Child–Robot Interaction in Education

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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The medium is the message.
—Marshall McLuhan

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ABSTRACT

Advances in the field of robotics in recent years have enabled the deployment of robots in a multitude of settings, and it is predicted that this will continue to increase, leading to a profound impact on society in the future. This thesis takes its starting point in educational robots; specifically the kind of robots that are designed to interact socially with children. Such robots are often modeled on humans, and made to express and/or perceive emotions, for the purpose of creating some social or emotional attachment in children. This thesis presents a research effort in which an empathic robotic tutor was developed and studied in a school setting, focusing on children's interactions with the robot over time and across different educational scenarios. With support from the Responsible Research and Innovation Framework, this thesis furthermore sheds light on ethical dilemmas and the social desirability of implementing robots in future classrooms, seen from the eyes of teachers and students. The thesis concludes that children willingly follow instructions from a robotic tutor, and they may also develop a sense of connection with robots, treating them as social actors. However, children's interactions with robots often break down in unconstrained classroom settings when expectations go unmet, making the potential gain of robots in education questionable. From an ethical perspective, there are many open questions regarding stakeholders' concerns on matters of privacy, roles and responsibility, as well as unintended consequences. These issues need to be dealt with when attempting to implement autonomous robots in education on a larger scale.

Keywords: child–robot interaction, education, robotics, ethics, responsible research and innovation, stakeholders

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Sammanfattning på svenska

Framsteg inom robottekniken de senaste åren har möjliggjort användandet av robotar inom ett antal olika områden i samhället. Ett utmärkande exempel som studeras i denna avhandling är användningen av robotar för sociala ändamål, nämligen robotar som kan undervisa och interagera med barn i skolan. Syftet med denna avhandling är att utforska och diskutera hur användandet av sådana robotar kan te sig i skolan, dels genom att studera hur barn i mellanstadiet interagerar med denna typ av robotar i en skolmiljö, och dels genom att undersöka lärares och elevers etiska och normativa perspektiv på framtida användning av robotar i skolan.

I avhandlingen presenteras resultatet från sex olika forskningsstudier, där de första tre studerar hur barn på en svensk grundskola interagerar med en humanoid robot utvecklad inom ett tre-årigt EU-projekt. I ett första experiment analyseras hur barnen reagerar på instruktioner som ges av roboten eller av en lärare. Resultatet visar att barnen är villiga att följa instruktioner från roboten, men till skillnad från i interaktionen med läraren, söker de inte hjälp från den. Den andra och tredje studien genomförs inom ramen för en tremånaders fältstudie, där barnens reaktioner på robotens sociala kommunikation, respektive hur och varför interaktionen misslyckas, analyseras. Resultatet från den andra studien visar att barnen besvarar robotens sociala kommunikation som om roboten var en social aktör, men detta minskar något över tid. I den tredje studien framgår det att interaktionen med roboten ofta misslyckas när roboten inte lyckas interagera på ett konsekvent och för barnen meningsfullt sätt.

I de andra tre studierna som presenteras i avhandlingen genomförs intervjuer med lärare, enkätundersökningar med elever, och slutligen fokusgrupper med lärare i Sverige, Storbritannien och England. Resultaten visar att lärare och elever ser ett flertal utmaningar kring användandet av robotar i skolan, såsom hur barns integritet kan säkerställas, hur barn kan påverkas av interaktion med robotar på sikt, samt vem som kan tänkas bära ansvaret för robotar i skolan, inte bara i relation till vad som sker i klassrummet, utan även i händelse av att oförutsedda och negativa konsekvenser inträffar av dess användning. Dessa etiska utmaningar bör hanteras innan robotar kan ses som en möjlig teknologi i skolan.

List of papers

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Serholt, S., Basedow, C., Barendregt, W., & Obaid, M. Comparing a humanoid tutor to a human tutor delivering an instructional task to children. In *Proceedings of the 14th IEEE/RAS International Conference on Humanoid Robots* 2014; 1134–1141.

II. Serholt, S., & Barendregt, W. Robots tutoring children: Longitudinal evaluation of social engagement in child–robot interaction. In *Proceedings of the 9th Nordic Conference on Human–Computer Interaction* 2016.

III. Serholt, S. Breakdowns in children's interactions with a robotic tutor: A longitudinal study. Submitted to an international journal 2017.

IV. Serholt, S., Barendregt, W., Leite, I., Hastie, H., Jones, A., Paiva, A., Vasalou, A., & Castellano, G. Teachers' views on the use of empathic robotic tutors in the classroom. In *Proceedings of the 23rd IEEE International Symposium on Robot and Human Interactive Communication* 2014; 955–960.

V. Serholt, S., Barendregt, W., Küster, D., Jones, A., Alves-Oliveira, P., & Paiva, A. Students' normative perspectives on classroom robots. In J. Seibt, M. Nørskov & S. Schack Andersen (Eds.), *What Social Robots Can and Should Do: Proceedings of Robophilosophy/TRANSOR* 2016; 240–251, IOS Press.

VI. Serholt, S., Barendregt, W., Vasalou, A., Alves-Oliveira, P., Jones, A., Petisca, S., & Paiva, A. The case of classroom robots: Teachers' deliberations on the ethical tensions. *AI & Society: Journal of Knowledge, Culture and Communication* 2016; 1–19.

Additional publications

Serholt, S., Barendregt, W., Ribeiro, T., Castellano, G., Paiva, A., Kappas, A., Aylett, R., & Nabais, F. EMOTE: Embodied-perceptive tutors for empathy-based learning in a game environment. In *Proceedings of the 7th European Conference on Games Based Learning* 2013; 790–792.

Serholt, S., & Barendregt, W. Students' attitudes towards the possible future of social robots in education. Paper presented at the 23rd IEEE International Symposium on Robot and Human Interactive Communication 2014: Workshop on Philosophical Perspectives of HRI.

Barendregt, W., & Serholt, S. Evaluation of an empathic robotic tutor for geography and sustainability learning. Paper presented at the 7th International Conference on Social Robotics 2015: First Workshop on Evaluating Child–Robot Interaction.

Jones, A., Küster, D., Basedow, C., Alves-Oliveira, P., Serholt, S., Hastie, H., Corrigan, L. J., Barendregt, W., Kappas, A., Paiva, A., & Castellano, G. Empathic Robotic Tutors for Personalised Learning: A Multidisciplinary Approach. In *Proceedings of the 7th International Conference on Social Robotics* 2015; 285–295.

Hall, L., Hume, C., Tazzyman, S., Deshmukh, A., Janarthanam, S., Hastie, H., Aylett, R., Castellano, G., Papadopoulos, F., Jones, A., Corrigan, L., Paiva, A., Alves-Oliveira, P., Ribeiro, T., Barendregt, W., Serholt, S., & Kappas, A. Map Reading with an Empathic Robot Tutor. Extended abstract presented at the 11th ACM/IEEE International Conference on Human–Robot Interaction 2016.

Ljungblad, S., Serholt, S., Barendregt, W., Lindgren, P., Obaid, M. Are We Really Addressing the Human in Human–Robot Interaction? Adopting the Phenomenologically-Situated Paradigm. In J. Seibt, M. Nørskov & S. Schack Andersen (Eds.), What *Social Robots Can and Should Do: Proceedings of Robophilosophy/TRANSOR* 2016; 99–103, IOS Press.

Distribution of work

The following people and institutions contributed to the publication of work undertaken as part of this thesis:

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Author details and their roles:

Paper I
Comparing a humanoid tutor to a human tutor delivering an instructional task to children
As the primary author, I planned the study and conducted the empirical work. Along with Authors 1 and 8, I modified an existing questionnaire, which I then translated to Swedish. Author 8 conducted the video and statistical analysis under my guidance. All authors co-wrote the manuscript. Authors 8 and 9 presented the work at an academic conference.

Paper II

Robots tutoring children: Longitudinal evaluation of social engagement in child–robot interaction

I was the primary author and I formulated the idea, empirical work, its formalization and development. Video analysis was conducted jointly by myself and Author 1. Author 1 assisted with refinement and presentation. I presented the work at an academic conference.

Paper III

Breakdowns in children's interactions with a robotic tutor: A longitudinal study

I was the sole author and conducted all the work.

Paper IV

Teachers' views on the use of empathic robotic tutors in the classroom

As the primary author, I planned and led the study. I conducted the interviews in Sweden along with Author 1, whereas Authors 2, 3, 4, and 7 conducted interviews in Portugal, Scotland, and England, respectively. Each author transcribed their own interviews, and thematic analysis was conducted jointly. All authors co-wrote the manuscript. I presented the work at an academic conference.

Paper V

Students' normative perspectives on classroom robots

As the primary author, I planned and led the study. I devised the questionnaire in English and Swedish with assistance from Author 1, while Author 10 translated the questionnaire to Portuguese. Authors 4 and 10 conducted the empirical work in England and Portugal, respectively, while Author 1 and I carried out the empirical work in Sweden. I conducted the analysis in consultation with Author 12. I took the lead on writing the manuscript with assistance from the other authors. I presented the work at an academic conference.

Paper VI

The case of classroom robots: Teachers' deliberations on the ethical tensions

I was the primary author, and with Authors 1 and 7 led the work. Authors 10 and 11 conducted the empirical work in Portugal, transcribed and translated audio recordings to English, and provided written summaries. Authors 7 and 4 conducted the empirical work in England, provided written summaries, while I transcribed the audio. Author 1 and I carried out the empirical work in Sweden, which I transcribed. I conducted the thematic analysis in consultation with the other authors. The manuscript was written primarily by myself with support from mainly Author 7.

Preface and acknowledgments

When I began this research journey over four years ago, I barely knew what a robot was. At the time, I had just recently acquired my teaching degree, and although one of my majoring subjects was in Learning and IT, social robots in education sounded almost like science fiction to me. I am sure that many can relate to this. Currently, the really intelligent and advanced 'robots' are mostly invisible, hiding out online, providing the services that we do not (know that we) want. Nevertheless, technical developments are growing exponentially, and it is likely that society will face increasingly more advanced physical robots, as well; robots that not only mow your lawn, assemble your car, or vacuum your living room floor, but that interact socially and emotionally with you on a human level. With this thesis, I provide a glimpse into this possible future, and leave it for you to take it from there.

This thesis would not be what it is without the tremendous support from the people around me. First and foremost, I am very thankful for my supervisors. Wolmet Barendregt, who has been my colleague, inspiration, critic, and friend over these past four years. It has been an adventure to say the least, and I am looking forward to future ones. Thank you for believing in me. Johan Lundin, my primary supervisor and boss. Your analytical expertise, solid leadership skills, as well as your ability to instill calm in some of the most stressful situations, have helped me enormously during my research process. I appreciate your never-ending support and sense of humor.

Further, I express my gratitude to the students and teachers who took part in my studies, as well as the parents, school leaders and staff who enabled the studies to take place. Also, I thank everyone in the EMOTE project, particularly the people part of the technical team who I worked closely with during the project. Not to mention all my co-authors. It has been an honor to work with such excellent people.

I would also like to thank all of my colleagues at the Department of Applied IT at the University of Gothenburg, especially all the people at the division for Learning, Communication and IT for brightening my time at the department, as well as everyone in the MUL group for giving me feedback on some earlier paper drafts.

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Table of contents

1 Introduction

Advances in the field of robotics in recent years have enabled the deployment of robots in a multitude of settings, ranging from industry, space exploration, and military, to elder care (Gallagher, Nåden, & Karterud, 2016), domestic life (Frennert, 2016), and education (Benitti, 2012; Mubin, Stevens, Shahid, Mahmud, & Dong, 2013). Between the years of 2014 and 2015, robot sales increased by 25% in areas of professional service, and 16% for personal service (i.e., robots for entertainment, assistance, or domestic tasks), indicating a rising trend (IFR International Federation of Robotics, 2016). IFR predicts that approximately 3 million robots will be sold for educational and research purposes between the years 2016 and 2019. These developments are thought to lead to a profound impact on society, where robots "eventually pervade all areas of activity, from education and healthcare to environmental monitoring and medicine. The broad spread of the future impact of robotics technology should not be underestimated" (euRobotics, 2013, p. 27).

My work for this thesis takes its starting point in educational robots; specifically the kind of robots that are designed to interact socially with children. Such robots can take different forms and functions, and are often designed with specific capabilities for one or more delimited tasks. They are typically made to appear either animal- (zoomorphic) or human-like (humanoid), which is a design choice that capitalizes on the human tendency to attribute human emotional and cognitive characteristics to inanimate objects or animals, and subsequently respond as though such objects act in a rational human manner (also known as *anthropomorphism*[1]) (Duffy, 2003). Such robots may interact with children orally or physically. They can be made to behave, produce gestures, or move about in a certain manner to resemble animals or humans (Duffy, 2003), and they are sometimes made to exhibit and/or express artificial emotions for the purpose of creating some social or emotional attachment in people (Fong, Nourbakhsh, & Dautenhahn, 2003). As my research was carried out as part of the EU-funded research and development project EMOTE (short for *Embodied perceptive tutors for* *empathy based learning*), working on the design and evaluation of educational robots, I focus on the kind of robot studied there, namely humanoid (empathic) robotic tutors.

While robotic tutors mainly feature in research currently, it is likely that they will eventually move out of the research laboratories and into actual classrooms. Indeed, the EMOTE project, which I was a part of, is only one of several EU-funded projects that study robotic tutoring; among others are EASEL[2] and L2TOR[3]. In the US, research initiatives have been carried out by, e.g., different researchers in the Personal Robots Group[4] at MIT Media Lab (cf. Gordon et al., 2016; Leyzberg, Spaulding, & Scassellati, 2014). In Asia, robots have a somewhat longer tradition (Kanda, Hirano, Eaton, & Ishiguro, 2004), where so-called robot-based learning systems have already been implemented in Korean classrooms (KIST).

A robotic tutor is not a technology that children are supposed to interact with others *through*, like a mobile phone, but a technology that they are supposed to interact *with* (Höflich, 2013; van Oost & Reed, 2011; Zhao, 2006). Thus, it is important to study how children interact with this new technology, and what happens when robotic tutors are implemented in education. Such studies cannot be limited to short-term studies, due to possible novelty effects, i.e., "the first responses to a technology, not the patterns of usage that will persist over time as the product ceases to be new" (Sung, Christensen, & Grinter, 2009). However, research in this area is relatively limited as of yet; only a few studies have been carried out using social robots in actual schools (c.f. Gordon et al., 2016; Kanda, Sato, Saiwaki, & Ishiguro, 2007; Kory Westlund et al., 2016; Tanaka & Matsuzoe, 2012). This can partly be explained by the difficulties inherent in conducting long-term studies with robots in naturalistic environments (Ros et al., 2011), since such studies require much work and preparation developing the robot's interactive capabilities, as well as the tasks that the robot is supposed to carry out. Notwithstanding, interactions with robots are highly influenced by the social context in which they take place (Šabanović, 2010; Severinson-Eklundh, Green, & Hüttenrauch, 2003), which means that laboratory studies likely only partly reflect how children would interact with robots in natural school settings.

Furthermore, when new technologies are brought into education, this affects not only how children interact and learn, but also the educational environment as a whole (Levine, 1999). While robotic tutors are thought to present a number of possibilities, such as to personalize education to individual students' needs (Leyzberg et al., 2014), support learning (Kory Westlund et al., 2017), and alleviate teachers' workload (Movellan, Tanaka, Fortenberry, & Aisaka, 2005), they may (like any technology) also bring about limitations and unintended consequences (Cuban, 2003; Selwyn, 2016), and thus, be met with public resistance. As indicated by a European survey conducted in 2012, the general public is concerned about the educational use of robots, where 34% responded that robots should be banned from education altogether (European Commission, 2012). In recent years, it has been emphasized that researchers need to be vigilant concerning technological innovations, and how they are designed and implemented in various social practices. There may, e.g., be ethical issues that need to be addressed (Sharkey & Sharkey, 2011; Sharkey, 2016). In essence, the design and development of robots should be guided not only by what is possible to accomplish with technology, but also informed by the needs and visions of the people who are affected by them (Taipale, Vincent, Sapio, Lugano, & Fortunati, 2015). To do so, stakeholders need to be involved in determining the social desirability (Eden, Jirotka, & Stahl, 2013), and possible applications for future innovations (Schomberg, 2007). Do stakeholders want robotic tutors to be implemented in education? And if so, how and why (not)?

1.1 Research aims

This thesis is about exploring an up-and-coming technology aimed for education. My research relates to the field of study known as Child–Robot Interaction (CRI), where I focus my efforts towards two objects of study. The first objective is about exploring how children interact with a humanoid robot in a tutoring role, performing a variety of activities with them, in their actual school setting, over time. Here, it is important to point out that this does not imply that I focus on learning and/or learning effects per se. Rather, I am concerned with possible *preconditions* for the educational use of robots in specific *roles* within the educational context. The second objective is about looking ahead towards future possible applications of robotic tutors, and exploring how a selection of educational stakeholders (teachers and students) view these possibilities from a normative and ethical perspective. My goal is to bring these two aspects of CRI together into a guiding discussion on the current and future implications facing the educational use of robots in social roles.

The following research questions thus guide this work:

RQ 1. How do children interact with a humanoid robotic tutor in a school setting, and what implications does this pose for the educational use of robots?

RQ 2. How do teachers and students view the possible implementation of robots in future classrooms in relation to educational practices and ethical tensions?

First, taking the humanoid robot featured in the EMOTE project as a starting point, I take a critical look at children's interactions with robots in authentic school settings. Specifically, three studies are conducted: the first explores how children respond to tedious instructions conveyed by the robot, the second explores how children respond to the robot's attempts at social interaction, and the third focuses on when interactions between children and the robot break down.

Second, I seek to explore the anticipated effects and social desirability of educational robots by turning to stakeholders in education, namely teachers and students. To do so, I draw on the Responsible Research and Innovation (RRI) framework, which is concerned with engaging stakeholders in ethical deliberations, assessments of social desirability and unintended consequences of future innovations in a given field (Eden et al., 2013; Owen, Bessant, & Heintz, 2013; Schomberg, 2007). Here, three studies are conducted as well. The first study focuses on teachers' needs and expectations for educational robots, the second examines students' normative perspectives on what robots should and should not be able to do in education, and the third explores practicing and training teachers' deliberations on the ethical tensions associated with having robots in future classrooms.

1.2 Thesis disposition

This thesis comprises eight chapters and six appended papers. In the first chapter, the area of research is introduced, and the research aims are specified. Chapter 2 describes in more detail what robots are, discusses various features of robots, and provides a background to different applications for robots in education. In Chapter 3, previous research related to the research questions is presented, along with considered research perspectives. Chapter 4 provides a description of the EMOTE project in which the research was conducted, as well as a description of the designed tasks and the robot employed in the studies. Chapter 5 describes the methods used to address the research questions, while Chapter 6 presents the main results of the six research studies. The research findings are then discussed in Chapter 7, along with considerations on methodology and future work in this field. Finally, conclusions are presented in Chapter 8.

Notes

[1] The term *anthropomorphism* derives from the Greek words *anthropos* (meaning "man" or "human") and *morphe* (meaning "form", "structure", or "shape") (Duffy, 2003; Epley, Waytz, & Cacioppo, 2007). It can be defined as the human tendency to ascribe human mental, or emotional states to animals, robots or other objects, in order to rationalize the behaviors of nonhuman entities within a social environment (Duffy, 2003, p. 180). Epley et al. (2007) suggest that anthropomorphism is a process of induction, which starts "with highly accessible knowledge structures as an anchor or inductive base that may be subsequently corrected and applied to a nonhuman target" (p. 865). Put simply, when people are faced with an entity, such as a robot, whose underlying mechanisms are unknown to them, they will understand its behaviors based on their knowledge of emotional or mental states in themselves or other human beings (Breazeal, 2003).

[2] http://easel.upf.edu/

[3] http://www.l2tor.eu/

[4] http://robotic.media.mit.edu/

2 Defining robots

Before moving further, it is necessary to establish what is meant by robots in this thesis. Robots are currently not in a state of innovation where they are ubiquitous in public spaces (at least not in Europe), which makes *what robots really are*, somewhat ambiguous. Although the term *robot* could refer to a number of things ranging from a decision-making software program to a fully autonomous physical robot, this thesis deals with robots more closely related to the latter. My research interests lie in the distinguishable aspects of such robots, namely that they possess a physical 'body', social interactive capabilities, and some level of Artificial Intelligence (AI) that enables them to act 'on their own'. This chapter details these different aspects, after which a section on different applications for robots in education is presented. Here, applications for robots are approached from a perspective where the digitalization of education plays an important role in shaping how robots are understood to be applied in educational settings.

2.1 Embodiment

Robots can be given a variety of different appearances (or embodiments). They can look mechanical, as is typically the case in factory applications (although there are some exceptions, such as Baxter, which is designed with a virtual cartoonish face on a tablet in order to facilitate collaboration with humans[1]). Robots can also be designed to resemble animals or humans in more explicit ways. In this thesis, I am particularly interested humanlike embodiments, which are described in the following paragraphs.

A *humanoid* robot can be described as having a body resembling that of a human, usually having a head, two arms and two legs or wheels (see Figure 1)[2]. In

Figure 1. Humanoid robots from left to right: Pepper, NAO and Asimo

humanoids, features are sometimes exaggerated in such a way that the robot appears almost cartoon-like. This has also been referred to as the 'baby-scheme' (Rosenthal-von der Pütten & Krämer, 2014), with big heads and big eyes in relation to the rest of the body (see, e.g., Pepper above).

Androids are robots with biomimetic bodies, where those referred to as *geminoids* model the physical appearance of their creators (cf. Abildgaard & Scharfe, 2012). While androids are used for different purposes, geminoids are mainly used to study the social implications of human tele-presence as they are remotely controlled by their respective creator (see Figure 2)[3].

Duffy (2003) argues that robots should be designed in ways that facilitate anthropomorphism, but that it is important to avoid inducing unreasonable expectations in the robot's capabilities. The *uncanny valley effect* is a phenomenon that has concerned roboticists for a long time in regard to making robots look too

Figure 2. Androids and geminoids from left to right: Geminoid DK, HRP-4C, Otonaroid, HI-4

humanlike. The uncanny valley effect was first proposed by Mori (2012 [1970]) to describe an eerie sensation that some people experience when encountering artificial and unfamiliar objects, and has since become an important area of study in Human–Robot Interaction (HRI) (Mathur & Reichling, 2016; Rosenthal-von der Pütten & Krämer, 2014). If a robot's appearance is much more advanced than its behavior, as is the case with very human-looking androids that are equipped with relatively limited natural movement and intelligence, there is a risk that people feel uncomfortable around the robot.

The robot under study in this thesis is the torso only version of the NAO robot (described in detail in Chapter 4). Although NAO is not an android such that it can be mistaken for a human being, it is nevertheless possible that it can induce expectations that go unmet, particularly if children do not have any previous experience interacting with robots (Belpaeme et al., 2013).

2.2 Sociability

An important aspect when developing robots that are going to interact with people is that they not only look humanlike, but that they can interact on human terms (Krämer, Eimler, von der Pütten, & Payr, 2011; Krämer, von der Pütten, & Eimler, 2012). Social interaction with humans, including human forms of communication, emotion and social mechanisms (Duffy, 2003), is perhaps considered the most important feature for robots to become an everyday part of society. Such *social robots* "overlap in form and function with human beings to the extent that their locally controlled performances occupy social roles and fulfill relationships that are traditionally held by other humans" (Edwards, Edwards, Spence, Harris, & Gambino, 2016, p. 628).

From an educational perspective, several robot capabilities are thought to facilitate a positive interaction between children and robots, e.g., empathy (Castellano et al., 2013), non-verbal immediacy (Kennedy, Baxter, & Belpaeme, 2017), social support (Leite, Castellano, Pereira, Martinho, & Paiva, 2012), personalization (Gordon et al., 2016; Leyzberg et al., 2014), and various levels of social behaviors (Kennedy, Baxter, & Belpaeme, 2015b).

Breazeal (2003) is considered one of the pioneers in regard to how robots can be designed to appear social. Accordingly, she defines social robots to be "those that people apply a social model to in order to interact with and to understand" (Breazeal, 2003, p. 168). In that sense, a robot's sociability rests in the eyes of the beholder. If a person perceives that a robot is social, a social design has been accomplished. Nevertheless, Breazeal (2003) also argues that there are levels of complexity in robot design that successively increase the sociability of robots on an ontological level as well as people's perceptions of them as social entities, such that they are able to support this perception in increasingly complex environments. These are (in order from least to most social): *socially evocative, social interface, socially receptive,* and finally, *sociable.*

Socially evocative robots are those that "encourage people to anthropomorphize the technology in order to interact with it, but goes no further" (Breazeal, 2003, p. 169). That is to say that while it may seem like the robot is responsive, it is inherently unable to be receptive to the actions of a human. Toys, such as robotic pets, belong to this category. A *social interface* refers to robots that are designed to express themselves using human social mechanisms, such as natural speech and social cues. This is done to ease people's interactions with the robot, but the robot does not model (or understand) the human. *Socially receptive* robots are those that extend the social interface by actually becoming affected by what humans do. They may, e.g., be able to learn new tasks that a human teaches them. Finally, the *sociable* robot is the sort of robot that is able to do all of these aforementioned things, but it also has some goals of its own. It may be designed to have a need to engage with humans in order to benefit its own learning process, performance, or survival. "Such robots not only perceive human social cues, but at a deep level also model people in social and cognitive terms in order to interact with them" (Breazeal, 2003, p. 169).

The robot under study in this thesis can be described as being on what Breazeal (2003) refers to as a *social interface* level. It can speak and express itself through social mechanisms using gaze and gestures. It models the child to a certain extent within the bounds of the educational activity being conducted, as well as in terms of their affective states. However, it does not develop new strategies by studying the child—it merely makes selections from a pre-programmed strategy.

2.3 Autonomy

Dating back to 1956, AI research has always been concerned with replicating human intelligence in different ways (Dautenhahn, 2007). As Dr. Rodney Brooks, the director of the MIT Artificial Intelligence Lab, stated a decade ago: "The latent goal of artificial intelligence researchers has always been to build something as intelligent, as humanlike, as we are. They haven't always admitted that, but that's really what they've wanted to do"[4]. Sometimes, this intelligence can reside on a virtual level, whereas in other cases, it can be placed within a physical robot, in which case this intelligence affords a certain level of autonomy.

Beer, Fisk, and Rogers (2014) define a robot's autonomy as "the extent to which a robot can **sense** its environment, **plan** based on that environment, and **act** upon that environment with the intent of reaching some **task-specific goal** (either given to or created by the robot) without external **control**" (p. 77). On a general level, Löwgren and Stolterman (2004) refer to this as built-in *independence*, i.e., the extent to which a technology has its own goals or makes its own decisions.

In HRI experiments, it is common practice to simulate autonomy when the robot in question is not fully developed. This is accomplished through Wizard of Oz (WoZ) studies, i.e., where robots are fully or partially controlled by a human being, acting as the 'wizard behind the curtain' (Dautenhahn, 2007). During such experiments, participants are led to believe that the robot is operating on its own. Research suggests that when the appearance of the robot corresponds to its cognitive level during such simulations, children become socially engaged with robots (Okita, Ng-Thow-Hing, & Sarvadevabhatla, 2011), as well as interested in developing social relationships with them (Oh & Kim, 2010).

The ways in which robots are able to make autonomous decisions vary depending on the technical implementation. Some robots are hard-coded to respond in specific ways given specific circumstances (as is the case for the robot studied in this thesis), whereas others are developed according to machine learning methods (i.e., where the robot learns based on its experiences). It is likely that future robot developments will increasingly rely on machine learning, which raises ethical issues regarding who can assume responsibility for what robots actually learn, and what unforeseen consequences this may introduce (Asaro, 2007; Gill, 2008; Marino & Tamburrini, 2006; Matthias, 2004).

In the three studies exploring children's interactions with a robotic tutor in this thesis, the robot's autonomy was simulated in the first study (Paper I), whereas in the other two (Papers II and III), the robot operated fully on its own.

2.4 Robots in education

The use of robots in education can be understood as a development in a long history of technology use in education. Indeed, technology has long been thought to revolutionize education; that is, to fundamentally change how teaching and learning are carried out (Cuban, 2003; Selwyn, 2016). In Sweden, computer use in education has been a topic of discussion since the late 1960's (Riis, 2000). At this time, emphasis was placed on learning about the mechanics and functions of computers. About a decade later, in the 1980 primary school curriculum, the idea that computers should be used as pedagogical aids by teachers in other subjects was introduced (Riis, 2000). It was also at this time that emphasis was placed on students' learning about the implications of computer use for people and society (Riis, 2000).

Research on educational technology has tended to focus on ways in which technology can enhance the learning experience. Often, but not always, technology is seen as promising for the possibility of personalizing education to individual students (Selwyn, 2016), the motivation being that personalization accounts for students' learning differences (Bloom, 1984), fostering an environment in which students can progress through the learning content, as argued by Skinner, both thoroughly, and at their own pace (McRae, 2013). In a personalized learning environment, Cuban (2003) argues that teachers no longer feature as predominant figures in the classroom, teaching the same content to all students, but instead, take a step back and guide individual students' learning processes from the sidelines. This is thought to provide students with the opportunity to become more independent and self-directed learners, and these ideas have, according to Selwyn (2016), dominated the mainstream educational thinking for the past fifty years.

A variety of applications for robots in education have been proposed and studied. For example, robots have been used as tools in order to support learning in Science, Technology, Engineering, and Math (STEM). This area of use draws on

Papert's (1980) notion of constructionism, "which states that learning occurs when a student constructs a physical artefact and reflects on his/her problem solving experience based on the motivation to build the artefact" (Mubin et al., 2013, p. 4). Here, students may, e.g., program or assemble robots from scratch either individually or in groups (Denis & Hubert, 2001; Nugent, Barker, & Grandgenett, 2012; Vandevelde, Wyffels, Ciocci, Vanderborght, & Saldien, 2015). According to Benitti (2012), such use of robots still occurs mostly as part of extra-curricular activities, but most research on educational robotics is still within this particular domain of tool-use; i.e., closely related to teaching students the field of robotics rather than other subjects, similar to how the use of computers was understood in the late 1960's.

Robots have also begun to play a role in distance education. While virtual workspaces, video conferencing, virtual environments, etc., have constituted a considerable role in bringing learners and/or teachers together, robots are now being studied as a novel medium in doing this (known as *tele-presence robots*). Tele-presence robots can take the form referred to as 'Skype on wheels' where the face of the operator is displayed, but they can also be made to display a virtual face on top of a robot body (Yun et al., 2011), or they can be designed to look like a human person (as with *Geminoids*) (Abildgaard & Scharfe, 2012).

In classroom settings, various studies have been carried out to study how tele-presence robots can be used and for what purposes. For example, studies have been conducted to explore whether robots can be used to bring children from different countries together, as in an international correspondence effort (Kim, Han, & Ju, 2014; Tanaka, Takahashi, Matsuzoe, Tazawa, & Morita, 2013). Another application is to use tele-presence robots in order to bring specific children into the classroom when they are unable to participate in person due to, e.g., chronic illness (Tanaka, Takahashi, Matsuzoe, Tazawa, & Morita, 2014). There are also cases where teachers are the ones remotely controlling a robot in a classroom full of students. For example, in South Korea, where there is a lack of teachers able to teach English, a robot known as EngKey has been used by teachers in other countries to teach these classes (Yun, Kim, & Choi, 2013).

The final and most important form of application as far as this thesis is concerned, is formed by robots that feature in social roles; particularly robotic tutors. The concept of robotic tutors can be traced back to the old teaching machines, advocated for by the behaviorist theorist Skinner during the 1960's. Using a teaching machine, students studied a subject individually, and then answered a series of questions, and finally, received feedback on their efforts from the machine. From a behaviorist and reinforcement learning perspective, teaching machines were seen to profit students by providing instant feedback on the correctness of their answers, reducing the anxiety associated with uncertainty, and reinforcing them to answer correctly. Preferably, there was also some reward given upon successful completion of the activity (McRae, 2013).

Due to advances in technology, teaching machines have since then evolved into Intelligent Tutoring Systems (or ITS), which are computer software in the form of virtual learning environments, where students are offered individualized and personalized support by the system to achieve some learning task. Motivated by Vygotsky's (1978) theories on social constructivism, where students are thought to learn better under the guidance of a more proficient other (Mubin et al., 2013), some ITSs are designed to include virtual humanlike characters that can scaffold and support learners in more ways than through merely written prompts (Johnson, Rickel, & Lester, 2000). Finally, these virtual characters are now beginning to move off the computer screen, and enter the classroom in the form of robotic tutors that are able to engage with students in the physical world (Castellano et al., 2013; Leyzberg, Spaulding, Toneva, & Scassellati, 2012).

Notes

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[1] http://www.rethinkrobotics.com/baxter/
[2] Photo attributions: Pepper by kyu3; NAO by Stephen Chin; Asimo by Wikimedia Commons / CC BY
[3] Photo attributions: Geminoid DK by pressgirlk; HRP-4C by Taro; Otonaroid by Wikimedia Commons; HI-4 by nrkbeta / CC BY
[4] http://techtv.mit.edu/videos/524-kismet

3 Research perspectives and related work

This chapter presents the research perspectives taken in addressing the research questions of this thesis, as well as previous research related to them. The chapter contains two main parts, where the first relates to RQ1, and the second relates to RQ2.

3.1 Children's interactions with robotic tutors

In order to address my first research question, i.e., how children interact with a humanoid robotic tutor in a school setting, I focus on three distinct aspects of interaction with robotic tutors: instruction, social interaction, and breakdowns (i.e., situations when the interaction does not go as planned, and cannot be easily repaired by the interactants). This section begins by presenting previous research related to how people respond to instructions conveyed by robots, and how this compares to other means of conveying instructions. In the following subsection, mechanisms inherent in social communication are related to previous research about how humans respond and interact socially with robots. Finally, the concept of breakdowns is presented, and the lack of research in this area is problematized.

3.1.1 Following instructions

While experiments have been carried out to study if adults willingly follow tedious and/or uncomfortable instructions from a robot (Bartneck, Bleeker, Bun, Fens, & Riet, 2010; Geiskkovitch, Cormier, Seo, & Young, 2016), there are not many studies exploring how children respond to instructions delivered by a robot. For adults, Geiskkovitch et al. (2016) studied participants' willingness to follow instructions from a robot on a tedious task of renaming computer files using a number of different embodiments, including the same humanoid robot studied in this thesis (NAO), and a human experimenter. It was concluded from the experiment that the participants were more willing to comply with the human experimenter than with the robots, and they also protested to a lesser degree in the human condition.

Several studies have compared the use of robots against other media, such as virtual agents (Bainbridge, Hart, Kim, & Scassellati, 2011; Kidd, 2003; Leyzberg et al., 2012; Pereira, Martinho, Leite, & Paiva, 2008). For example, Leyzberg et al. (2012) compared robots against a set of different conditions including virtual agents, and found that the robot condition led to greater learning gains for participants. While the authors did not go into detail regarding the cause of these results, they suggested that the physical presence of the robot was likely influential (Leyzberg et al., 2012).

The aforementioned studies were all conducted with adults. However, Han, Jo, Jones, and Jo (2008) compared a robot designed to teach children English at home against books, audiotapes, and web-based instructions, and concluded that the robot condition facilitated children's interest, concentration, and learning outcome. Tanaka and Matsuzoe (2012) compared a teaching situation with a robot present with an experimenter during a word learning task, against a condition when no robot was present, and found that children recalled more words in the robot condition. However, children's responses to instructions as such, were not elaborated upon in the studies. As Sharkey (2016) argues, it is important to compare robots against more traditional teaching methods, such as human teachers, in order to determine their efficacy. Paper I of this thesis thus addresses this research gap by comparing children's compliance with tedious instructions across two conditions: a humanoid robotic tutor, and a human teacher.

Nevertheless, following the publication of Paper I, other studies have been carried out with children using a similar methodology although the research aims have differed. For example, Kennedy, Baxter, and Belpaeme (2015a) compared children's learning outcome when conducting a discovery learning task with either a humanoid robot (NAO) or a virtual representation of the same robot in a short-term study. The study found no significant differences between the two embodiments in terms of children's willingness to follow instructions, where the children complied with the robot's suggestions in 87% of the cases. In a later study, Kennedy, Baxter, Senft, and Belpaeme (2016) compared a humanoid robot (NAO) against a human tutor, and found that children learned more from the human, although the study did not explore how the children followed the different instructions. Finally, Kory Westlund et al. (2017) conducted a study that compared a zoomorphic robot with a human, teaching pre-school children names of unfamiliar animals. It was found from the study that children recalled the words equally well in both conditions; however, the authors did not explore instructions specifically.

3.1.2 Social interaction

As explained earlier in this thesis, many robots designed for children are designed in ways that draw on anthropomorphic ideas, not least within education (Mubin et al., 2013). The aim of such designs is to facilitate social interaction, and the formation of social relationships (Belpaeme et al., 2012), which is thought to have a positive impact on learning (Castellano et al., 2013). A precondition is therefore to study if and how children actually interact socially with robots. In this thesis, a specific focus is placed on how children respond verbally and non-verbally to a robotic tutor's social cues, and how these responses evolve over time.

It has been argued that "humans in their interactions with robots and agents will not stop to employ and expect the communicative mechanisms they are used to" (Krämer et al., 2011, p. 497). These communicative mechanisms may include such things as establishing eye-contact, and communicating through facial expressions, gestures, or speech. According to Argyle and Dean (1965) humans gaze intermittently into each other's eyes for short periods of 3 to 10 seconds during communication, and the duration of direct eye-contact tends to increase if two people like each other. In previous research, direct eye-contact with robots has often been measured and interpreted as a sign of engagement (Anzalone, Boucenna, Ivaldi, & Chetouani, 2015; Sidner, Lee, Kidd, Lesh, & Rich, 2005), which can also be coupled with positive facial expressions, such as smiling (Castellano, Pereira, Leite, Paiva, & McOwan, 2009; Tielman, Neerincx, Meyer, & Looije, 2014), and/or head nodding (Sidner et al., 2005). In a study by Okita et al. (2011), children made eye-contact with a robot when they were expressing interest and emotion, seeking attention and approval, or when they had a question. Yet, in this particular study, the robot was controlled remotely by a human, and was therefore substantially more socially responsive in its behavior than current autonomous robots are.

Additional social mechanisms, such as mirroring and/or adaptation to the pace of speaking and movement of a robot, can also be interpreted as signs of engagement. Between humans, Vacharkulksemsuk and Fredrickson (2012) found that pairs of strangers who showed more mirroring behaviors in self-disclosure-tasks, rated their social interaction more positively, mutually, and vitally. This may also hold for interactions between humans and robots. In terms of children's interactions with robots, children have, e.g., shown tendencies to adapt their physical movements to synchronize with a dancing robot (Ros et al., 2014), and they have also been shown to mirror facial expressions (Tielman et al., 2014).

The tendency to respond socially to robots, has been shown to exist even in such cases where participants have been informed that the robot does not perceive anything other than specific commands. For example, Sidner et al. (2005) observed that head nodding was a frequently occurring response among adults interacting with a robot although they were aware that the robot could not react to it. In regard to virtual agents, Krämer et al. (2012) found a similar tendency, where participants, e.g., addressed the agent by name, or comforted it when it did not understand, although they had been informed that the agent only understood specific orders that it had been trained to perceive.

All in all, the occurrences of the different communicative mechanisms detailed in the previous paragraphs are suggestive not only of humans' social responses to robots, but also that both adults and children can become socially engaged with robots. However, it seems to the be case that children become more engaged with robots that are operated remotely, due to their humanlike perception (Oh & Kim, 2010; Okita et al., 2011). An important aspect of remotely controlled robots is that the human operator is able to recall the whole interaction, as well as to adapt to children much more easily than autonomous robots can. This adaptation seems to be of particular importance in the formation of social relationships with robots. For example, when Kanda et al. (2004) equipped an educational robot with the ability to adapt to individual students by recalling previous interactions, this facilitated students' relationship formation with the robot and subsequently their learning outcome; however, how children responded to the robot was not explicitly investigated in the study. Taken together, while these studies provide some indications that children respond socially to robots, it is not certain whether such behavior would occur in traditional classroom settings where robotic tutors are aimed to feature autonomously, nor how it might develop over time. Paper II in this thesis addresses this research gap by exploring how children respond to social probes delivered by an autonomous robotic tutor, in a school setting, over three consecutive interaction sessions.

3.1.3 Breakdowns in interaction

Despite attempts to make robots social, they are restricted in social communication. As Belpaeme et al. (2013) concluded from several years of study in the field of CRI, problems and challenges surfaced that they had not expected when they started. These problems could be of a technical nature, e.g., that robots were limited in perceptive capabilities and therefore did not function well in unconstrained environments, or that robots had trouble selecting the right actions at the appropriate time. The authors proposed that researchers in CRI should make sure that participants do not hold unreasonable expectations of a robot's capability prior to implementation. At the same time, the authors argued that expectation setting mainly applies to the adults in care of the children interacting with a robot, since these aspects usually go undetected by the children themselves; children have a tendency to anthropomorphize robots and are therefore prone to believe that robots perceive more than they do (Belpaeme et al., 2013).

However, as Selwyn (2008) points out, it is problematic that research efforts surrounding state of the art-technology (such as robots) tend to emphasize the positive aspects of technology, and not focus explicitly on the problems, which risks leading to situations where unexplored issues surface only once a given technology is implemented in classrooms on a larger scale. While Belpaeme et al. (2013) are indeed bringing forth some noteworthy challenges facing the field of CRI in their paper, I would argue that each application for robots (in this case, robotic tutors in a school setting), needs to be rigorously evaluated in terms of the issues that children encounter, so that these can be explored more in-depth.

In the field of Human–Computer Interaction (HCI), breakdowns have been described as situations when a person's process of using a computer application becomes interrupted by something occurring within the application, e.g., if a tool behaves unexpectedly (Bødker, 1995). This disrupts the flow of the activity, and causes a shift in focus from the objectives, to something irrelevant. Suddenly, the person becomes aware of the tool itself rather than the task that he/she was initially doing (Urquijo, Scrivener, & Palmén, 1993). In some cases, and perhaps increasingly so in human communication, this can be resolved swiftly through repair strategies, in which case it can be regarded as temporary trouble (Jordan & Henderson, 1995; Plurkowski, Chu, & Vinkhuyzen, 2011). In other cases, the problems remain unresolved, leading to breakdowns and disengagement (Plurkowski et al., 2011).

Breakdowns have not been explicitly studied in the field of CRI; however, following a series of CRI experiments in a hospital pediatric department, Ros et al. (2011) pointed out that technical issues that typically occur in children's long-term interactions with robots can cause breakdowns in engagement. If, e.g., a robot falls over or malfunctions, they note that children can become quite upset. As Šabanović (2010) argues, studying how people interact with robots in real-world environments is important for revealing aspects related to faulty design assumptions about social interaction, as well as what robot and human actions lead to breakdowns. In Paper III in this thesis, I do so by studying breakdowns in children's interactions with a robotic tutor over time and across two different educational scenarios.

3.2 The social desirability of robots in education

In order to address my second research question, i.e., how teachers and students view the possible implementation of robots in future classrooms in relation to educational practices and ethical tensions, I adopt an RRI approach. This section begins by presenting the RRI approach, followed by a subsection devoted to previous research on stakeholders' expectations of robots and educational technology more broadly. Finally, the ethical issues surrounding robots and their use in education that this thesis focuses on, are presented.

3.2.1 Responsible Research and Innovation

RRI is a practice concerned with engaging stakeholders in ethical deliberations, assessments of social desirability and unintended consequences of future innovations in a given field. Here, it is the responsibility of researchers to pay attention to stakeholders' concerns, and report them, so that processes of innovation can be made transparent and responsive to societal needs (Owen, Bessant, et al., 2013; Schomberg, 2007). RRI is not restricted to a specific product design, but considers potential applications of future technologies not yet designed or developed (Eden et al., 2013).

In essence:

> "RRI entails **engaging all actors** (from individual researchers and innovators to institutions and governments) through inclusive, participatory methodologies in all stages of R&I processes and in all levels of R&I governance (from agenda setting, to design, implementation, and evaluation). This in turn will help R&I tackle societal challenges — like the seven Grand Challenges formulated by the EC — and align to values, needs and expectations of a wide public. This is not only ethically and societally worthwhile, but also produces better science, making research agendas more diverse and taking better account of real-world complexities" (RRI Tools Project, 2016).

According to Owen, Stilgoe, et al. (2013), an RRI approach entails continuously committing to being *anticipatory, reflective, deliberative,* and *responsive*. Simply put in the context of educational robots, *anticipation* deals with describing and analyzing both intended and potentially unintended consequences of educational robots. The *reflective* dimension concerns reflecting upon the underlying motivations and purposes of designing and developing robots, and how these may impact education in terms of ethics and regulation. It is closely related to anticipation, but it also compels the question, "Why are we doing this?" Regarding *deliberations*, this entails engaging stakeholders in the visions and ethical dilemmas concerning robots in education—making them transparent, so that teachers and students can take an active role in shaping and reframing what is important for researchers to recognize. Engaging stakeholders in deliberations should be motivated by both normative ideas (e.g., that it is the right thing to do for democratic reasons) as well as substantive, such that the trajectory of educational robots be co-produced to embody social knowledge and values from a diverse set of sources. Finally, the *responsive* dimension concerns allowing lessons learned from stakeholders to influence the direction, trajectory and pace of innovations (Owen, Stilgoe, et al., 2013).

From an RRI perspective, concerns associated with implementing robots in education can be considered in their entirety by taking a step back and dismissing any preconceptions of desirable solutions. From this perspective, teachers' and students' views as reported in research can be brought to the forefront in future design processes of similar technologies. In practice, it entails making predictions about what might become a reality in terms of social robots in education, and involving teachers and students in assessing the desirability of such implications. By doing so, designers and developers will be better equipped to assert what effects to strive for and what effects to avoid. Thus, the RRI perspective stands in stark contrast to the idea of convincing stakeholders that robots are good for their practice (cf. Reich-Stiebert & Eyssel, 2015). It entails a shift in perspective from *what is possible* towards *what is desirable*. At the same time, it opens up a discussion where researchers can learn from educational stakeholders, and subsequently become proactive on their behalf.

3.2.2 Stakeholders' expectations of robots

Teachers and students are perhaps the most important stakeholders to consider when developing learning technologies for the classroom. While parents, educational leaders, politicians, and society at large certainly can be considered stakeholders, as well, I needed to limit my object of study, in which case I chose to focus on the primary 'users' of technology in the classroom.

Much research has been devoted to exploring perceptions and factors influential for technology adoption in the classroom. For teachers, studies show that it is important that the technology in question contributes to students' learning (Kim, Kim, Lee, Spector, & DeMeester, 2013), and meets other professional needs (Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010). Also, previous research indicates that technologies should be practical and useful (Teo, 2011). Getting started with working with technology in the classroom should therefore not be overbearing or too complex (Aldunate & Nussbaum, 2013). If teachers are provided the necessary guidance for using technologies early on, this may facilitate success, but this does not necessarily mitigate teachers' faced time constraints (Kopcha, 2012). It helps if there are other teachers present at the school who are enthusiastic and able to master the technology in question (Aldunate & Nussbaum, 2013), but some teachers may still be reluctant to embrace new technologies due to fears (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012). This makes technology adoption a process in which several factors interplay, where specific factors may vary in importance depending on the teacher.

Research on robots in particular follows a similar theme, where usefulness for students' learning or the teaching profession has been found to be an important factor for teachers' adoption of robots (Fridin & Belokopytov, 2014; Kennedy, Lemaignan, & Belpaeme, 2016; Lee, Lee, Kye, & Ko, 2008). If, e.g., robots become disruptive to the general educational process, as some teachers predict, they would not be very positive about using them (Reich-Stiebert & Eyssel, 2016). According to Kory Westlund et al. (2016), however, such concerns may shift once teachers acquire practical experience. In a longitudinal study, they found that while teachers were worried that robots would become disruptive to their classroom, they changed their opinion after they had a robot in their classroom for a while. This suggests that the potential disruptiveness of specific robots can only be evaluated sufficiently by including teachers in an intervention. In Kory Westlund's (2016) study, children interacted with the robot in the corner of the classroom behind divider walls, and they wore headphones so that the robot's voice was not heard by anyone else. Setting up the hardware and starting the sessions were all researchers' responsibilities. If teachers would have had to do these things themselves, it is possible that robots would have been perceived as disruptive yet again. Naturally, this should also be dependent upon the complexity of the robot, such that very 'user-friendly' robots that do not require much handling and preparation to get started working with, or do not occupy a lot of space, are deemed less disruptive. Moreover, it is also possible that the teachers' evaluations of the robot's disruptiveness were primarily based on practical issues within the everyday classroom setting, rather than through a lens of future possible educational uses of robots, as the research conducted in this thesis, is primarily concerned with.

Considering what roles robots should and should not take on in a classroom, studies indicate that teachers are concerned about such things as robots taking on the role of a full-blown teacher (Lee et al., 2008), or that robots could negatively affect the development of human interpersonal relationships in education (Reich-Stiebert & Eyssel, 2016). Based on this, teachers envision robots to take on more practical and unsophisticated roles (Diep, Cabibihan, & Wolbring, 2015), such as that of advanced tools in STEM subjects (Reich-Stiebert & Eyssel, 2016). As will become clear in the remainder of this thesis, some of these concerns also surfaced in my early studies. However, it should be noted that my studies were published prior to the ones referenced here.

When it comes to students, on the other hand, much research has focused on how children would like robots to look or behave and how this can be accounted for in robot design. Young children tend to focus on a robot's appearance, while such things as robot perception and mobility is increasingly reflected upon the older the children get (Sciutti, Rea, & Sandini, 2014). Technology interest also plays a role, where children who are more interested in technology produce more mechanical-looking robots when envisioning an educational robot, while the more inexperienced technology users tend to produce more humanlike robots (Obaid, Barendregt, Alves-Oliveira, Paiva, & Fjeld, 2015). Young children have also been shown to attribute positive qualities to robots they consider to look female rather than male (Woods, Dautenhahn, & Schulz, 2004; Woods, 2006). Despite this, it has been argued in parallell that it is plausible that children will (in time) become accustomed, and adapt to whatever robot is placed in front of them (Belpaeme et al., 2013; Pearson & Borenstein, 2014). However, despite the abundance of studies focusing on children's concrete design ideas for robots, there is a lack of studies reflecting students' perspectives on ethical issues of robots entering education; what students think robots should or should not be able to do within the context of education, making this a pressing issue.

3.2.3 Ethical perspectives

What is generally lacking in previous research are stakeholders' normative and ethical perspectives on robots in education, i.e., what is referred to as social desirability within the context of RRI. What outcomes should we strive for in relation to the educational use of robots, and what outcomes should we avoid? These are important issues that should not be taken lightly since whatever technology enters education could potentially lead to undesirable consequences (Cuban, 2003; Selwyn, 2016). Indeed, there has been an extensive amount of literature written on the ethical issues associated with robots in society, some of which is specifically addressing long-term elderly care (Sparrow, 2015; Wu, Fassert, & Rigaud, 2012), and robot companions for children (Kahn, Gary, & Shen, 2013; Turkle, 2006). Children, like the elderly, constitute a vulnerable group in society. They may not have much influence over the robots implemented in their particular setting. Instead, it is typically decided by a third party, i.e., those responsible for the institution.

To address this gap, this thesis focuses on a number of specific ethical issues that I understand as key issues in relation to the future use of robots in education. While they may not be obviously relevant quite yet, this is mainly due to current limitations in robotic technology. However, one might ask how to deal with these issues in the future when education is faced with technical possibility rather than limitation. The issues dealt with include: privacy, roles of robots and human replacement, developmental effects on children, and responsibility. These are addressed briefly in the remainder of this chapter, but more thoroughly in Papers IV, V, and VI of this thesis.

In regard to privacy, it is no surprise that educational robots store data about children. Although there is no uniform approach when it comes to data gathering for robots, it may include video capturing, facial expression capturing, speech recognition, learner modeling based on an educational task, or other physiological data such as skin conductance (Jones, Küster, et al., 2015). In future classrooms, robots may be present whether children agree to interact with them or not, capturing and interpreting various aspects about the children and the classroom. Kahn et al. (2007) question whether this type of data gathering has the potential to infringe on people's privacy *in itself*, i.e., if a robot 'understands' a person. Yet, there are also risks associated with robots being used as surveillance systems (Kahn et al., 2007), or where data are accessed by third parties (Sharkey, 2016).

While not much research has been devoted to children's perspectives surrounding robots and privacy, Steeves and Regan (2014) found that young people indeed value their privacy even though they behave seemingly contradictory when posting sensitive and private information about themselves online. They argue that social participation requires some form of disclosure, and that young people instead "relied on a complex set of norms to govern who should and should not look and how the viewer should respond to what they see. When these norms are violated, they report a general sense of discomfort and unease" (p. 302). In other words, children may rely on their trust for adults to uphold their rights to privacy.

When it comes to the roles that robots should play in society in general, this is often associated with concerns regarding robots replacing human labor. Similar to the debates surrounding how jobs were affected by the industrialization, the use of robots in factories has sparked analogous queries. According to Benedikt Frey and Osborne (2013), approximately 47 percent of current job occupations in the US are susceptible to computerization, but teacher replacement is deemed to be unlikely because robots are currently not in a state of innovation able to fill such a role (see also Sharkey, 2016). However, it has also been argued that social contact with other human beings is too important to replace nonetheless (Heersmink, van den Hoven, & Timmermans, 2014; Nordkvelle & Olson, 2005; Turkle, 2006). In regard to roles that social robots can adopt in education, Sharkey (2016) identifies three notable examples that she discusses from an ethical perspective: as classroom teacher, as companion or peer, or as care-eliciting companion. According to Sharkey and Sharkey (2011), robots are perhaps best put to use for the facilitation of robotic literacy, i.e., to teach children how robots work, are manufactured, as well as how humans are socially and emotionally vulnerable to the anthropomorphic nature of robots. Nevertheless, Sharkey (2016) argues that if robots are to adopt autonomous roles in classrooms, care should be taken surrounding the decision-making capabilities assigned to such robots, in order to ensure that robots do not exert inappropriate influence over such things as children's performance or learning outcome.

In relation to developmental effects on children interacting with robots, Turkle (2006) argues that social robots are becoming relational artefacts that evoke feelings of attachment in people. There is a certain attraction associated with the adaptive and individualized treatment offered by robots (Bryson, 2010). Thus, it has been speculated that children may prefer, and give priority to, their interactions with robots over humans in the future, due to a false belief that human–robot interaction measures up to human–human interaction (Sharkey & Sharkey, 2011). Sharkey and Sharkey (2011) argue that extensive interactions with robots risk impeding children's development in terms of how to understand and interact with humans, linguistic ability, and understanding of reciprocity in human relationships. In a similar vein, Turkle (2006) argues that robots could impede the development of empathy in children. Bryson (2010), on the other hand, considers it likely that children who prefer to interact with robots will display more introvert behaviors; however, she points out that this does not necessarily have to be a bad thing, arguing that it could provide children with stability in their lives, and increase their sense of self-worth. It has further been argued that extensive interactions with adaptive robots could create a master–servant relationship where robots are objectified by children, which could subsequently carry over to their human relationships (Kahn et al., 2013; Sharkey, 2016).

When it comes to responsibility, social robots are increasingly being designed to function autonomously. An underlying assumption surrounding robotic tutors is that they may eventually function without control or much interference from a teacher. Yet, negative consequences may occur as a results of having a robot in the classroom, e.g., that it causes physical or psychological harm to children (Kahn et al., 2007; Sharkey, 2016). It could also be the case that a robot treats children unfairly or otherwise behaves in an unjust manner (Kahn et al., 2007). Whether this is due to error in programming or an unforeseen result of robot autonomy, it is not clear who could assume responsibility for such negative consequences (Marino & Tamburrini, 2006). It has been argued that it is unreasonable to expect that developers or users can predict any situation that may arise (Gill, 2008; Matthias, 2004), which makes it uncertain how responsibility and accountability will be handled on a legal basis.

4 The EMOTE project

In this chapter, I turn my attention to the project within which I carried out my research. This chapter is intended to provide the reader with an understanding of *what* we did within the project and *why*. The design choices we made, and the motivations behind these, are not always central to my research process. Nevertheless, it does provide the reader with an understanding of the context within which this thesis was written.

The name of the project was *Embodied perceptive tutors for empathy based learning*, or EMOTE. It was an interdisciplinary effort funded by the European Union's Seventh Framework Programme (FP7) on Research and Innovation for the years 2007–2013. The participating universities were situated in Sweden, England, Scotland, Portugal and Germany. The project sought to design and develop tutoring robots that could engage and motivate schoolchildren between the ages 10–13 to learn new educational content by equipping these robots with simulated empathy.

> As detailed in the description of work, the overall aim of the EMOTE project was to:
>
> > "(1) research the role of pedagogical and empathic interventions in the process of engaging the learner and facilitating their learning progress and (2) explore if and how the exchange of socio-emotional cues with an embodied tutor in a shared physical space can create a sense of connection and social bonding and act as a facilitator of the learning experience" (EMOTE, p. 5).

As the title suggests, the core of the project was about exploring empathy; whether empathy was something that could be created artificially, and whether children could grow socially or emotionally attached to such a robot if we succeeded. Empathy is considered an important characteristic when designing social robots, particularly when those robots are developed for settings or roles in which they are thought to establish relationships with humans (Duffy, 2003; Lee et al., 2008; Leite, Martinho, & Paiva, 2013; Shin & Kim, 2007). In education, Bergin and Bergin (2009) argue that social bonding between teachers and students is fundamental for their well-being and academic achievement. A contributing factor for a successful attachment is that the teacher behaves empathically and pays attention to the "child's signals, accurately interprets those signals, understands the child's perspective, and responds promptly and appropriately to the child's needs" (p. 143). Specifically, the robot was supposed to have *affect sensitivity*, which is defined as "the way social affective cues conveyed by people's behaviour can be used to infer behavioural states, such as affective or mental states" (Castellano et al., 2010, p. 90). These inferences then affect how the robot responds. The hypothesis was that by drawing on successful teaching (or tutoring) practices and, most notably, empathy, children would develop socio-emotional bonds with these robots which would then facilitate their learning processes (Castellano et al., 2013).

The robots in EMOTE were developed for use in England, Portugal and Sweden. They were programmed virtually the same, except that they spoke different languages depending on the country.

4.1 Benchmarks decided by the project consortium

During the outset of the project, certain benchmarks were already decided pertaining to aims and scope. These included such things as the robot being empathic as well as the educational activities being placed within the areas of geography and sustainable development. Aside from these broad aspirations, there were additional aspects that were more or less decided early on by the project consortium. These mainly related to the hardware components that we were going to use, which proved influential for the design of the educational content as well.

Concerning the choice of robot, it was decided that a NAO T14 robot torso from Aldebaran Robotics (now Softbank Robotics) would be used for the research. NAO is a fully customizable humanoid robot with an infantile appearance, and a

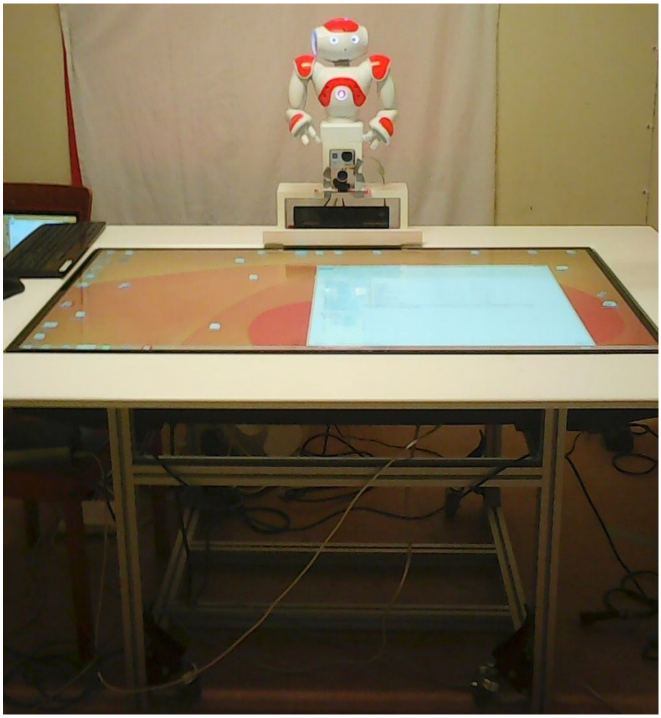

Figure 3. Setup with NAO T14 and interactive table

popular choice for the kind of HRI-research we sought to conduct. The project members also had some prior experience with this particular robot. There were, however, certain technical limitations with robotic technology at the time (and still are), related to speech recognition software and visual perception, which meant that the robot could not understand any speech or other sounds conveyed by the student; nor could it tutor students on any freely chosen activity. Instead, the educational material needed to be in a delimited, digital format so that the robot could perceive what the students were doing. We used a 55" touch-sensitive interactive display from MultiTaction in a tabletop format, for which we could develop educational applications. Additional sensors such as a Microsoft Kinect 2.0 were used to collect necessary information about the students' affective states, in order to create the illusion that the robot was empathic (see Figure 3 for the technical setup).

While the use of an interactive table was highly motivated for practical and technical reasons, there were also pedagogical reasons for doing so. A traditional table, by itself, is an object that encourages social interaction, sharing of ideas and communication between people (Morris et al., 2006). In an educational context, having students working in groups at a table improves collaboration, and this can be amplified by the use of interactive tables. Interactive tables have been shown to facilitate collaboration, equal participation, and learning (Higgins, Mercier, Burd, & Joyce-Gibbons, 2012; Higgins, Mercier, Burd, & Hatch, 2011). Interactive tables also bring about more flexibility that allow for organization of the materials presented on the screen (Higgins et al., 2012). The objects on the table are located according to individual and group needs: individual objects are closer to the learner and the rest is set in the middle of the table (Antle, Bevans, Tenenbaum, Seaborn, & Wang, 2011), easing the work for the robotic tutor when directing students' attention to relevant information or goals.

4.2 User-centered design process

When designing a robot for education, there is a need to start from the potential users, taking into account what they may need in their practice (Ljungblad, Serholt, Barendregt, Lindgren, & Obaid, 2016; Rogers & Marsden, 2013; Šabanović, 2010; Taipale et al., 2015). The EMOTE project did so by adopting a User-Centered Design (UCD) approach, which "is a broad term to describe design processes in which end-users influence how a design takes shape" (Abras, Maloney-Krichmar, & Preece, 2004, p. 763). The level in which end-users are involved in such an approach can vary between partaking in the establishment of design requirements and usability testing, to acting as design partners during the entire design process (Abras et al., 2004). By involving end-users, the product is thought to become more efficient, effective, and safe (Abras et al., 2004), provide a more positive user experience (Sharp, Rogers, & Preece, 2007), which in turn, leads to increased acceptance and success.

UCD can be understood as fitting under the umbrella term of interaction design (ID), which is "concerned with the theory, research, and practice of designing user experiences for all manner of technologies, systems, and products" (Sharp et al., 2007). When embarking on a process of designing interactive products that are usable, the designer has to consider who is going to use the products, how, and in what settings (Sharp et al., 2007). There are three types of users or stakeholders that could potentially be involved in the UCD process: primary, secondary or tertiary. The primary stakeholders are those that will be directly using the system. The secondary stakeholders are those that may use the system either occasionally or through an intermediary. The tertiary stakeholders are those that will be affected by the use of the system or responsible for its purchase (Abras et al., 2004).

Aside from the benchmarks decided by the project consortium, the educational content as well as the robot's behavior were designed through a UCD approach along with teachers and students. Given my background in educational science (i.e., a teaching degree), I was very much involved in conducting these studies and provided design recommendations for the technical implementation. In this chapter, I only mention the studies where I played a significant role, i.e., studies associated with aspects like the users/stakeholders themselves, the design of the robotic tutor's pedagogical approach, and the design of the educational activities.

Abras et al. (2004) exemplify how a UCD process can unfold. First, thorough investigations of stakeholders' needs should be performed through, e.g., background interviews or questionnaires. The EMOTE project did so by consulting teachers, but first, school curricula were reviewed in order to narrow the scope regarding the educational content. Here, a particular focus on map-reading was deemed to optimize the functionalities of the interactive table, making this the starting point. Then, teachers were interviewed in order to derive user requirements for the design, participatory design workshops with teachers were carried out in order to derive design specifications surrounding the structure of the educational activities, and additional interviews were held surrounding difficulty levels and the potential inclusion of backstories that could facilitate students' engagement. Concrete output from these studies that was taken into account during the technical implementation was that (1) teachers emphasized the need for group-based activities, rather than just the individual map reading activity that was initially planned, (2) different difficulty levels needed to be implemented such that students on different levels would be able to interact with the robot, and (3) the backstories needed to be serious but not frightening for the students.

Second, designers can develop various solutions to be evaluated by stakeholders through practical or interactive activities, on-site observation or focus groups, which can provide information that was not discovered during the initial phase (Abras et al., 2004). At this point, two educational scenarios were developed by the technical partners, where the first was an individual map-reading activity (Scenario 1), and the other was a collaborative game on sustainable energy consumption to be played by pairs of students (Scenario 2). The first scenario would be designed and developed from scratch. Here, the idea was that the activity would constitute a trail-following concept, likened to a treasure hunt. In essence, students would practice map-reading skills considering cardinal directions, distances and landmarks by following a pre-determined trail, and to practice more complex skills when locating an artifact at the end. For the second scenario, we used an existing game about sustainable energy consumption[1] where the aim was to build a sustainable city able to provide housing for a growing population. The decision to use an already developed game as our starting point was motivated by time management reasons. To acquire design considerations for the robot's pedagogical strategy during these scenarios, the EMOTE project carried out a set of mock-up studies, which utilized prototypes of the educational activities that had been designed thus far (either paper-based [Scenario 1] or computer-based [Scenario 2]). Here, teachers guided their students in carrying out the designed tasks, and this provided input for designing the robot's behavior.

Third, as the design process subsequently progresses, prototypes of the system can be developed and tested by users through walkthroughs, mock-ups or simulations, at which time formative evaluations are conducted and usability criteria are identified (Abras et al., 2004). Usability criteria relate to such things as how effective the system is, its efficiency, safety aspects, utility, how easy it is to learn and remember how to use the system, as well as how satisfied stakeholders are with using the system (Abras et al., 2004). Here, the EMOTE project conducted two WoZ-studies with children; one with Scenario 1 in England, and one with Scenario 2 in Portugal. With my background as a teacher, it was natural that I would play the wizard role (for Scenario 1). For Scenario 2, a partner in Portugal with a psychology background performed the role of the wizard (Sequeira et al., 2016). Following these studies, the robotic tutor's strategies were fully implemented by the project through a collaborative effort.

Throughout the project, additional studies[2] were continuously being conducted in parallel by our collaborating partners. These could be of a more technically-oriented nature (Janarthanam, Hastie, Deshmukh, & Aylett, 2014; Ribeiro et al., 2014), related to developing artificial empathy for the robot (Küster & Kappas, 2014), validating hardware components (Kappas, Küster, Basedow, & Dente, 2013), or applications for animation of the robot (Ribeiro, Paiva, & Dooley, 2013). A small-scale WoZ-study of a very early prototype was also performed by researchers (Deshmukh, Janarthanam, Hastie, Bhargava, & Aylett, 2013), which was followed up with a teacher discussion group commenting on how the robot behaved. Other studies included interactive table engagement studies with adults, learner or engagement modelling studies (Corrigan, Peters, & Castellano, 2013; Corrigan et al., 2014; Jones, Bull, & Castellano, 2015; Papadopoulos, Corrigan, Jones, & Castellano, 2013), as well as comparative studies of different robot embodiments or settings (Foster et al., 2014; Foster et al., 2015).

4.3 The final product

When the robot was fully developed, it had a certain level of affect sensitivity, which was based on levels of valence and arousal exhibited by the students (Hall et al., 2016; Ribeiro et al., 2015). However, it did not, e.g., try to comfort the students if they were upset. Instead, it tried to adapt its pedagogical strategy, provide more or less help when needed, depending on the affective state of the student.

Furthermore, much work was devoted to how the robot would communicate with the students, e.g., what voice (text-to-speech engine or *TTS*) it would have, and what sorts of things it could say. However, it is important to point out that it could not perceive verbal utterances from the students—not even keywords.

Concerning the robot's behavior, the UCD process yielded many important foundations, such as the content of utterances involved in tutoring students within the given tasks based on teachers' behaviors, while also taking into account such things as the appearance and limitations of the NAO robot. In Sweden, I settled for using a TTS in the form of an artificial child's voice[3] that came with the purchase of the robot. Concerning what the robot could say, a long list of possible utterances was compiled in a database which the robot could access. Each utterance was assigned to a particular category such as *greeting, question, feedback,* etc. Each category had approximately ten different utterances, and they executed suitable accompanying body gestures (e.g., waving, pointing, or head nodding) and gaze directions (e.g., student's face, or different parts of the interactive table). However, as the robot was limited in expressiveness (e.g., no facial expressions or verbal intonations), we implemented additional behaviors that were not observed in our studies of teachers. These included certain gestures (the raising of the robot's arms in order to reflect happiness or excitement), and sound emblems (Kappas, Küster, Dente, & Basedow, 2015) that could be used to convey different forms of feedback. Also, the LEDs in the robot's eyes changed colors and intensity to reflect the intended emotion of the utterance, which was based on the work by Greczek, Swift-Spong, and Mataric (2011).

4.3.1 Scenario 1

In the first scenario for individual students, the task consisted of following a trail on a local city map by selecting appropriate map symbols (see Figure 4). Several different trails were developed to support a longitudinal study. Each trail was situated in a different city with an accompanying backstory to make the task more engaging and provide some interesting information and history about each city. For instance, in one particular city, the task was to recover a stolen treasure from a local museum known for its collections of ancient silver.

Each step instruction in the trail was delivered verbally by the robot while also being visible on the screen until the step was completed. A step instruction always included three elements (map symbol, cardinal direction and distance), e.g. *"Go*

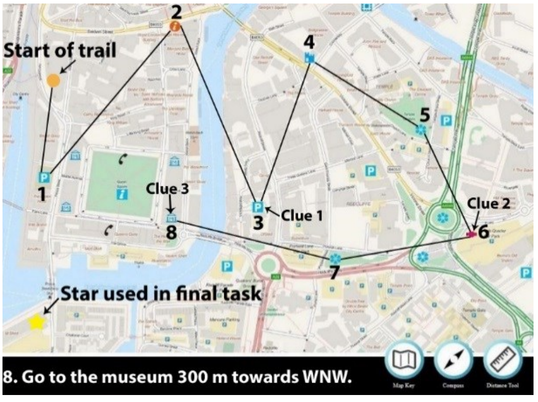

Figure 4. Scenario 1 interface

east 500 meters until you reach a bus stop". For each step, only one map symbol corresponded to all of these, whereas all other symbols were incorrect in at least one of the elements. This design made it possible for the robot to detect specific flaws in the student's selections. As the task progressed, the difficulty level increased. There were map reading tools available within the task in the form of a compass, map key and measuring tool, which the robot encouraged the student to use.

At specific steps in the trail, a pop-up window appeared that displayed information in the form of clues that the student was to use at the end of the trail to find a hidden location (for example, the location of the stolen treasure). Each trail contained three clues that needed to be combined in order to find the location. These could, e.g., be: (1) *The treasure is northeast of a museum,* (2) *The treasure is 250 meters from an information center,* and (3) *The treasure is buried in a lake*. For each trail, there was only one possible location that corresponded to all three clues. This phase required the student to combine clues, and choosing the correct location was required to complete the activity.

In this scenario, the robotic tutor tried to help the student progress in the task through a set of possible utterance categories. These were partly inspired by Vygotsky's (1978) notion of ZPD, literature on scaffolding (Wood & Wood, 1996), observations of practicing teachers' scaffolding behaviors on paper-based mock-up studies with students, as well as the WoZ study. The different categories included encouraging the student to figure out the answer for him- or herself by asking and repeating questions (Graesser, Wiemer-Hastings, Wiemer-Hastings, & Kreuz, 1999). The robot could also deliver hints (Graesser et al., 1999), keywords (Anghileri, 2006; Parson, 1998), and elaborations or tutorials on difficult concepts (Graesser et al., 1999). Different forms of feedback on students' performances were also implemented (Hattie & Timperley, 2007). However, we refrained from including negative utterances such as *"That was incorrect"* as the teachers in our mock-up studies preferred other ways of guiding students in the right direction. Research furthermore suggests that negative feedback may lower intrinsic motivation (Deci, Vallerand, Pelletier, & Ryan, 1991).

4.3.2 Scenario 2

The collaborative sustainable development game was based on an existing single-player game developed by Paladin Studios about sustainable energy consumption, where the aim was to build a sustainable city able to provide housing for a growing population (see Figure 5). Here, the robot acted both as a player of the game, as well as a facilitator of the interaction between the two participating students. For example, the robot could express 'its own' views regarding how to build a sustainable city in order to encourage similar conversations among the students for the sake of illustrating that there may be conflicting perspectives when it comes to creating a sustainable society (Antle, Warren, May, Fan, & Wise, 2014; Gough & Scott, 2003).

To proceed to the next level in the game, the players had to make the population of the city grow to a certain amount by building residential areas. At the same time, if the city ran out of non-renewable resources, the game ended. The game had a turn-taking dynamic, where each student adopted either the role as environmentalist or economist, whereas the robot always featured as the mayor. In each turn the group of players collaborated to decide how they would like to build their city, but one of the players was supposed to perform the physical action of making a selection (e.g., to build parks, industries or energy supplying constructions, upgrade existing constructions, apply environmentally friendly policies, etc.). In order for them to decide, they had to take into consideration the city indicators and how their actions influenced the sustainability of their city. Each decision could have both positive and negative effects on the environment,

Figure 5. Scenario 2 interface

economy, and citizens' well-being, which was indicated by a score for each of these factors. The robot tried to provide balance to the factors and advance the game by selecting constructions that were lacking.

4.4 Evaluation approach

Once the setup was completely developed, it was time for a summative evaluation. The empathic robotic tutor developed in EMOTE was essentially a type of educational technology, and the evaluation process needed to adhere to approaches for the evaluation of such technologies. Yet, evaluating educational technologies is not clear-cut. When discussing a suitable scope for the evaluation, the project consulted previous evaluation frameworks that had been developed. For example, in their framework, Hamilton and Feldman (2014) state that evaluation methodologies should correspond to the stage of program development, which goes from idea generation (*exploratory*), to development and implementation (*development and innovation*), to a fully developed program which is not yet tested (*efficacy and replication*), and finally to a fully developed program with some indication of effectiveness (*scale-up*).

Given the work plan and scope of the EMOTE project, it was clear that it fell somewhere within the first two stages of program development: *exploratory* and *development and innovation*. According to Hamilton and Feldman (2014), this stage calls for more descriptive kinds of evaluation approaches. Here, the project took its starting point in the Kirkpatrick model framework (1998), which provides an overview of different factors that need to be considered during descriptive evaluations. The framework was originally developed for evaluating the effectiveness of training programs, but has since been utilized by Jeremic, Jovanovic, and Gasevic (2009) when evaluating an ITS. It has also been modified for use in evaluation of higher education (Praslova, 2010), which was the version utilized in the EMOTE project. The framework consists of the following four levels of criteria: *reaction, learning, behavior*, and *results*, where EMOTE focused on the first two.

The evaluations took place in schools in either Sweden, Portugal or England. In England, one-day studies were carried out at a school with Scenario 1 only (Obaid et al., 2017), whereas a longitudinal study of Scenario 2 was conducted in Portugal

(Alves-Oliveira, Sequeira, & Paiva, 2016). In Sweden, I conducted a field study spanning across 13 weeks. This study utilized both educational scenarios, starting with Scenario 1 for about 2 months, and then moving on to Scenario 2 for the rest of the study.

When researching the impact of ICT on education, it is important to consider the educational context and not focus on the controlled manipulation of a single variable (Salomon, 1990). As advised by Savenye and Robinson (2004), the EMOTE project adopted a mixed methods approach consisting of both quantitative and qualitative measures. This included performance tests, and assessments of students' negative attitudes towards robots (NARS) both before and after the study (The NARS is described in detail in Section 5.3.1). Following the study, students' perceived learning and attitudes towards the two scenarios were measured, as well as their perceptions of the robot's empathic capabilities. The more qualitative methods used were field note taking, videos of the interaction sessions, as well as students' long-term user experience.

During the time of the study, I was present at the school, and part of everyday activities in the classroom. Apart from monitoring students' sessions with the robot (see Figure 6), I worked with the students and helped them with their lesson material, assisting the teacher when needed. I also engaged in informal conversations, had lunch with both students and teachers, and talked with them during their breaks and free time.

Figure 6. Student(s) interacting with the robot individually in Scenario 1 (left), and collaboratively in Scenario 2 (right).

To mitigate the impact of the artificial situation that I had introduced into the school, I made several choices to make it feel similar to what it might be like if a teacher had purchased a robot for their classroom. First, I placed the setup in close vicinity of the classroom, in a small 'group-room' that the students were familiar with using for other educational activities such as individual study or group work. Second, I consulted with teachers regarding which lessons they would consider appropriate for practicing map-reading and/or playing the sustainable development game. Third, I asked teachers to decide upon (and announce in class) whose turn it was to conduct a session with the robot.

Notes

[1] The original version of the sustainability game is available for online play at https://www.enercities.eu/

[2] For a list of deliverables and publications, see www.emote-project.eu

[3] The English voice 'Kenny' most closely resembles the TTS used in Sweden, which can be listened to here: http://www.acapela-group.com/

5 A mixed methods approach

The research presented in this thesis focuses on the educational use of robots. Firstly, my research is concerned with designing a specific product (or innovation) that can actually be *studied* in a real social context. In this case, the product is a humanoid robotic tutor aimed for a school setting. Secondly, my research is about assessing the desirability of the *concept* of robots in education itself, outside the domain of a specific product.

5.1 Research design

The thesis comprises six papers, where RQ1 is addressed in the first three papers, and RQ2 is addressed in the latter three. Each study had its own specific research objective(s) and accompanying method(s), which contributed to addressing the overall research questions in different ways. My research process did not unfold in a straight timeline moving from RQ1 to RQ2; instead, the studies described in Papers I and IV were conducted early on, whereas the other studies came later. Nevertheless, for the sake of clarity, the upcoming subsections are structured according to research question, where the research designs are presented for each.

5.1.1 Children's interactions with a robotic tutor

To address RQ1, three studies were conducted, all of which were carried out at the same school with the same humanoid robot (NAO). The school was an F–9[1] school located in a small town in Sweden. It was selected based on convenience sampling, which is a common approach in qualitative educational research (Cohen, Manion, & Morrison, 2013). The particular school was located close to my home, and the staff at the school had shown interest in participating in the EMOTE project. I knew many of the teachers personally, as well as some of the children, given the fact that I live in a small town. The classes were small, generally comprising two grades per class depending on the number of students enrolled in a particular year.

This sampling choice had both pros and cons. Pros, in the sense that I was not viewed as a stranger, and the people there seemed to trust me, which is an important foundation when conducting qualitative research (Cohen et al., 2013). The fact that the school was a few minutes away from my home was also of practical significance given the long-term nature of the field study. I was able to stay for long hours at the school, or come in during holidays, in order to sort out technical issues with the robot setup, making the studies run more efficiently during the actual school hours. The cons were of course that my personal involvement in the participants risked presenting bias.

The first study sought to explore children's willingness to follow instructions from a robot compared against their willingness to follow instructions from a human being. This study took the form of a 3-day-long field experiment, where children interacted with the robot on one occasion (Paper I). The experiment was driven by several hypotheses surrounding task success, attitudes towards robots, and children's help-seeking behavior, which were either confirmed or rejected based on video analysis and questionnaire responses.

The second and third studies took place during the field study carried out during the evaluation phase of the EMOTE project (see sections 4.3 and 4.4 for the setup and setting). The field study included several tests and questionnaires, but in this thesis, I focus on the interaction videos and follow-up interviews, which were analyzed qualitatively. Also, it was deemed important to take into account potential novelty effects that have previously been observed in CRI (Kanda et al., 2004; Leite et al., 2013) by studying the interactions over time for each child. Both the second and third studies utilized the same data corpus, but the object of study differed. Whereas the second study investigated children's social responses to the robot when it delivered social probes to them (i.e., utterances designed to elicit social responses from the children) (Paper II), the third study focused on breakdowns in interaction (Paper III). In the third study, interaction breakdowns were analyzed across both educational activities for each child (i.e., both the individual map-reading activity, and the collaborative sustainability game), since interactions with robots are likely to vary depending on the social context and/or constellation (Höflich, 2013; Severinson-Eklundh et al., 2003).

5.1.2 The views of teachers and students

To address RQ2, teachers and students were recruited from several different schools across different countries to participate in either semi-structured interviews (Paper IV), workshops (Paper V), or focus groups (Paper VI). Here, the research approach was not straightforward. It was evident from EMOTE's UCD process that teachers had a difficult time partaking in designing robots that they had no experience using. Engaging stakeholders in deliberations of situations or technologies that they have yet not encountered may be an even more difficult process; they may have trouble envisioning how they would react to a novel situation with a robot in the classroom, or to anticipate challenges that may arise (Mancini et al., 2010). Providing participants with fictive scenarios of robots was an approach that seemed promising in that it could encourage research participants to begin to consider and reflect upon futuristic technologies (Little, Storer, Briggs, & Duncan, 2008; Mancini et al., 2010). This approach has also been applied within RRI (Stahl, McBride, Wakunuma, & Flick, 2013).

In Papers IV and VI (with teachers), audio recordings of interviews/focus groups were transcribed and analyzed thematically (Braun & Clarke, 2006). These processes were both theory-driven and inductive. During workshops with students, questionnaires were collected and analyzed quantitatively.

5.2 Outline of research studies

Taken together, the studies carried out within the context of this thesis comprised a total of 317 participants: 232 children enrolled in education, and 85 practicing or pre-service teachers. In Table 1, an overview of the included studies is provided, detailing each study, the data analyzed, and the title of the paper.

Table 1. Overview of the studies included in this thesis

		STUDIES INCLUDED	DATA ANALYZED	PAPERS
RESEARCH QUESTION 1	3-day WoZ experiment	Video and questionnaire analysis of a between-subject field experiment at a school in Sweden comparing children's responses to instructions conveyed by either a humanoid robot or a human.	Participants: 25 students aged 11–15. – Approximately 3 hours of video recorded interaction sessions, – 50 pre- and post-NARS questionnaires (see section 5.3.1), – 25 post-engagement questionnaires (adapted from McGregor & Elliot, 2002).	**Paper I.** Comparing a humanoid tutor to a human tutor delivering an instructional task to children
RESEARCH QUESTION 1	13-week field study	Video analysis of children's responses to a robotic tutor's social probes over time in a longitudinal field study at a school in Sweden.	Participants: 30 students aged 10–13. – Approximately 1 hour of video data drawn from 45 hours of interaction sessions.	**Paper II.** Robots tutoring children: Longitudinal evaluation of social engagement in child–robot interaction
RESEARCH QUESTION 1	13-week field study	Interaction analysis and thematic analysis of video recorded breakdowns in children's interactions with a robotic tutor over time in a longitudinal field study at a school in Sweden.	Participants: 6 students aged 10–13. – Approximately 14.5 hours of video recorded interaction sessions and follow-up interviews, – 92 pre- and post-NARS questionnaires (see section 5.3.1).	**Paper III.** Breakdowns in children's interactions with a robotic tutor: A longitudinal study

		STUDIES INCLUDED	DATA ANALYZED	PAPERS
RESEARCH QUESTION 2	Interviews	Thematic analysis of interview transcripts from semi-structured interviews with teachers about their views on robotic tutors in education. Conducted in Sweden, Portugal, and the UK.	Participants: 8 teachers aged 25–48. – Transcripts of approximately 4 hours of audio recorded interviews.	**Paper IV.** Teachers' views on the use of empathic robotic tutors in the classroom
	Questionnaires	Quantitative analysis of students' normative perspectives on robots in education through questionnaire responses. Conducted in Sweden, Portugal and the UK.	Participants: 175 students aged 11–18. – 175 normative perspectives questionnaires (see section 5.3.3).	**Paper V.** Students' normative perspectives on classroom robots
	Focus groups	Thematic analysis of focus group transcripts from 12 focus group sessions with teachers' about ethical issues associated with robots in education. Conducted in Sweden, Portugal and the UK.	Participants: 77 practicing or pre-service teachers aged 18–64. – Transcripts of approximately 12 hours of audio recorded focus group sessions, – 77 technology usage questionnaires (adopted from Little et al., 2008).	**Paper VI.** The case of classroom robots: Teachers' deliberations on the ethical tensions

5.3 Materials

Most of the materials used in the studies can be found in detail in each respective paper. However, due to a limited amount of space afforded in academic publishing, some self-developed materials are only briefly described there, and hence, are afforded presentations here.

5.3.1 Child-friendly NARS

The Negative Attitudes Toward Robot Scale (NARS) is a questionnaire developed by Nomura, Kanda, and Suzuki (2006), and a common instrument used to investigate adults' attitudes towards robots in general. In Papers I and III, the

NARS was adapted for the specific context of education, and the questions were rephrased to make them more understandable for younger participants.

This adaptation took the form of a collaborative effort between myself and two other researchers involved in the first study. First, we each made individual alterations to the language and context. These were then compared and discussed, and pre-tested with a child of the intended age-group before arriving at a final scale. I then translated the questions to Swedish. A list of the items on the scale, as well as subscales associated with each question, can be found in Paper I. Here, the NARS was used to explore a hypothesis in a field experiment, whereas in Paper III, it was used as a participant selection criterion.

5.3.2 Fictive scenarios

In Papers V and VI, fictive scenarios (a video, and written scenarios) were used to engage stakeholders in deliberations on ethical tensions associated with the future of educational robotics. These were developed through a collaborative effort with my co-authors and two teacher education students.

The video was 5 minutes long, and presented current developments in social robotics. The video first showed different kinds of robots, e.g., an industrial robot, a hospital robot, and a lawn mower. The video also showed several robots (both tele-presence and autonomous humanoids) currently in use in primary education in various countries, including Engkey, ROTi, NAO, and VGo. Then it showed how external sensors and software programs could be used in order to interpret children's emotional states (e.g., the use of Kinect for affect recognition, depth perception, and facial expression recognition). This technology was then exemplified through a segment from a WoZ study carried out with an English student interacting with the setup developed within EMOTE. The video ended with two short segments of some futuristic possibilities of robots depicted in two science fiction movies (*I, Robot* and *Robot and Frank*) in order to inspire participants to think beyond their current experiences with technology. The videos were intentionally edited so that *I, Robot* was deemed to be perceived in a more negative light, and *Robot and Frank* in a more positive light.

Inspiration for such an approach encompassing polarized points of view on the same topic (i.e., possible futures with robots) was drawn from the ContraVision approach (Mancini et al., 2010), which uses "futuristic videos, or other narrative forms, that convey either negative or positive aspects of the proposed technology for the same scenarios" (p. 1). The authors argue that "the use of two systematically comparable representations of the same technology can elicit a wider spectrum of reactions than a single representation can" (p. 1). In these studies, the aim was to facilitate articulation of both positive and negative feelings toward robots. Since priming effects may occur based on the part of the video experienced last, the ordering of the last two segments was counterbalanced for half of the groups.

Concerning the written scenarios, teachers read a short story, whereas students read a short comic book with a similar storyline. The written scenarios illustrated a situation in which an educational robot was bought for a school, its subsequent unpacking and use in interactions with students. In the short story, the story was told from a class teacher's perspective, whereas the comic book was conveyed from a student's perspective.

5.3.3 Normative perspectives questionnaire

To survey students' normative perspectives on educational robots in Paper V, i.e., which robot capabilities they deemed beneficial versus problematic, a questionnaire was developed. The questionnaire was designed to include a set of different criteria on ethical issues and areas of concern surrounding robots. These issues were drawn from two separate sources, of which the first was the Negative Attitudes Towards Robots Scale (NARS) (Nomura et al., 2006), and the second was a collection of normative issues compiled in a deliverable by the EU-project ETICA (Heersmink et al., 2014). Thereafter, analysis of previous work on educational robots served as a lens in developing questions particularly relevant for the educational context, relating to such aspects as children's relationships to robots, data collection by robots, robot responsibility, etc.

When surveying children, it is important to give special consideration to the construction of questionnaires so that they are tailored according to the social and cognitive development of the target age group (de Leeuw, 2011). It is important that the language is simple and direct, and that ambiguity is avoided. Also, children are more likely to respond in socially desirable ways, so prescribing value or posing questions in certain ways may easily sway them (de Leeuw, 2011).

It is furthermore not advisable to present too many response options. In some cases, five point scales may be valid for older children, whereas with younger children, response options should be limited to a maximum of three (de Leeuw, 2011). As such, I chose to refrain from the more conventional use of five point scales in favor of merely yes, no, or I don't know/I don't want to answer. Considering that this particular study comprised students ages 11–18, it was decided by the authors to make the questionnaire more adapted for lower ages, and maintain this design for all participants (see Table 2).

Table 2. Questionnaire items used in Paper V

1. Do you think that robots with human characteristics should be present in schools?
2. Do you think that robots should show feelings?
3. Would you be able to talk to a robot?
4. Could you ask a robot for help with your schoolwork?
5. Could you become friends with a robot?
6. Would you be able to talk to a robot in front of your schoolmates?
7. Would you want a robot to grade your schoolwork?
8. Would you be able to trust a robot?
9. Do you think that children in preschool should have robot teachers/assistants?
10. Do you think robots should decide things in society?
11. Would you like a robot to record the things you do and say?
12. Would you like a robot to be able to analyze your feelings based on, e.g. your facial expression and pulse?
13. Do you think robots should be held responsible if they do something wrong?
14. Do you think robots should replace teachers in school?

5.4 Ethical considerations

In terms of research ethics, I acquired informed consent, parental consent when participants were children, as well as ethical approval from the university. However, when it comes to participant privacy, my research was situated somewhere on the brink of what can be considered sensitive for people. First, it involved making video recordings of children in possibly sensitive situations. To ensure that these data could not be hacked by a third party, I operated on the robot so that any wireless transmission was made impossible. I have also been restrictive when it comes to sharing identifiable data with other researchers. Second, my research involved asking teachers and students to take a stance on issues that they may not always feel comfortable in discussing. Here, I opted to collect data via audio rather than video, and in the case of students, through anonymous questionnaires.

Furthermore, the aim of EMOTE was to develop a robotic tutor that could potentially form a social bond with children in order to promote learning in a personalized way. As Fridin (2014) describes for the use of assistive robots for pre-school children, this entails some ethical dilemmas, especially related to long-term interaction. These ethical dilemmas include, e.g., attachment to the robot, deception about the robot's abilities, robot autonomy and authority. It was therefore deemed important that children were given a thorough introduction prior to the field study which dealt with these ethical concerns without jeopardizing the possibility to explore how children naturally interact with robots in the classroom. Thus, the protocol presented in Table 3 was used for all the field studies conducted within the EMOTE project in order to prepare each class.

Table 3. Introduction protocol for the field study

Hi [name of the child/group], I am [name] and I come from [university name]. Your school has agreed to help us evaluate the robotic tutor that we are developing in the EMOTE project. This robot will try to understand you and help you with tasks surrounding Geography and Sustainability. It will stay in the school for [number of weeks] weeks. The robot does not understand speech, but it uses several other advanced ways of trying to understand how to help you in the best way, e.g., by reading your facial expressions. Although you will be asked to work with this robot individually or in small groups during the school days, the robot will not be able to force you to work with it, and your teacher is responsible for your grading and planning. The robot is programmed to help you with topics related to Geography and Sustainability and it will not do anything else by itself. If there are any technical problems you can always talk to me and I will try to fix it. In order for the robot to work it needs to record you, and we also want this data in order to improve or evaluate our robot. As we also explained in the consent form which was sent to your parents, these recordings are only kept for research purposes. If you have any questions you can ask me now, or any time later. I hope you will have fun with our robot!

In a review meeting for EMOTE, the EC alerted us to the sensitive nature of removing the robot from the school setting if children had developed a socio-emotional bond to it (indeed, that was what the whole project was trying to do). Children needed to be prepared and given an opportunity to say goodbye to the robot. Thus, after the field study, I returned to the school with the NAO robot so that the students could say goodbye and ask questions about the study. To thank them for their participation, each class received a robot dog[2] following agreement from the teachers.

Notes

[1] F–9 schools comprise grades from pre-school class [or grade 0] to grade 9.
[2] Robot dog Zoomer developed by Spin Master Ltd. http://www.zoomerpup.com

6 Summary of studies

In this chapter, a brief presentation of each study, along with its key findings, is provided in turn. For a more detailed account, see the relevant appended paper.

6.1 Children's interactions with a robotic tutor

In this subsection, the papers related to RQ1 are presented, moving from children's responses to instructions conveyed by a robot, to their social responses to a robot, and finally, breakdowns in children's interactions with a robot.

6.1.1 Paper I. Children's responses to a robot's instructions

The first study was a field experiment comprising 25 students between the ages of 11 and 15 at a primary school in Sweden, which sought to explore whether children were willing to follow instructions conveyed by the robot used in the EMOTE project. The experiment was a between-subject design which compared two conditions: either a humanoid robot or a human, who delivered step-by-step instructions on the construction of a LEGO house. The following hypotheses guided the experiment: it was expected that (H1) the human condition would lead to increased student attention and success, measured through correct LEGO house completion and the number of requests for a repetition of the instruction, (H2) students would be more inclined to ask for help from the human than from the robot, (H3) students would be less engaged with the robot than with the human, measured through gaze attention/direction and post-engagement questionnaires, and finally (H4) the student's interaction with the robot would result in a more positive attitude toward robots, measured as a decrease of their subjective scores on the child-friendly NARS.

Through video analysis and non-parametric statistical analysis (Mann-Whitney U), the first hypothesis (H1) was rejected. There were no statistically significant differences across conditions in terms of either successful task completion or instruction repetition requests. The second hypothesis (H2) was confirmed, where students asked for help on average 1.69 times in the human condition, while this never occurred in the robot condition. Regarding the third hypothesis (H3), the results were not straightforward. Here, there was no significant difference between how much time students spent looking at either the robot or the human. However, students in the robot condition spent significantly more time gazing at the cameras in the room, while they spent more time gazing at the LEGO blocks in the human condition. There were no significant differences in the engagement post-questionnaire, apart from one question where students in the robot condition responded more affirmatively that it was important for them to perform well on the task. Finally, the fourth hypothesis (H4) revealed by means of a Wilcoxon signed-rank test that students developed a more positive attitude towards robots following the experiment, but this occurred across both conditions. Although differences in more positive attitudes were not statistically significant across condition, they were nonetheless slightly higher in the robot condition.

The results of the study suggested that there was a certain novelty effect, which is perhaps best described as unfamiliarity with the concept of a humanoid robot. Here, attitudes became more positive following the experiment across both conditions, perhaps related to a newly invested interest in exploring what robots really are. From a methodological point of view, it was apparent that students needed to be granted experience actually interacting with robots in order to inform their attitudes towards them, or at the very least, to be given information and examples of different robots to be able to form an informed opinion. Furthermore, it was concluded that the short-term nature of the experimental design was not telling of whether children are willing to follow instructions from a robot over time. Despite our efforts to make the task tedious and to entice students to disregard the instructions by granting access to a variety of more 'fun' LEGO pieces, they followed the instructions nonetheless. This suggests that this needs to be studied over time when the novelty effect has worn off.

6.1.2 Paper II. Children's responses to a robot's social probes

In this study, videos of students' interactions with the robotic tutor during the EMOTE evaluation phase were analyzed in a sample of 30 students between 10 and 13 years old. The aim of the study was to analyze students' social engagement with a robotic tutor over time; if and how students responded to social probes delivered by the robotic tutor in the map-reading scenario. This was analyzed over three consecutive sessions, starting from the very first interaction experience. In total, 225 events in the interactions were analyzed.

Here, children expressed a variety of indications of social engagement with the robot, where perhaps the most interesting and surprising finding related to the fact that students responded verbally to the robot although they had been informed that it did not understand speech. This occurred particularly when the robot asked the students whether they were ready to begin the task. Such verbal responses could also be accompanied by head nodding, but students also sometimes simply nodded in response. Furthermore, students' gazes were almost always directed at the robot during the events, which was not unexpected since the task had not yet started on the interactive table when the robot delivered the probes. In terms of facial expressions, these were mostly serious, but smiling (typically accompanied with gazing at the robot) occurred in 30% of the events, where it was most prominent when the robot praised the students for their preceding performance (e.g., *"I remember that you were very good with the compass last time we worked together, [student]"*). Over time, all signs of engagement decreased, but this decrease was subtler than was expected considering a reduction in the novelty effect. Apart from these research results, a coding scheme that can be used to study social engagement in CRI was an additional output of the study.

A methodological reflection concerning the study that should be mentioned is that while these results suggested that the students were socially engaged with the robot, we only analyzed exclusive moments in time devout of any wider context. Indeed, we looked at the beginning of the interaction session before any actual tutoring was taking place; it does, therefore, not reveal anything about how students responded during the actual task. The study also did not take into account a situation with more than one student at a time, which might influence how the students interacted with the robot. It was therefore decided to take a more in-depth look at individual cases, to follow individual students for the whole duration of the study, taking into account more than their reactions, in order to gain a richer understanding of how the interactions evolved. This motivated the third paper in this thesis.

6.1.3 Paper III. Breakdowns in children's interactions with a robot

In the final study analyzing children's interactions with a robot, videos of six students' interaction sessions across the whole duration of the EMOTE evaluation field study in Sweden were analyzed in-depth. Here, their interactions with the robot in both the individual map-reading scenario and the collaborative sustainability game were analyzed. The aim of the study was to analyze the occurrences and causes of breakdowns. Over 14 hours of video data were considered, where breakdowns were selected depending on a number of indicators. The indicators included children's expressions of adverse emotional states, inactivity, off-task activity, and their requests for researcher assistance. In total, the study uncovered 41 breakdowns across four different themes understood as the causes of the breakdowns: *the robot's inability to evoke initial engagement and identify misunderstandings*, *confusing scaffolding*, *lack of consistency and fairness*, and finally, *controller problems*.

Concerning the first theme, there was a clear interplay between what occurred at the onset of the interaction, and what happened later. Simply put, the robot devoted some time towards introducing and explaining the tasks at hand at the beginning of the sessions. When the robot failed to engage the students at this time, and was subsequently unable to identify that this resulted in the students misunderstanding the task, breakdowns occurred. Here, the students could try communicating their confusion to the robot by verbally stating that they did not understand what to do, or shrug their shoulders while pointing to the task. Some of the other students became more withdrawn from the robot and the task, expressed through either inactivity or emotional distress. While the students were in pairs, they could, instead, start mocking the robot.

In relation to the second theme, breakdowns were due to the robot providing irrelevant and confusing scaffolding (i.e., guidance which stood in direct contradiction to the actual solution). It could, e.g., point in the wrong direction, repeat the same guidance over and over, or question the students' current line of action, making them second guess whether they were on the right track. When interacting with the robot individually, the students either requested assistance from the researcher in order to solve the task when this happened, or they expressed frustration. While in pairs, however, the students acquired social support from each other, and tended to make fun of the robot instead of becoming frustrated.

When it comes to the third theme, several breakdowns occurred when something happened within the scenarios that was either inconsistent with what the students had encountered earlier, or that the students perceived as unfair. During some sessions, there could, e.g., be important pieces of information missing from the map-reading task, which the robot nevertheless kept referring to. This could cause frustration in the students. In the sustainability game, the students could, e.g., express that the robot was not cooperative with their strategies, or that it had not informed them that the game could end if they ran out of non-renewable resources. In such cases, the students tended to blame the robot, and explained in the follow-up interviews that the robot did not adhere to the strategy that the students had decided upon. After the students had played the sustainability game a few times, they tried to overrule the robot's decisions (since they could not communicate with it) by taking over its personal menu upon its turn. This typically caused the robot and the game to malfunction, which subsequently resulted in breakdowns where the researcher needed to provide assistance.

The fourth and final theme related specifically to technical problems with the interactive table or the robot, but such problems could also be the result of poor design choices. For example, during the map-reading task, the interactive table was often not responsive to the students' touch. Thus, correct answers were often times not registered, which meant that the robot did not provide positive feedback, but instead, additional scaffolding to the student. At the beginning of the study, the students seemed to think that the robot could see where they pressed on the table, making them rely on the robot's feedback. After some time, however, the students realized that they needed to be more persistent when selecting their answers on the table, which, of course, caused problems when the students were persistent about selecting answers that were incorrect. In the collaborative sustainability game, poor design choices, such as providing the option to quit the game without any option to resume, or placing a button which afforded the possibility of skipping a turn very close to where the students liked to casually lean on the interactive table, could result in arguments among the students, where the researcher needed to intervene. When the robot malfunctioned (i.e., it simply stopped speaking), the students usually tried to communicate with the robot first, but called for the researcher when this did not work. At such times, the session needed to be restarted.

Given the frequency of breakdowns in the interaction sessions, it was concluded from the study that the interaction sessions could not have transpired without a researcher present able to assist the students when needed. While the study illustrated the sensitivity of this specific technology when implemented in naturalistic school settings, it also showed that breakdowns are not primarily associated with this issue. Indeed, the observed breakdowns could in most cases be traced back to expectations that the students had of the robot as an intelligent agent, which it failed to fulfill.

6.2 Stakeholders' views on robots in education

In this subsection, the papers related to RQ2 are presented, moving from teachers' views, to students' normative perspectives, and finally, teachers' deliberations on ethical tensions.

6.2.1 Paper IV. Teachers' views on robots in education

In the first study with teachers, we interviewed eight teachers in Sweden, Portugal and the UK about their views surrounding the kind of empathic robotic tutors that were going to be developed within the EMOTE project. The interviews were semi-structured, and analyzed thematically. The study revealed a set of implications and concerns surrounding the educational use of this kind of robotic tutors in classrooms. The analysis derived the following five themes: *robots as disruptive technology, robots designed for classrooms, robots supporting teachers, aspirations for teaching and learning,* and *forming social and affective bonds with robots*.

First of all, the potential *disruptiveness* of the technology was considered. In their professions, teachers already face time restraints, where their administrative responsibilities are increasing. Robots were seen as potentially more demanding in this regard, e.g., if teachers had to deal with ensuring fair access to the robot among students. The teachers envisioned there to be conflict surrounding such issues, but reasoned that this might reduce in line with the novelty effect wearing off.

Second, the teachers thought it necessary that robots were *designed for classrooms*, i.e., functioned within the existing constraints of the setting. They wanted the robot to adapt to them and not the other way around. For practical reasons, they suggested that robots would be preferred if they could handle groups of students and not just individual work. Teachers did, however, reason that the robot would need to have a proper monitoring, and understanding of, social interactions so that it could deal with potential conflicts that could arise when students work in groups. However, for technical reasons, they were not convinced that a robot could accomplish this.

Third, the teachers recognized that robots could *support teachers* with administrative tasks and student assessment if they functioned autonomously. However, this was not different from the kind of assessment carried out by existing technology. For example, they saw the potential of robots recording information that teachers later could use for assessment purposes, but they were not interested in having a robot do any grading for them. Indeed, it was mentioned that grading responsibility was not even something they would allocate to a different teacher.

Fourth, in terms of how they envisioned the *aspirations* for robotic tutors to facilitate *teaching and learning*, they considered a robot to offer more opportunities for personalization of education. Here, robots were seen as possible motivators who could ask questions of students and encourage them to apply extra effort to their schoolwork.

Finally, when the teachers contemplated the possibility of robots forming *social and affective bonds* with students, the teachers expressed subtle concerns about the aims of research projects such as EMOTE. They questioned whether robots were intended to replace them as teachers, and expressed that this would constitute an undesirable consequence from their point of view. They also questioned whether robots could ever reach a stage of humanlike emotional intelligence, which they argued to be essential for actual human relationships.

From a methodological perspective, it was derived from the study that it was difficult for participants to envision what robots could do in a classroom, let alone have a strong opinion about it. It seemed that teachers required a more tangible experience than the abstract explanations made possible by the interview setting. It was therefore clear that robotic tutors really needed to be studied in situ, or that participants needed to have a clearer illustration of what a robot could potentially be or do in an educational setting before offering their in-depth views.

6.2.2 Paper V. Students' normative perspectives on robots in education

The second study related to RQ2 aimed to elicit students' normative perspectives on possible roles and functions of educational robots in the future through the use of a questionnaire. The study was conducted with 175 students in Sweden, Portugal and the UK. How participants were recruited differed, but in common was that school teachers were responsible for signing up for half-day workshops surrounding discussions on the future of educational robots. During the day of the study, the students took part of the fictive scenarios described in Section 5.3.2, and group discussions, before filling out the questionnaire described in Section 5.3.3.

The results of the study indicated that students considered robots to be acceptable additions to classroom practices: a majority of the students could envision robots featuring in schools. For example, a majority of students responded that they would like to have humanlike robots in education; that they could envision talking to such robots both alone and with classmates, as well as to ask robots for help with their schoolwork. However, when going into detail about different robot roles and features which are technically possible or may be so in the future, it was clear that some aspects of educational robots were deemed more acceptable than others. About 70% of the students responded that they thought that robots should both express emotions, as well as interpret the emotions of students. In addition, a little over half of the students thought that they could develop a friendship with a robot. In contrast, some aspects of educational robots were deemed less desirable; working with young children, replacing teachers or grading students' schoolwork were all undesirable practices. Also, most students did not think that they would be able to trust a robot, nor would they like a robot to record them, or make decisions on a more general level concerning matters in society. Nevertheless, the majority of the students responded that robots should be held responsible for potential wrongdoings.

There were potential limitations to this study which may have impacted the results. While the intention was not to bias the students, it is likely that the use of fictive scenarios and the previous group discussions influenced their responses. However, this risk was weighed against the known challenges inherent in envisioning futuristic technologies, and it was therefore concluded from the study that the students could not have been engaged in a study on the social desirability of specific robot capabilities in education unless they were given a thorough walkthrough on what these different capabilities are beforehand.

6.2.3 Paper VI. Teachers' ethical deliberations on robots in education

The aim of the final study was to involve teachers in ethical deliberations on the future use of educational robots through focus group discussions (Cohen et al., 2013; Vaughn, Shay Schumm, & Sinagub, 1996). Practicing teachers and students with teaching backgrounds currently pursuing a Master's degree were recruited for the study, amounting to a total of 77 participants in Sweden, Portugal and the UK. Most participants had teaching experience and a teaching degree at the time of the study. There were twelve focus groups, four in each country. Each group took part of the fictive scenarios described in 5.3.2. The focus groups lasted approximately one hour each. The focus group facilitators had a small set of key issues that were supposed to be addressed during the discussions, namely participants' views on children's privacy, responsibility, their own teaching roles, and effects on children's behaviors if they were to have robots in the classroom. The discussions were transcribed and translated to English when necessary, which were then analyzed thematically around the four key issues.

The thematic analysis revealed that participants compared issues of privacy against existing problems in this area (such as the use of CCTV in UK classrooms), but saw 'empathic' robots as more intrusive due to their capturing of affective data. Teachers were also concerned about the fact that students would not be able to make an informed choice in this regard. Moreover, teachers were skeptical towards the idea that emotions could be measured, or that robots would be able to make accurate assessments of children's emotions. They were also concerned about the risks versus the benefits surrounding robots collecting data on students, which could potentially be hacked by a third party, or be used for purposes of surveillance or commercial benefit.

Second, in relation to the second theme concerning what roles a robot could assume in a classroom, teachers expressed that a robot should not engage in teaching activities which implied a certain pedagogical expertise, such as the teaching of novel concepts or evaluating students' assignments. Moreover, they were concerned that robots were part of a plan to replace their roles in education. Also, they were worried that robots would introduce an extra burden for them, and as a response to this, they argued that they would need technical support onsite and proper training on how robots work. Finally, they also felt that purchasing such a technology would lead to costs that threaten other more basic needs within education.

In relation to the third theme of how interactions with robots may affect children, several subthemes were discussed. Teachers were concerned about de-humanization resulting from these interactions. For example, it was assumed that robots would not be able to interact on a human emotional level. Thus, they were concerned that children would start to struggle understanding human facial expressions leading to impaired emotional intelligence, or that their speech would become affected. They were also concerned that children would not develop a proper understanding of consequences in human relationships if they interacted too much with robots. Moreover, teachers were concerned about the moral implications of engaging in asymmetrical power relationships with robots, where children may have the upper hand. Here, they once again conceived that this might be carried over to their human relationships. Conversely, the opposite scenario was also considered where robots are deployed with sinister motives in order to influence and control children. Teachers were also concerned that children may grow too attached to robots, preferring them over human contact. At the same time, they recognized that such a relationship would be unbalanced and potentially damaging, and they considered that children may later feel deceived by this.

Fourth, the responsibility issue was considered both instrumentally and ethically. From an instrumental perspective, they considered that teachers should be responsible for what happens in the classroom, as well as the safety of their students. However, they did not want responsibility for the safekeeping of the robot, arguing that children may very well damage it intentionally or unintentionally. From an ethical perspective, they argued that there was a risk that some teachers would allocate too much responsibility to a robot. Also, the irreversibility of possible emotional damages to children resulting from interacting with robots over a long time was highlighted. Here, it was not clear who they thought could be held responsible, but they advocated for a cautious approach.

7 Discussion

There has been an increase in research efforts in recent years aiming at the exploration of robots featuring in various settings. The combination of technical developments, on the one hand, and the digitalization of education, on the other, now provides the conditions for increased interest in enabling the future deployment of social robots in education on a larger scale. In this thesis, a number of lessons has been learned regarding how children interact with a particular kind of social robotic tutor in a naturalistic educational setting, and about the ethical perspectives of both teachers and students related to the use of such robotic tutors in education.

In this chapter, the research findings derived from the six studies are discussed in relation to previous research in this field. The chapter contains a series of sections, where the first deals with findings related to RQ1, i.e., how children interact with robotic tutors in education. The second section discusses how teachers and students view possible future uses of robots in education, related to RQ2. Thereafter, implications related to the educational use of robots are discussed by integrating findings from both research questions. In the fourth section, limitations concerning the methodologies used in this thesis are discussed, whereas the fifth and final section provides ideas and suggestions for future work in the field of CRI.

7.1 Understanding children's interactions with robots

This thesis has studied in detail how children interact with a robotic tutor in a classroom setting. The first study explored how children responded to step-by-step instructions delivered by a robot or a teacher through video analysis (Paper I). It was found in the study that children fully complied with the robot's instructions, as did children in the teacher condition. This finding supports previous research studying adults' compliance with instructions conveyed by robots (Bartneck et al., 2010; Geiskkovitch et al., 2016), but stands in contrast to the study by Kennedy et al. (2015a), which found that children complied with a robot's instructions in only 84% of the cases. These differences are likely due to the differences in task, i.e., a simple LEGO house construction in my study versus a discovery learning activity in the study by Kennedy et al. (2015a). In the former, the instructions were structured and clear, whereas in the latter, the instructions were more similar to suggestions made by the robot, in order to facilitate progress and learning. This suggests that children's compliance with instructions from robots is more related to the complexity of the task. Thus, it was concluded from the study that children's interactions with robots needed to be studied through more complex tasks, as well as over a longer time period, so that the interactions could become more natural and reflective of traditional tutoring situations.

While the first study particularly focused on following instructions given by a robotic tutor, it did not pay much attention to the social interaction between the children and the robot. Therefore, in the second study (Paper II), children's responses to a set of social probes delivered by a robot during an individual map-reading activity were investigated over time through video analysis. The study found that children responded to the robot's probes through social mechanisms, including gaze, verbal interaction, gestures, and facial expressions. This finding supports previous studies that have found that humans interact with robots in social ways (Anzalone et al., 2015; Castellano et al., 2009; Sidner et al., 2005; Tielman et al., 2014). The study also revealed that these responses decreased over time in step with a possible novelty effect wearing off, which is in agreement with previous research on children's interactions with robots (Leite et al., 2013). However, since the video analysis was only conducted at the beginning of each session, it was deemed important to take a more in-depth look at individual children's interaction sessions over time, in order to explore this further.

Therefore, the third and final study associated with RQ1 explored breakdown situations that occurred in children's interactions with a robot during both an individual map-reading activity, as well as during a sustainability game where children played in pairs over several sessions. Through video analysis, the course of events and causes of breakdowns were identified (Paper III). It was found in the study that breakdowns frequently occurred in children's interactions with the robot, and that these were due to the robot's inability to evoke initial engagement and identify misunderstandings, its confusing scaffolding, lack of consistency and fairness, or problems of a more technical nature (referred to as controller problems). While this study was highly explorative since breakdowns have not previously been thoroughly studied in the field of CRI, the findings support the observations made by Ros et al. (2011), who noted that technical issues with robots can cause breakdowns in engagement. However, the findings also highlight a set of more complex social issues that take place in children's interactions with robots, and in that sense, contradict the proposition by Belpaeme et al. (2013) that a robotic embodiment in and of itself provides enough assurance for children to compensate for a robot's perceptive and social shortcomings. It is possible that the occurrences of breakdowns also influenced children's perceptions of the robot as a social actor such that its limitations only became apparent after some time had passed. This could explain the decreased social responses to the robot over time as reported in Paper II. In congruence with Ros et al. (2011), the findings suggest that robots may need to be equipped with appropriate strategies in order to repair potential breakdowns. However, these strategies are not only needed to repair technical breakdowns, but also social breakdowns, as well as other breakdowns that bring the learning activity to a halt—such repair strategies require great technical advancements.

As these studies show, current robotic tutors are not advanced enough to fulfill children's expectations and uphold interactions over time (only in the short term). They are therefore not feasible additions to education yet. In line with an RRI approach, this provides the opportunity to study the social desirability of robots before they actually make their way into education, so that insights gathered can shape future developments in this field. Thus, in the next section, my research studies associated with RQ2 are discussed.

7.2 The social desirability of robots in education

Besides looking at children's actual interactions with a robotic tutor, this thesis has studied in detail what concerns teachers and students have related to the introduction of robots in educational settings. The first study explored practicing teachers' views on empathic robotic tutors in education through semi-structured interviews (Paper IV). It was found that teachers' felt that robots should be designed with the practical contexts of classrooms in mind, that robots could potentially alleviate some of their teaching duties, and that they could personalize education to individual students' needs; yet, the teachers were concerned about robots becoming disruptive for classrooms, highlighted the undesirability of the interaction with robots replacing human relationships, and questioned whether robots could really be responsive to the emotions of children. These findings resonate with previous research related to influential factors for teachers when adopting new educational technologies and/or robots in the classroom: robots should meet practical needs (Ottenbreit-Leftwich et al., 2010), and be useful (Fridin & Belokopytov, 2014; Kennedy, Lemaignan, et al., 2016; Lee et al., 2008; Teo, 2011); however, teachers may still feel reluctant to embrace new technologies such as robots in the classroom because of fears (Ertmer et al., 2012) associated with the potential disruptiveness of their use (Reich-Stiebert & Eyssel, 2016), as well as robots potentially replacing human relationships (Diep et al., 2015; Lee et al., 2008; Reich-Stiebert & Eyssel, 2016). In regard to the former concern, Kory Westlund et al. (2016) found that teachers' perceptions of robots as disruptive technologies diminished after having a robot in their classroom for some time. In regard to the latter concern, scholars in the field have argued that it might even be likely that children will prefer to interact with robots, possibly influencing the development of human relationships (Bryson, 2010; Kahn et al., 2013; Sharkey & Sharkey, 2011; Turkle, 2006). Taken together, it seems to be the case that robots introduce additional concerns for teachers compared to the adoption of educational technologies in general.

From an RRI perspective, it was deemed important to focus more explicitly on the ethical issues and social desirability of robots entering education. Thus, in the second study, students' normative perspectives on a set of issues were explored by means of a questionnaire (Paper V). The study found that students considered the educational use of humanlike robots to be socially desirable, but robots replacing teachers, interacting with young children, grading schoolwork, and recording students were all considered undesirable features of such robots. These findings support previous research surrounding students' concerns regarding privacy (Steeves & Regan, 2014). While these privacy concerns do not seem to be associated with being observed and understood by the robots themselves, as raised by Kahn et al. (2007), they do seem to be associated with fears of being surveilled (Kahn et al., 2007; Sharkey, 2016). Also, like teachers in the previous study, students were concerned about the impact of robots on younger generations, and they did not find it socially desirable to afford robots too much autonomy or influence in future classrooms. These findings also show that even if we reach a stage where robots become advanced enough to be able to replace human teachers, as discussed by Sharkey (2016), this would be deemed undesirable from students' points of view. In line with what has been argued by scholars concerning the importance of human relationships (Heersmink et al., 2014; Nordkvelle & Olson, 2005; Turkle, 2006), students seem to value their relationships with teachers, and consider them irreplaceable by technology even if truly sociable robotic tutors would become technically possible in the future.

Since the first study with teachers comprised only eight participants, all directly involved in providing design considerations for the EMOTE project's development, it was considered necessary to involve additional teachers that did not have any stakes in the project itself. Thus, the third and final study involved practicing and pre-service teachers in focus group deliberation on ethical issues and the social desirability of robots in education (Paper VI). It was found that teachers were concerned about the implications for children's privacy, where there were perceived risks associated with the recording of personal data and/or data about children's emotional states. Here, risks of surveillance and improper usage were emphasized. Similar to students' normative perspectives, they found it socially undesirable to replace teachers with robots, and were concerned that education might be moving in such directions nonetheless. They expressed concerns that extensive interactions with robots could affect children in the longer term, where children would not, e.g., develop proper empathic skills, in which case they perceived a moral impasse since no one could assume legal responsibility for such effects. These findings illustrate that teachers have ethical concerns that are similar to those presented in Section 3.2.3, such as the risk of extensive interactions resulting in psychological harm (Kahn et al., 2007; Kahn et al., 2013; Sharkey & Sharkey, 2011; Turkle, 2006), or that sensitive data on children can be used for unjust means and ends (Kahn et al., 2007; Sharkey, 2016).

Taken together, the studies conducted with stakeholders illustrate quite clearly that robots are not seen as desirable replacements for teachers in education, and that movements forward in the field should consider stakeholders' concerns regarding the level of autonomy and influence that robots should have on the assessments and evaluations carried out in education. It can also be derived from the studies that privacy is highly valued, and any form of data collection for surveillance and/or commercial purposes, should have no place in educational robotics as far as teachers and students are concerned. Nevertheless, robots are thought to potentially fit into the educational context, as long as the safety and wellbeing of children can be ensured through legal frameworks. Otherwise, there is a possibility that educational institutions will opt out when it comes to the educational use of robots. In sum, the studies revealed that stakeholders hold normative perspectives about the use of robots in education that stand in contrast to how robots are currently developed.

7.3 Robotic tutors in education

A clear tension can be understood if one takes a step back and considers the interplay between the findings related to RQ1 and the findings related to RQ2 in this thesis. In regard to the former, it can be derived that children are prone to interact socially with robots in natural classroom environments. However, when robots do not live up to children's expectations because they lack the necessary perception and/or intelligence to interact functionally in the setting, this causes breakdowns, and a decrease in students' social engagement over time. In order to address this issue, there are two possible solutions; either robots only function in structured and simple tasks, in which case they do not hold the proposed educational benefit, or, as the research field is striving toward, robots need to become more perceptive, and more intelligent. The problem is that once this happens [and it will likely happen, although, perhaps not in the nearest future (Sharkey, 2016)], this holds a number of potential implications that are considered undesirable and unethical by stakeholders in education: children may spend too much time interacting with robots over humans, and will therefore not be allowed to develop as they should psychologically and emotionally (Kahn et al., 2013; Sharkey, 2016; Turkle, 2006); robots need to collect a vast amount of data for their perception to function, which can be hacked or used for surveillance and/or commercial purposes (Kahn et al., 2007; Sharkey, 2016); and finally, robots may behave in ways that are unethical due to their advanced programming that neither developers nor teachers can acquire a sufficient overview of (especially if robots become self-directed learners) (Gill, 2008), which leads to a responsibility gap where no evident party can be held legally accountable (Asaro, 2007; Marino & Tamburrini, 2006). Thus, much work is required from researchers and developers alike, in order to find a balance.

7.4 Methodological considerations

A methodological limitation related to the studies addressing the first research question in this thesis is that only one type of robot was studied. It was a humanoid embodiment, featuring in a tutoring role, operating within delimited tasks. Therefore, it is possible that my findings may not hold across all types of social robots in education. Two of the tasks (i.e., the LEGO construction and the map-reading task) were structured and had clear trajectories, whereas one of the tasks (the sustainability game) was more open and creative. The setting probably also played a role. For the LEGO task, children interacted with the robot while alone in a classroom; during the other two tasks, children interacted with the robot in a small group-room adjacent to the classroom [similar to divider walls used to screen off children in other classroom-based CRI studies (Gordon et al., 2016; Kory Westlund et al., 2016), but where the group-room setting offered a sound proof environment in which the children and the robot could speak out loud rather than use the otherwise necessary headphones].

Moreover, although the interactions spanned across a little over three months, this can perhaps not be considered long-term in the true sense of the word, where children would potentially interact with robots over the course of their entire educational experience. However, such a study is only possible to carry out if more robust robots are developed, and actually implemented in education on a larger scale, and even then, this would require a large intrusion and effort.

Taken together, there are a number of methodological lessons learned from my research carried out with children and robots in a naturalistic school setting, which I consider to be important considerations for future research:

- Short-term, experimental studies in CRI must be increasingly complemented with longitudinal studies in order to understand how interactions develop over time.
- More effort must be put into recognizing the effects of different settings when it comes to studying different applications for robots (in this case a school setting).
- Individual versus group interaction play a significant role in CRI, where one child may interact entirely differently with a robot alone versus in collaboration with others.

- The educational scenarios developed to be used with the robot play a significant role, not only for the potential educational gain, but also for how the interaction evolves.
- Studying breakdowns in CRI reveal important considerations regarding the practical application of robots in specific settings.
- The researcher onsite needs to be responsive to children, make sure to have a sufficient overview of what occurs during the interactions, and always be ready to intervene.

In relation to the methodology used to address my second research question, there were limitations associated with how educational robots were introduced to the participants. Whichever choice was made regarding to what degree the concept was introduced, there would always be drawbacks. When comparing the two studies with teachers, where the first was a semi-structured interview setting without an extensive introduction to robotics, and the second showed the fictive scenarios, it was apparent that it was easier for teachers in the second study to reason and discuss the topic (as was also the case for students). When no such introduction was given, teachers had difficulties envisioning what it might be like to have a robot in their classroom. The fact that teachers lacked practical experience using robots in their classroom, coupled with a certain level of skepticism regarding the ability of technology to, e.g., interpret human emotions, made it difficult to get to a point of discussing the desirability of such aspects. This made the use of fictive scenarios, as was done in the latter studies, effective when seeking to elicit discussions. However, when providing participants with fictive scenarios, it is important to consider what one wishes to accomplish. On the one hand, it affords the possibility of going more in-depth regarding different issues, but on the other hand, it also risks introducing bias. A possible solution to this could be to make it possible for teachers to acquire practical experience using robots in their classroom [as was done in the study by Kory Westlund et al. (2016)], followed by more futuristic scenarios.

7.5 Future work

Following this work, a number of suggestions for future work in this field can be made. First, the work suggests that there is tentative evidence of a relationship between a reduction in children's social responses to robots, and the breakdowns that occur throughout the interactions. It would therefore be interesting to explore whether this is a causal relationship, such that breakdowns in interaction reduce children's perceptions of robots as social actors, and thereby also their social responses to them, or if children's social responses to robots are only novelty effects that simply reduce when children have grown accustomed to their presence.

Second, it is evident from this research that future work would benefit from a combination of naturalistic interventions, followed by deliberations with participants using fictive scenarios. Here, focus should be on what is realistic to accomplish with robots in education, and avoid making grand claims about the capabilities of robots to alleviate teachers' workload or support learning, without also considering the potential downsides. In relation to the dimensions of RRI, the studies carried out to explore teachers' and students' views on robots in education in this thesis, answered to three out of four commitments, i.e., they were *anticipatory, reflective,* and *deliberative* (Owen, Stilgoe, et al., 2013). Further research therefore needs to be conducted, so that developers and future research projects can commit to the fourth dimension in RRI of being *responsive* to whatever needs and concerns stakeholders may have.

However, it should be noted that being involved in such research projects, makes it difficult to be responsive, since there is typically a pre-proposed solution.

As Clark (1994) argues:

> "Part of the difficulty, in my view, is that we tend to encourage students (and faculty) to begin with educational and instructional solutions and search for problems that can be solved by those solutions. Thus we begin with an enthusiasm for some medium, or individualized instruction, or deschooling—and search for a sufficient and visible context in which to establish evidence for our solution" (Clark, 1994, p. 28).

Further, as Rogers and Marsden (2013) put it: "Researchers take it upon themselves, with varying degrees of user involvement or participation, to work out ways of helping those we have identified as potential user groups whose lives we can improve through our various technological interventions" (p. 51). Šabanović (2010) refers to this approach as 'technocentric', in that the "research aims emphasize the exploration of technical capabilities and define social problems in terms that make them amenable to technological intervention" (p. 439).

As suggested by Ljungblad et al. (2016), one way of amending this situation when moving forward in practice could, e.g., be to complement the existing robotics-centered research projects with projects that do not propose a fixed solution within the research funding application. To do so might facilitate the early involvement of target users in the design process to a greater extent. Here, stereotypes regarding what stakeholders might need should be avoided, and efforts should be geared towards creating solutions that solve stakeholders' problems, and to open up the design space for active public involvement in the technologies that are developed for society (Ljungblad et al., 2016).

8 Conclusion

When novel technologies are implemented in education, this affects the social and practical environment in the classroom as a whole. When robots are introduced, children are faced with a technology that interacts with them in a social way, and that they can respond to in kind, if they choose. At the beginning of this thesis, I set out to offer a guiding discussion on the current and future implications facing the educational use of robots in social roles. This has been explored through the following two research questions: *How do children interact with a humanoid robotic tutor in a school setting, and what implications does this pose for the educational use of robots*, and, *How do teachers and students view the possible implementation of robots in future classrooms in relation to educational practices and ethical tensions?*

By studying children's interactions with a robotic tutor in a school setting over time, the thesis finds that there are complex issues at play in these types of interactions. Taking Selwyn's (2008) argument regarding the *state of the actual* seriously, it is clear that robotic tutors might be innovations of the future, rather than the present. There are a number of challenges of a purely technical nature, such as robots lacking the necessary perceptive capabilities to interact in a socially acceptable manner or really help students with their learning tasks in a meaningful way, that limit their feasibility. Nevertheless, the future may have something entirely different in store in terms of technical capacity, making the presence of such social robots a question about desirability rather than possibility. In turn, ethical questions have been addressed regarding whether this shift in interaction is a development that we want to see amplified in education, seen from the eyes of teachers and students. Here, the thesis identifies ethical issues associated with privacy, what sorts of autonomous decisions robots can actually make, and other aspects that make educational robots a delicate matter. Taken together, these contributions offer some new perspectives on Child–Robot Interaction—what we could do with robots in education—and what we should.

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Collection of papers

Paper I

Comparing a humanoid tutor to a human tutor delivering an instructional task to children

Sofia Serholt, Christina Basedow, Wolmet Barendregt, and Mohammad Obaid

Paper II

Robots tutoring children: Longitudinal evaluation of social engagement in child–robot interaction

Sofia Serholt and Wolmet Barendregt

Paper III

Breakdowns in children's interactions with a robotic tutor: A longitudinal study

Sofia Serholt

Submitted to an international journal

Paper IV

Teachers' views on the use of empathic robotic tutors in the classroom

Sofia Serholt, Wolmet Barendregt, Iolanda Leite, Helen Hastie, Aidan Jones, Ana Paiva, Asimina Vasalou, and Ginevra Castellano

Paper V

Students' normative perspectives on classroom robots

Sofia Serholt, Wolmet Barendregt, Dennis Küster, Aidan Jones, Patrícia Alves-Oliveira, and Ana Paiva

Paper VI

The case of classroom robots: Teachers' deliberations on the ethical tensions

Sofia Serholt, Wolmet Barendregt, Asimina Vasalou, Patrícia Alves-Oliveira, Aidan Jones, Sofia Petisca, and Ana Paiva