do you think Roomba would like to change?

5. Roomba's impact

On other cleaning tools usage

Can Roomba replace the vacuum cleaner or other tools? Why (not)?

- Did they use the VC in the last time? When?
- Do they use the VC more / less with Roomba?
- Who uses the VC? Was there a change?
- What are the differences between the VC and Roomba?
- For what do you use the VC and for what do you prefer Roomba?
- If you compare Roomba to your VC, what do you appreciate about it?
- What about the brooms and dust pan?

Roomba's impact on cleaning routine

How did cleaning routine change since they have Roomba?

- Do they clean different? What exactly changed? (amount, role, responsibility, task sharing, tools used, places)
- Do they clean more / less with Roomba?
- Do they have the impression that the apartment became cleaner?

6. Satisfaction with Roomba

What additional values does Roomba bring to your household?

- What is easier / more efficient to do with Roomba than before?
- What is cumbersome with Roomba?

<u>3 things I love/hate about Roomba</u> (probably already said before)

- Ask people to fill out the 3 bubbles
- Ask them to justify their answers

<u>Rating card/scale</u>

- Go through each line
- After all rankings have been given, ask why they gave such answers

<u>3 wishes to say to Roomba</u>

- What do you miss about Roomba?
- What would you like to change about it? (in terms of interaction, size, handling, performance, usability …)

7. Perception of Roomba – its true value add

For us to keep in mind: is Roomba something functional, aesthetic, social, symbolism

- Who / what is Roomba for you?
- How would you describe Roomba?
- What has Roomba brought to your household?
- Would you buy a Roomba now? For 350 CHF?
- What would happen if I took Roomba away today?
- Would you recommend Roomba?
- Do you think you will further use Roomba?

Perception of robots:

- Did Roomba change the picture you have about robots?
- Could you imagine other domestic robots in your home?
- What type? What would it do?
- For each type they name, ask them as well:
  - How should its shape look like (human form, pet like…)
  - What should be its interface (should it talk, should it have a display…)
  - How big should it be
  - Anything else important?
- What would be your definition of robots now?
- What would be the key points to make a robot
  - acceptable in a house?
  - NOT acceptable?

8. Ending

Take with you:

- Photos of : home base, Roomba home
- Diary
- Videos/photos they took

Explain:

- next and last meeting will be 6 months after you brought Roomba
- you might send a new diary in between
- they can phone/write you if something is happening

Roomba study: Interview 5th visit

Warm up: Live with Roomba for 6 months

Explain:

- The last study meeting, so we conclude the last meetings and are interested to see whether and how Roomba changed the daily routine or how people clean

1. Any major change?

1. Has anything major happened since we met **regarding your family** (habits…)?
2. Have you had any major event happening with Roomba?
    a. Positive: fun moment, …
    b. Negative: any break down, …
   Any video or photo shot to show?
3. Have you had any major event happening concerning your cleaning routine?

2. Roomba usage

Development of usage over time

- Are you still using Roomba?
- Why? What drives them nuts about Roomba / what is fine?
- How do you think your usage has evolved over time?

Debrief diary:
Go through the **diary**
Goal of the debriefing is to identify patterns or very surprising **vacuuming usage:**

- **Who** uses Roomba? (main user, non user)
  What do the children do? What about the pets?
- **For what** exactly is Roomba used for? (clean up something special, intentionally, e.g. only to clean up crumbs after meal)
- **How much** is Roomba used? (is it used fewer than in the beginning? Why?)
- **When** is Roomba used? (related to an event?)
- **How long** is Roomba used? (do they stop it manually or let it return to base?)
- **Where** do they use Roomba, where not? away one time for any reason? (guests …)
  → **flat map high lightening**
- **Why** is it so?

Other Roomba specific usage question

- Have you left Roomba working on its own? Why?

Handling Roomba

- Storing: Where is the home base? Why? (do they want to keep it in one area ? why? how do they solve that?)
- Cleaning and emptying it
- Fill up the battery
- Who cares for Roomba?

3. Was Roomba used for other activities?

- Do the **Roomba activity map**
- Can you describe the last interaction you have had with Roomba?
- What about your dog? Your kids?
- Is it always that way?
- Did it change over time?

4. Further exploration of Roomba

- Did they look at the **manual**? Search **information** on the internet? Why (not)?
- Where and why did Roomba get **stuck**? How did they solve it?
- Did they try out the different **functions**: DOCK, SPOT, VIRTUAL WALLS, SCHEDULING?
- How do you think Roomba moves around?
- Have you tried to understand that?
- Have you opened Roomba? Why? What did you do?
- Overall how much effort do you think you have invested in learning Roomba?

5. Roomba's impact

On other cleaning tools usage

Can Roomba replace the vacuum cleaner or other tools? Why (not)?

- Did they use the VC in the last time? When?
- Do they use the VC more / less with Roomba?
- Who uses the VC? Was there a change?
- What are the differences between the VC and Roomba?
- For what do you use the VC and for what do you prefer Roomba?
- If you compare Roomba to your VC, what do you appreciate about it?
- What about the brooms and dust pan?

Roomba's impact on cleaning routine

How did cleaning routine change since they have Roomba?

- Do they clean different? What exactly changed? (amount, role, responsibility, task sharing, tools used, places, cleaning strategy: room per room versus all at once)
- What about vacuuming?
- Do they clean more / less with Roomba?
- Do they have the impression that the apartment became cleaner?
- Have they had the opportunity to skip one particular activity?

6. Satisfaction with Roomba

- Read them aloud again their **original wishes** about Roomba:
  - Have they evolved?
  - Have they come true?
  - How have you dealt with that?
- Read them aloud again their **original fears** about Roomba:
  - Have they evolved?

- Have they come true?
- How have you dealt with that?

What additional values does Roomba bring to your household?

- What is easier / more efficient to do with Roomba than before?
- What is cumbersome with Roomba?

<u>3 things I love/hate about Roomba</u> (probably already said before)

- Ask people to fill out the 3 bubbles
- Ask them to justify their answers

<u>Rating card/scale</u>

- Go through each line
- After all rankings have been given, ask why they gave such answers

<u>3 wishes to say to Roomba</u>

- What do you miss about Roomba?
- What would you like to change about it? (in terms of interaction, size, handling, performance, usability …)

7. Perception of Roomba – its true value add

For us to keep in mind: is Roomba something functional, aesthetic, social, symbolism

- Who / what is Roomba for you? Is it a robot?
- What does it mean to you?
- How would you describe Roomba?
- Has it evolved over time?
- What has Roomba brought to your household?
- Would you buy a Roomba now? For 350 CHF?
- What would happen if I took Roomba away today?
- Would you recommend Roomba?
- Do you think you will further use Roomba?

8. Perception of robots:

Redo the **<u>robot matrix</u>**

- Do you think your perception of robots has changed over time?
- Did Roomba change the picture you have about robots?
- Could you imagine other domestic robots in your home?
- What type? What would it do?
- For each type they name, ask them as well:
    - How should its shape look like (human form, pet like…)
    - What should be its interface (should it talk, should it have a display…)
    - How big should it be
    - Anything else important?
- What would be your definition of robots now?
- What would be the key points to make a robot
    - acceptable in a house?
    - NOT acceptable?

9. Ending

- How do you feel about the study?

Take with you:

- Photos of : home base, Roomba home
- Diary
- Videos/photos they took

Roomba Impression

1. How intelligent do you think Roomba is?

1	2	3	4	5	6	7
not at all intelligent						very intelligent

2. How useful is Roomba for you?

1	2	3	4	5	6	7
not at all useful						very useful

3. How easy is it to use?

1	2	3	4	5	6	7
very difficult						very easy

4. How entertaining / fun is Roomba?

1	2	3	4	5	6	7
not at all entertaining						very entertaining

5. How attached do you think you are to Roomba?

1	2	3	4	5	6	7
not attached at all						very attached

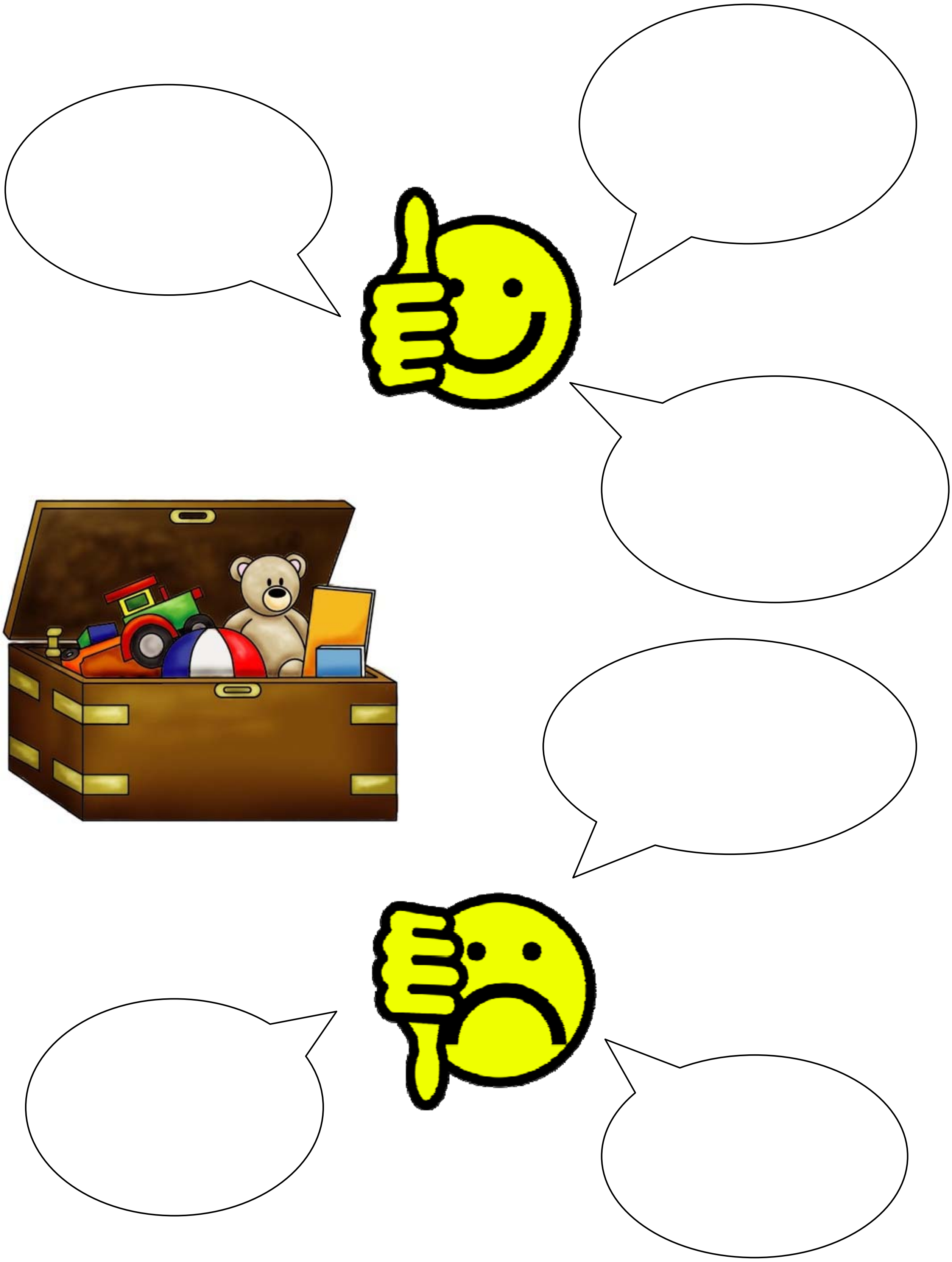
6. How much of impact do you think it holds for your household? (i.e., cleaning routine, communication pattern, furniture layout)

1	2	3	4	5	6	7
very little impact						very high impact

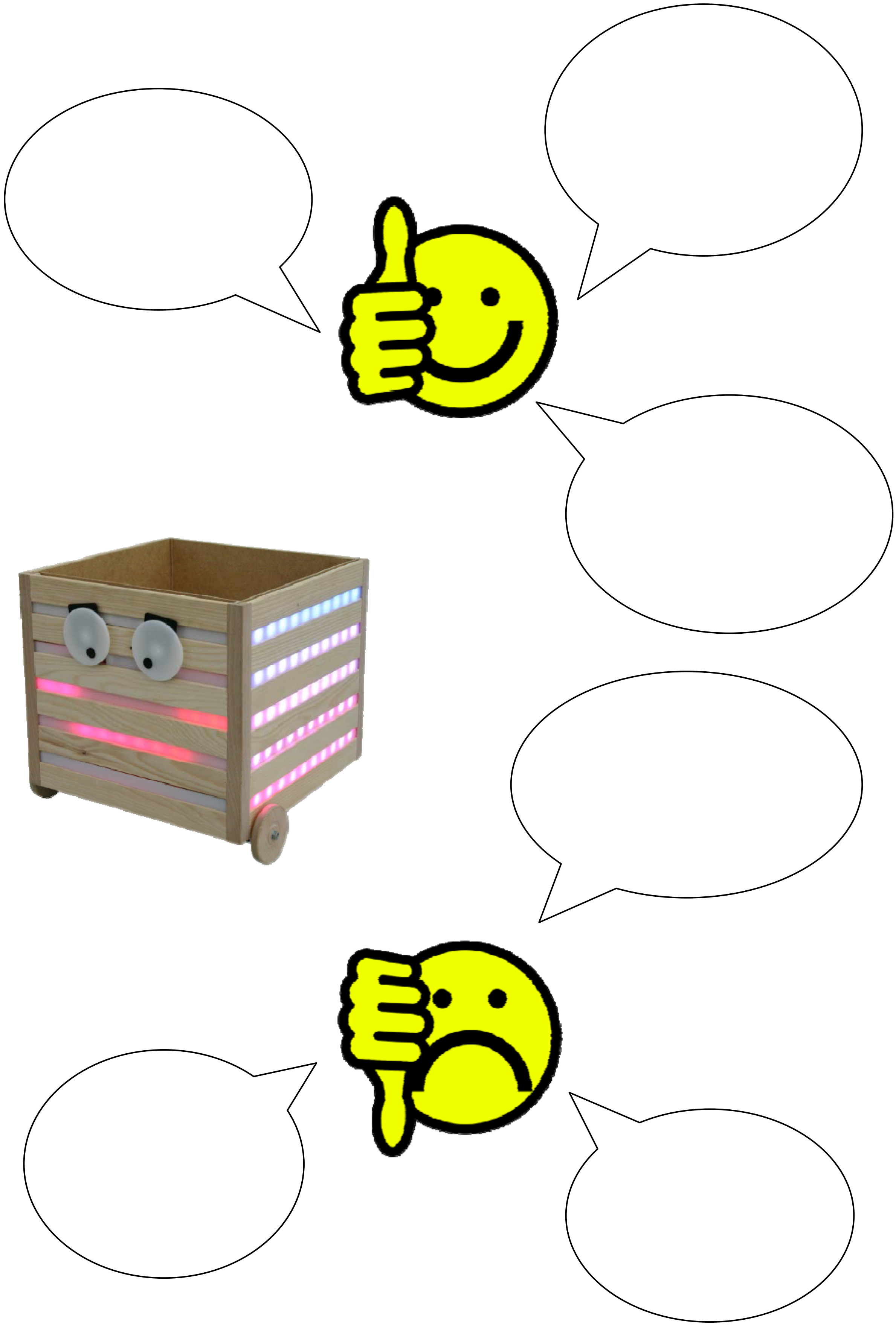
7. How is your overall impression about Roomba?

1	2	3	4	5	6	7
very bad impression						very good impression

Likes and Dislikes about Cleaning up the Children’s Room



Likes and Dislikes about Ranger



Evaluation of Ranger

I find Ranger easy to use.

agree ☐ ☐ ☐ ☐ ☐ disagree

Ranger is useful.

agree ☐ ☐ ☐ ☐ ☐ disagree

It would be convenient for me to have the robot.

agree ☐ ☐ ☐ ☐ ☐ disagree

I would be afraid to make mistakes with Ranger or to break something.

agree ☐ ☐ ☐ ☐ ☐ disagree

I think it's a good idea to use Ranger.

agree ☐ ☐ ☐ ☐ ☐ disagree

I think I would use Ranger during the next few days.

agree ☐ ☐ ☐ ☐ ☐ disagree

I find Ranger boring.

agree ☐ ☐ ☐ ☐ ☐ disagree

I enjoy Ranger responding to me.

agree ☐ ☐ ☐ ☐ ☐ disagree

I think Ranger is nice and pleasant to interact with.

agree ☐ ☐ ☐ ☐ ☐ disagree

I can imagine Ranger to be a living creature.

agree ☐ ☐ ☐ ☐ ☐ disagree

My overall impression of Ranger.

very good ☐ ☐ ☐ ☐ ☐ very bad

Thank you!!

Ranger DOMINO: Interview

EXPECTATION

Comment imaginez-vous un robot ?
How do you imagine a robot?

À quoi est-ce qu'il peut ressembler un robot ?
What could a robot look like?

Est-ce que vous avez déjà vu un robot?
Have you ever seen a robot before?

IMPRESSION

Quand vous avez vu Ranger qu'est-ce que vous avez pensé ?
When you first saw Ranger, what did you think?

Penses-tu que Ranger est un robot ? Comment sais-tu ?
Is Ranger a robot? How do you know?

Quand Ranger venait vers toi (quand tu l'as appelé) est-ce que tu étais surpris ?
Est-ce que tu as attendu qu'il vienne vers toi quand tu l'appelles ?
Were you surprised when Ranger came over to you (when you called it)?
Did you expect it would come over to you when you call it?

Qu'est-ce qui s'est passé quand tu as mis le domino dans la boîte ?
What happened when you put the domino inside the box?

ASCRIBE INTENTION

Est-ce que tu penses que Ranger pourrait sortir de la pièce tout seul ?
Do you think that Ranger could go out the door all by itself?

Est-ce que Ranger vient toujours lorsque tu l'appelles ? Est-ce que Ranger t'obéit toujours ?
Does Ranger always come over when you call it? Does Ranger always obey to you?

Penses-tu que Ranger peut faire des bêtises parfois (est malin)?
Comment sais-tu? (Quels bêtises fait-il ?)
Do you think Ranger could do a bêtise (do something silly)?
How do you know? (Which silly things could it do?)

Qu'est-ce qui c'est passé quand Ranger est allé par ici ?
Pourquoi est-ce qu'il ne venait pas vers toi quand tu l'as appelé ?
What happened when Ranger went over there?
Why did Ranger not come over to you when you called it?

ASCRIBE COGNITIVE ABILITIES

Voilà un domino. Penses-tu que Ranger arrive à le voir? Comment sais-tu ?
Here is a domino. Do you think Ranger can see it? How do you know?

[Scientifique dit à Ranger, "Salut Ranger !"]
Penses-tu que Ranger arrive à m'entendre? Comment sais-tu ?
[Experimenter says to Ranger: "Hello Ranger!"]
Do you think Ranger can hear me? How do you know?

ASCRIBE EMOTIONAL STATE

Est-ce que tu crois que Ranger peut être content ou malheureux parfois ?
Si oui, quelles choses pourrais-tu faire pour le rendre content ?
Do you think Ranger can feel happy or sad sometimes?
If yes, what kinds of things could you do to make Ranger happy?

SOCIAL ACCEPTANCE

Est-ce que tu aimes bien Ranger? Pourquoi (pas) ?
Do you like Ranger? Why (not)?

Qu'est-ce qui était bien / pas bien ?
What was good / not good?

Aimerais-tu avoir Ranger à la maison?
Would you like to have Ranger at home?

COMPANIONSHIP

Est-ce que Ranger pourrait être ton copain? Pourquoi (pas) ?
Can Ranger be your friend? Why (not)?

ASCRIBE MORAL STANDING

Disons que tu pars une semaine en vacances avec ta famille.
Est-ce que tu le laisserais à la maison tout seule ? Si "non", pourquoi pas ?
Assume you go on a holiday for two weeks.
Is it alright to leave Ranger alone at home? If "no", why not?

ADDITIONAL PHRASES

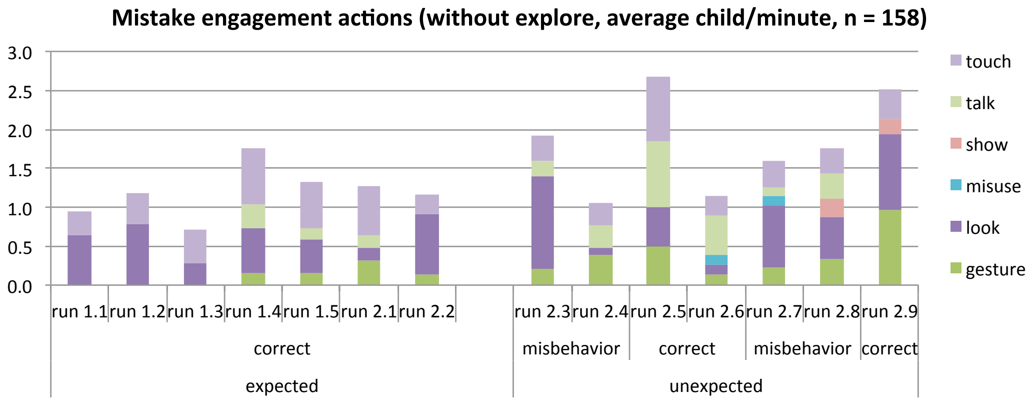
Est-ce que vous avez remarqué quelque chose? Quoi?
Did you notice something? What?

Comment est-ce que ça c'est passé ?
How did it go?

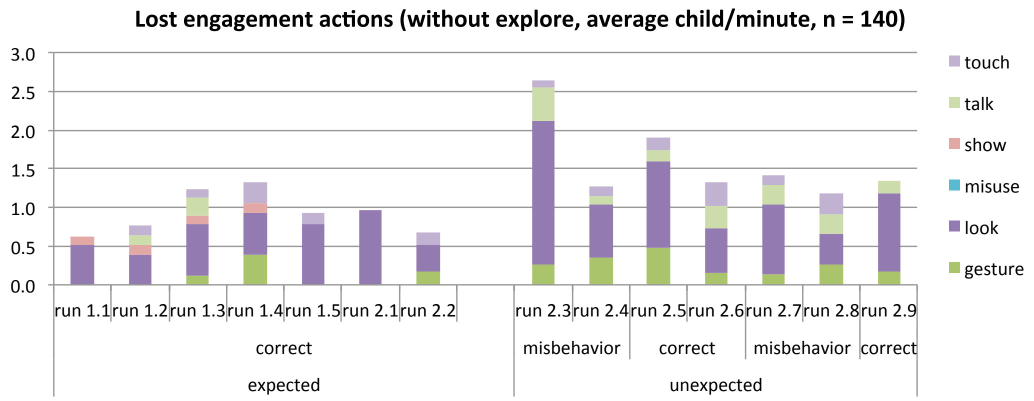
Domino Study Additional Graphs

See Chapter 6, Section 6.3.1, page 181.

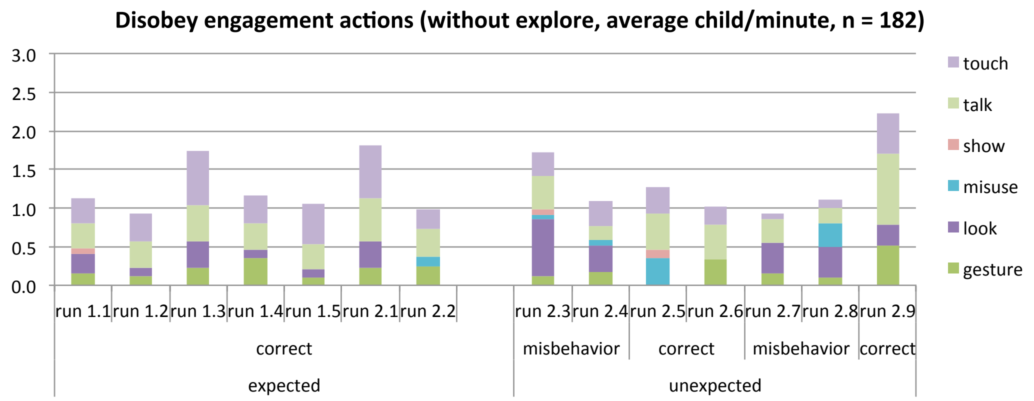
How children's engagement with Ranger evolved during the course of the experiment comparing the three different robot behavior conditions, is not clear. In the *mistake* condition (Figure A.1a), there is a huge peak of engagement actions in run 2.5. This appears hard to explain, as one would expect such an increase rather in run 2.3, when the robot misbehaved the first time. We can note that children in this condition tried to develop strategies of "helping" the robot as soon as they realized it went wrong. They somehow increased *talking* to robot and using *gestures* toward it, as well as, toward the end, started *showing* domino tiles to the robot.
In the *lost* condition (Figure A.1b), there was a generally high amount of *look* at the experimenter, even during the first interaction phase, and especially in run 2.3, when Ranger misbehaved the first time. There was one child in this condition that in the beginning tended to *show* domino tiles to the robot. They boy stopped doing so later. During the second phase, children slightly increased *talk* to the robot and *touch*. Peaks and variations of engagement actions can be observed every time the robot changed its behavior from expected to unexpected and *vice versa*.
In the *disobey* condition (Figure A.1c), the last run (2.9) engaged children more than the first run in which the robot misbehaved. In this condition, there were two boys who tended to misuse the robot by shaking it, kicking it, or physically blocking its way when they suspected it to misbehave. Also, one boy talked to robot more than any other child. He frequently gave commands and instructions to the robot, sometimes almost shouting at it.



(a) mistake



(b) lost



(c) disobey

Figure A.1: **Engagement actions for each run per condition** (average for one child per minute, without *explore* action).

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Julia FINK

Campus address:
CHILI lab – Ecole Polytechnique Fédérale de Lausanne (EPFL)
RLC D1 740 | Station 20 | CH-1015 Lausanne | Suisse

E-mail: julia.fink@epfl.ch | **phone:** +41 21 693 22 74 | **mobile:** +41 76 742 81 80

Born on 15.05.1986 in Augsburg (Germany) | German citizen, Swiss Permit B

EDUCATION

Sep 10 – Aug 14	PhD in Human-Robot Interaction, Ecole Polytechnique Fédérale de Lausanne (EPFL) Computer-Human Interaction in Learning and Instruction Lab (CHILI) Thesis: *Dynamics of Human-Robot Interaction in Domestic Environments* Advisors: Prof. Pierre Dillenbourg, Prof. Francesco Mondada Funding: Swiss National Science Foundation (SNSF) - NCCR robotics
Sep 08 – Mar 10	M.A. in Media and Communication, University of Augsburg Thesis: *Social Network Analysis of the STELLAR Scientific Research Network* Advisors: Prof. Gabi Reinmann, Prof. Klaus Bredl, Dr. Nina Rebele Funding: 7th EU Framework Programme - STELLAR European Network of Excellence
Sep 05 – Sep 08	B.A. in Media and Communication, University of Augsburg Thesis: *Searching for Scientific Resources – Information Literacy among Students* Advisors: Prof. Gabi Reinmann, Prof. Christiane Eilders Funding: German Research Foundation (DFG) - project i-literacy

EXPERIENCE & INTERNSHIPS

Sep 10 – Aug 14	Research Assistant, Ecole Polytechnique Fédérale de Lausanne (EPFL) Computer-Human Interaction in Learning and Instruction Lab (CHILI) Employment: full time, fixed term 4 years
Aug 08 – Aug 10	Intern international project / event management, Rehm race days GmbH Motorcycle trainings and events on circuits in whole Europe Employment: part- and full time internship, 2 years
Oct 07 – Jan 10	PR-assistant / student intern, candid communications GmbH Public relations and communication service agency Employment: part-time (freelance), 2 years 4 months
Mar 07 – Sep 07	Market research assistant / student intern, Verlagsgruppe Weltbild GmbH Publisher and book / media retailer Employment: part-time, fixed term 6 months

PUBLICATIONS & INVITED TALKS

Books and Book Chapters

[B2] **J. Fink**, "Soziale Netzwerkanalyse im EU-Exzellenznetzwerk STELLAR: Beschreibung einer Forscher-Community," AV Akademikerverlag, 2012 [German]

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Journal Articles

[J5] **J. Fink**, S. Lemaignan, C. Braboszcz and P. Dillenbourg, "Dynamics of Anthropomorphism in Human-Robot Interaction," frontiers research topic: The Uncanny Valley and Beyond, M. Cheetham, A. P. Saygin (Eds.), 2014 *(accepted for publication)*

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[J2] **J. Fink**, V. Bauwens, F. Kaplan, and P. Dillenbourg, "Living with a Vacuum Cleaning Robot," International Journal of Social Robotics, vol. 5, no. 3, pp. 389–408, 2013

[J1] V. Bauwens and **J. Fink**, "Will your Household Adopt your new Robot?," interactions, vol. 19, no. 2, pp. 60–64, Mar. 2012

Peer Reviewed Conference Papers

[C7] S. Lemaignan, **J. Fink**, and P. Dillenbourg, "The Dynamics of Anthropomorphism in Robotics," Late Breaking Report at the 9th ACM / IEEE International Conference on Human-Robot Interaction (HRI), 2014, Bielefeld, Germany ***(Best Late Breaking Report Award)***

[C6] **J. Fink**, P. Rétornaz, F. Vaussard, A. Berthoud, F. Wille, K. Franinović, S. Lemaignan, F. Mondada, P. Dillenbourg, "Which Robot Behavior Can Motivate Children to Tidy up Their Toys? Design and Evaluation of "Ranger"," in 9th ACM / IEEE International Conference on Human-Robot Interaction (HRI), 2014, Bielefeld, Germany

[C5] **J. Fink**, "Anthropomorphism and Human Likeness in the Design of Robots and Human-Robot Interaction," in Social Robotics (ICSR), S. S. Ge, O. Khatib, J.-J. Cabibihan, R. Simmons, and M.-A. Williams (Eds.), Springer Berlin Heidelberg, 2012, pp. 199–208

[C4] S. Bonardi, J. Blatter, **J. Fink**, R. Moeckel, P. Jermann, P. Dillenbourg, and A. Jan Ijspeert, "Design and evaluation of a graphical iPad application for arranging adaptive furniture," 21st IEEE International Symposium on Robots and Human Interactive Communications (RO-MAN), 2012, Paris, France, pp. 290 –297

[C3] **J. Fink**, O. Mubin, F. Kaplan, and P. Dillenbourg, "Anthropomorphic language in online forums about Roomba, AIBO and the iPad," in IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO), 2012, Munich, Germany, pp. 54 –59

[C2] F. Riedo, **J. Fink**, M. Freire, and F. Mondada, "Analysis of Impact of an Annual Robotics Festival," in IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO), 2012, Munich, Germany, pp. 30–35

[C1] **J. Fink**, V. Bauwens, O. Mubin, F. Kaplan, and P. Dillenbourg, "People's Perception of Domestic Service Robots: Same Household, Same Opinion?," in Social Robotics (ICSR), vol. 7072, B. Mutlu, C. Bartneck, J. Ham, V. Evers, and T. Kanda (Eds.), Springer Berlin Heidelberg, 2011, pp. 204–213

Posters

[P8] "Unexpected Robot Behavior in Child-Robot-Interactions", 3rd Site Visit of the NCCR robotics, 20-22 November 2013, Lausanne, Switzerland

[P7] "Motivating Children to Tidy up their Toys with a Robotic Box", 8th International Conference on Human-Robot Interaction (HRI), 3-6 March 2013, Tokyo, Japan

[P6] "How Children Tidy up their Room with "Ranger" the Robotic Box",

[P5] "Scientific Challenges to Make RObjects a Reality",

[P4] "Roombots: Modular Robots for Everyday Environments", and

[P3] "Co-Writer: Learning to Write with a Robot", 2nd Site Visit of the NCCR robotics, 24-26 October 2012, Zurich, Switzerland
[P2] "Roomba is not a Robot; AIBO is still Alive!", 3rd International Conference on Social Robotics (ICSR), 24-25 November 2011, Amsterdam, The Netherlands
[P1] "HRI in the home: A Longitudinal Ethnographic Study with Roomba", 1st Symposium of the NCCR robotics, 16 June 2011, Zurich, Switzerland

Technical Reports

[T4] NCCR Robotics Report 2013, Swiss National Centre of Competence in Research, Active Environment Scenario, Sub-project 5.1: Interaction Analysis, pp. 68-71
[T3] NCCR Robotics Report 2012, Swiss National Centre of Competence in Research, Sub-project 5.1: Interaction Analysis, pp. 72-73
[T2] NCCR Robotics First Annual Report 2011, Swiss National Centre of Competence in Research, Sub-project 5.1: Interaction Analysis, pp. 58-59
[T1] N. Heinze, J. Fink, and S. Wolf, Informationskompetenz und wissenschaftliches Arbeiten, Arbeitsbericht Nr. 21, Augsburg: Universität Augsburg, Medienpädagogik, 2009

Workshop Contributions & Presentations & Invited Talks

- "Ranger, an Example of Integration of Robotics into the Home Ecosystem", paper and presentation at Workshop and Summer School on Medical and Service Robotics (MESROB), 10-12 July 2014, Lausanne, Switzerland
- "The Dynamics of Anthropomorphism and its Cognitive Correlates", paper and presentation at Workshop: HRI - a Bridge between Neuroscience and Robotics, 9th International Conference on Human-Robot Interaction (HRI), 3 March 2014, Bielefeld, Germany
- "Unexpected robot behavior in child-robot interaction: A study with 4-5 year old children playing domino with the Ranger robotic toy box", presentation at the Institute de Psychologie du Travail et des Organisations (IPTO), 20 February 2014, Université de Neuchâtel, Switzerland
- "Motivating Children to Tidy up Their Toys with a Robotic Box", presentation at Workshop HRI Pioneers, 8th International Conference on Human-Robot Interaction (HRI), 3 March 2013, Tokyo, Japan
- "Human-Robot Interaction Analysis", presentation at NCCR robotics annual retreat, 12-13 June 2012, Villars-sur-Ollon, Switzerland
- "7 Steps to Ensure Roomba's Adoption", presentation at Workshop "Robots for Life –Project on RObjects for Kids", 19 December 2011, ZHdK, Zurich, Switzerland
- "Robots for Homes & Interaction Analysis", presentation at NCCR robotics 1st Site Visit, 8-9 November 2011, EPFL, Lausanne, Switzerland
- "Human-Robot Interaction Analysis in Domestic Environments", presentation at Workshop "Robots for Daily Life", NCCR robotics, 26 September 2011, EPFL, Lausanne, Switzerland
- "A Robot at Home? People's Perception of a Domestic Service Robot", invited talk at International Workshop on Bridging the Robotics Gap, 11-12 July 2011, University of Twente, The Netherlands
- "Characteristics of a Technology-Enhanced Learning Community – A Social Network Analysis in STELLAR European Network of Excellence", paper and presentation at 7th International Conference on Applications of Social Network Analysis (ASNA), 16-17 September 2010, ETH Zurich, Switzerland

OTHER ACADEMIC ACTIVITIES

Reviewer

- Frontiers in Psychology, Cognitive Science Research Topic, "The Uncanny Valley Hypothesis and Beyond", 2014
- International Journal of Social Robotics, Springer
- ACM International Conference on Human Factors in Computing Systems / Human-Computer Interaction (CHI), 2014
- ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2014

- International Conference on Social Robotics (ICSR), 2013
- IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO), 2012

Academic & Public Events

- Festival de Robotique 2011 / 2012 / 2013, EPFL, Lausanne, Switzerland
- SINDEX (Schweizer Messe für Technologie), NCCR robotics, 4-6 Sep 2012, Bern, Switzerland
- Innorobo / Robolift conference, 2011 / 2012, Lyon, France
- Conference student helper eMOOCS 2014, EPFL, Lausanne, Switzerland
- Conference student helper HRI 2011, EPFL, Lausanne, Switzerland

Teaching and Supervision

- Co-supervision for bachelor and master student projects, EPFL, fall 2011 / fall 2012
- Teaching Assistant, School of Computer and Communication Science (IC), EPFL, 2010 – 2014

Press Coverage of Scientific Work

- Interview for "Science Update" podcast, American Association for the Advancement of Science (AAAS), Mar 2014
- Newspaper article in "Le Matin Dimanche", "Roomba, le robot aspirateur, ne réconcilie pas les couples", Jun 2013
- Newspaper article in "Le Temps", "L'ethnographie, un outil à exploiter pour analyser les besoins des clients", Apr 2012
- Interview for Swiss-German TV channel 1 (SF1), reportage "Kassensturz", Mar 2012
- Interview for Swiss-French TV channel 1 (tsr1), reportage "A bon entendeur", Jan 2012
- Newspaper article in "Le Matin", "Les aspirobots ne séduisent pas les Suisses", Dec 2011

Honors & Awards

- Best Late Breaking Paper Award, HRI conference in Bielefeld, Germany, Mar 2014
- Participant and selected speaker at the "HRI pioneers workshop" in Tokyo, Japan, Mar 2013
- Nomination "Gerhard-Lustig-Prize" for best thesis in Information Sciences, 2009
- Finalist "Pall Mall Foundation Initiative" for job training in the U.S., 2008
- Winner "Crazy People Casting" Augsburg, 2005

Scientific Communities & Organizations

- Student member IEEE, since 2012
- Member NCCR robotics, Swiss research network, since 2010
- Student representative "Media and Communication", 2008 – 2009
- Author at "AV Akademikerverlag", scientific publications / literature, 2009 / 2012
- Author at "w.e.b.Square", online magazine for students, 2007 – 2010

SKILLS & TOOLS

Operating Systems

Mac OS, Windows, Linux (Ubuntu)

Software and Tools

MS Office Tools, LaTex, ELAN, SPSS, R, WordPress, Typo3, convento

Empirical research / Methods / Data analysis

Ethnography, field studies, lab experiments, surveys, interviews, focus groups, content analyses, qualitative and quantitative data analysis, grounded theory, statistics, reviews

User-centered design / Participatory design

Usability studies, eye-tracking, social network analysis, user experience, interaction analysis

Web competencies / Online media

Social media, social networks, web design, web search

Communication / Public Relations
Corporate identity, communication strategy, monitoring, press coverage, media planning, editing, writing, ghostwriting, reportages, speech writing, marketing services, contact management, contact database maintenance

Information / Management
Information literacy, knowledge management, content management, data administration, archiving, reporting, documentation, structuring business processes

Organization / Services
Press conferences, events, support for clients / customers, acquisition of clients, translations

Social skills
Working in a multi-cultural and -disciplinary team, social / emotional intelligence, social networking, listen and understand, teach & learn, mentoring, coaching, team-building, leadership

LANGUAGES

German	native speaker
English	full professional proficiency (10 years formal training, 4 years professional use)
French	professional working proficiency (5 years formal training, 4 years daily life use)
Italian	limited working proficiency (1 year of formal training, A1-2 certificate)
Spanish	elementary proficiency (6 months formal training)
Russian	elementary proficiency (2 years formal training)

VOLUNTEER EXPERIENCE

- Volunteer at sport events of the city of Lausanne (VSL), 2011 / 2012
- Assistant at the school counselor's bureau at my previous German high school, 2005 – 2009
- Summer work at activity camps with children with and without disabilities

BEYOND WORK

Sports	Running; outdoors activities in the mountains (member Alpine Association South Tyrol); basketball (active player for 4 years)
Music	Vocals: singer in a pop/rock band for 4 years, song writing, concert & stage experience; guitar; violin
Arts & Design	Writing (poetry, essays); drawing; tinkering with wood; furniture design & construction; interiors
Personality	ambitious, communicative, creative, diligent, future-oriented, humorous, motivated, multi-faceted, natural, open-minded, positive, reliable

Lausanne, August 2014