POLITECNICO
DI TORINO

Doctoral Dissertation
Doctoral Program in Management, Production and Design
(30th Cycle)

Design for Child-Robot Play

The implications of Design Research within the field of Human-Robot Interaction studies for Children

By Maria Luce Lupetti

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ScuDo
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WHAT YOU ARE, TAKES YOU FAR

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The implications of Design Research within the field of Human-Robot Interaction studies for Children

By
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Politecnico di Torino
2017

To my beautiful family.

Luciana
Moreno
Francesca
Maria
Lorenzo

Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Maria Luce Lupetti
2017

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Abstract

This thesis investigates the intersections of three disciplines, that are *Design Research*, *Human-Robot Interaction studies*, and *Child Studies*. In particular, this doctoral research is focused on two research questions, namely, *what is (or might be) the role of design research in HRI?* And, *how to design acceptable and desirable child-robot play applications?*

The first chapter introduces an overview of the mutual interest between robotics and design that is at the basis of the research. On the one hand, the interest of design toward robotics is documented through some exemplary projects from artists and designers that speculate on the human-robot coexistence condition. Vice versa, the robotics interest toward design is documented by referring to some tracks of robotic conferences, scientific workshops and robotics journals which focused on the design-robotics relationship. Finally, a brief description of the background conditions that characterized this doctoral research are introduced, such as the fact of being a research founded by a company.

The second chapter provides an overview of the state of the art of the intersections between three multidisciplinary disciplines. First, a definition of Design Research is provided, together with its main trends and open issues. Then, the review focuses on the contribution of Design Research to the HRI field, which can be summed up in actions focused on three aspects: artefacts, stakeholders, and contexts.

This is followed by a focus on the role of Design Research within the context of children studies, in which it is possible to identify two main design-child relationships: design as a method for developing children's learning experiences; and children as part of the design process for developing novel interactive systems.

The third chapter introduces the *Research through Design* (RtD) approach and its relevance in conducting design research in HRI. The proposed methodology, based on this approach, is particularly characterized by the presence of design explorations as study methods. These, in turn, are developed through a common project's methodology, also reported in this chapter.

The fourth chapter is dedicated to the analysis of the scenario in which the child-robot interaction takes place. This was aimed at understanding what is edutainment robotics for children, its common features, how it relates to existing children play types, and where the interaction takes place. The chapter provides also a focus on the relationship between children and technology on a more general level, through which two themes and relative design opportunities were identified: physically active play and objects-to-think-with.

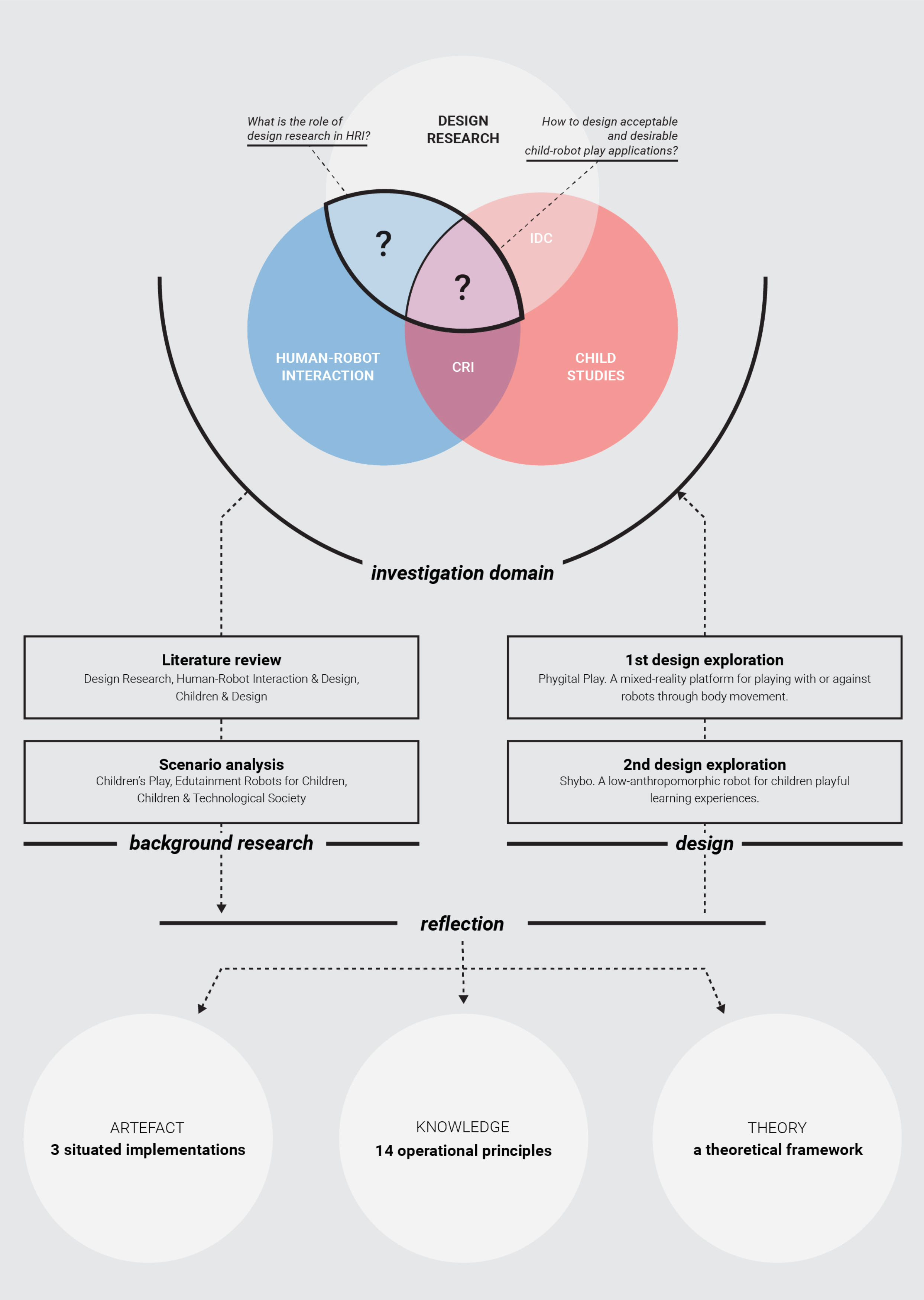
These were respectively addressed in the two design explorations presented in this thesis: *Phygital Play* and *Shybo*.

The *Phygital Play* project consists of an exploration of natural interaction modalities with robots, through mixed-reality, for fostering children's active behaviours. To this end, a game platform was developed for allowing children to play with or against a robot, through body movement.

Shybo, instead, is a low-anthropomorphic robot for playful learning activities with children that can be carried out in educational contexts. The robot, which reacts to properties of the physical environment, is designed to support different kinds of experiences.

Then, the chapter eight is dedicated to the research outcomes, that were defined through a process of reflection. The contribution of the research was analysed and documented by focusing on three main levels, namely: artefact, knowledge and theory. The artefact level corresponds to the situated implementations developed through the projects. The knowledge level consists of a set of actionable principles, emerged from the results and lessons learned from the projects. At the theory level, a theoretical framework was proposed with the aim of informing the future design of child-robot play applications.

The last chapter provides a final overview of the doctoral research, a series of limitations regarding the research, its process and its outcomes, and some indications for future research.



What is the role of design research in HRI?
DESIGN RESEARCH
How to design acceptable and desirable child-robot play applications?
?
?
IDC
HUMAN-ROBOT INTERACTION
CRI
CHILD STUDIES
investigation domain
Literature review
Design Research, Human-Robot Interaction & Design, Children & Design
Scenario analysis
Children's Play, Edutainment Robots for Children, Children & Technological Society
background research
1st design exploration
Phygital Play. A mixed-reality platform for playing with or against robots through body movement.
2nd design exploration
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design
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Chapter 1

Introduction

The first chapter of the thesis consists of the introduction to the area of investigation, at the intersection between design research, human-robot interaction studies, and child studies. The research area is introduced through a brief overview of the motivations, consisting of the interest in robotic technologies that are moving into the people's everyday life bringing a series of both positive and negative effects. The interest of design toward robotics is documented through some exemplary projects from artists and designers that speculate on the human-robot coexistence condition. Vice versa, the robotics interest toward design is documented by referring to the track of robotic conferences, scientific workshops and robotics journals that focused on the design-robotics relationship. Finally, a brief description of the background conditions that led to this doctoral research is introduced, namely a company interest toward integrating design into robotic-related research projects.

1.1 Why dealing with robotics from a design perspective

Nowadays, technology has reached a maturity that is enabling a wide diffusion of robotics in many areas of daily life. Until few years ago, this technology sector was seen as being confined to the research field or, at most, applied in the manufacturing or military sector.
Today, instead, the lowering costs and improved performances of both hardware and software components are opening up new applications opportunities also in the service domain, such as in the case of educational robots that started to spread also thanks to the possibility of constructing relatively inexpensive solutions (Ben-Ari and Mondada, 2017).
Thus, together with technological advances, robotics experienced not only a wide diffusion but also a transformation, both in research and in the applications. In fact, the challenges introduced by the automation of production processes, started in the sixties (Garcia et al., 2007), and by the use of remote controlled vehicles in military applications, diffused in the seventies (Fong and Thorpe, 2001), differ from the current challenges generated by the growth of the coexistence condition (Salvini et al., 2010) between humans and robots in many areas of daily life.
The early challenges regarding human-robot interaction, in fact, were mainly concerned about aspects like teleoperation, supervisory control, and task performance (Goodrich and Schultz, 2007). The co-presence condition of service robotics in many aspects of daily life, instead, adds further challenges. In addition to usability and safety issues, in fact, other facts regarding social acceptance, user experience and societal impact (Weiss et al., 2009) assume a crucial role.
More and more important, then, is becoming the practice of taking into account non-expert viewpoints and studying people's attitude and behaviours toward robots (Weiss et al., 2011).
The interest toward the potential users and indirect users of robots is not only oriented to getting information for informing the robot's design processes. More and more research, in fact, is being dedicated to the theme of mutual shaping between robotics and society (Šabanović, 2010), a theme whose relevance is due to a main issue. The enthusiasm for technological innovation regularly precedes the discussion of social needs (Šabanović, 2010), which reflects also on the fact of being a domain supported by politics for its expectations, promises and potentials, rather than for the problems actually addressed (Weiss et al., 2011).
Together with different challenges, the spread of robotics into daily life is also introducing different robot identities. In fact, the conventional types of robot, such as humanoids, arms, and vehicles, are now flanked by hybrid entities that embed animating principles and autonomous behaviours in existing and familiar objects. This emerging type, named "*RObjects*" by Fink et al. (2015), introduces a new interesting condition of objects as potential social agents.
The evocative power of the novel coexistence scenarios and of these new entities is what, today, qualify these as objects of investigation from writers, artists, and designers, who explore both opportunities and possible consequences of robotics, through their works.

1.1.1 Service Robotics

A useful categorization of robots according to their areas of application is provided by Ben-Ari and Mondada (2017).
According to the authors, two main categories can be identified: industrial and service robots.
Industrial robotics includes robots for manufacturing, such as articulated robots, and for logistics, consisting mostly in mobile platforms.
Service robotics, instead, includes robots for four main areas of application, that are medical, home, educational, and defence.
Medical robotics includes surgical robots, that enable minimally invasive procedures and also remote interventions, and robots for rehabilitations, aimed at supporting therapies and autonomous human actions, through robotic supports, such as exoskeleton.
Home robotics is very varied. To this category, in fact, belong both cleaning robots, such as robotic vacuum cleaners, and assistive robots, such as home personal assistants. Both types of robots are

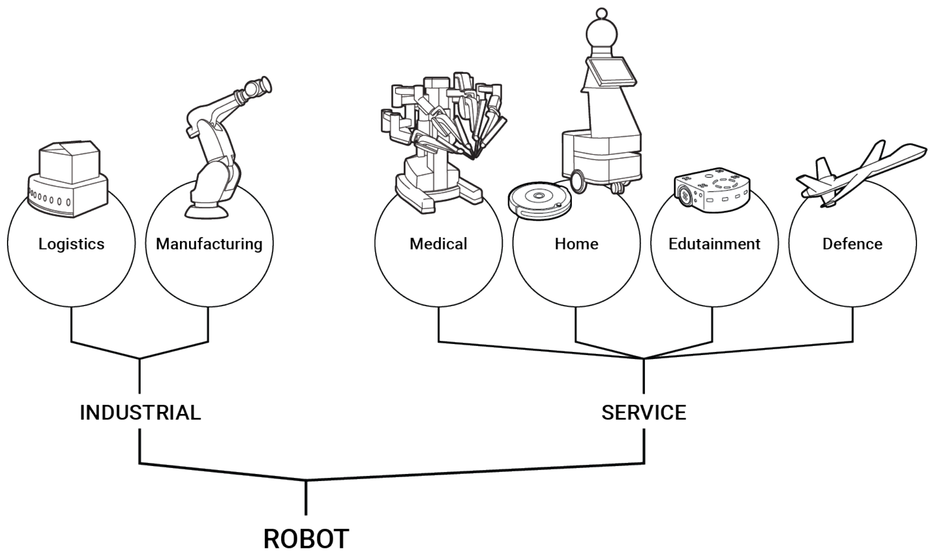


Fig. 1.1 - Robot categories, based on the classification by Ben-Ari and Mondada.

making this category increasingly more relevant. On the one hand, robotic vacuum cleaners have become a widely diffused product (Vaussard et al., 2014) that is perceived as a cleaning tool rather than a robot (Vaussard et al., 2014), enabling a number of in-wild studies that contribute to the understanding of robots' acceptability (Sung et al., 2010; Forlizzi and Di Salvo, 2006).

On the other hand, assistive robots, in particular for elderly people, are a category of robots that is still little diffused but with an extensive potential impact. Especially western countries, in fact, are experiencing a trend of aging in the population (Broekens et al., 2009) that will lead to a shortage of qualified healthcare in the near future. Thus, a large body of research is currently dedicated to the study of assistive robotics for elders, and people affected by disabilities, with the intent of understanding how robotics might support independent and active living (Forlizzi et al., 2004), and which aspects can increase the robot acceptance (Broadbent et al., 2009).

The category of educational robotics includes a large number of products intended for supporting learning, mostly for children. These products, usually, consist of mobile platforms that can be controlled and programmed through embedded tangible interfaces or educational programming software, such as Scratch (Resnick et al., 2009). These products are becoming more and more diffused, especially in schools, because of their acknowledged importance for learning both robotics principles and STEAM disciplines (science, technology, engineering, art and mathematics) (Kradolfer et al., 2014). The growing awareness about the importance of practice-based learning approaches and of STEAM education is leading many countries to introduce robot programming courses in the schools curricula. For instance, in Italy, 70% of primary schools carried out computational thinking and educational robotics activities, in the last two years (Solda and Lanfrey, 2017).

Although Ben-Ari and Mondada (2017) make reference only to the educational robots, this category can be expanded both in the definition and the contents by including also those robots designed for entertainment.

The resulting category, commonly identified with the name of edutainment robots, includes products for both children and adults, that can be more oriented to the educational or entertaining aspects, such as robotic construction kits or teleoperated drones. In fact, robotic products with a primary entertainment purpose, that started to be popular in the last years, become also facilitator for introducing programming concepts through play, especially for children.

Finally, defence robotics consists of military applications for explorations, transportation, rescue, attack and supervision. These can be both terrestrial mobile platforms or unmanned aerial vehicles (UAV).

1.1.2 Robotics in contemporary art and design

As in many technology sectors, the development and commercialization of robotic products require also the participation of designers, that are usually involved for dealing with the design of robot morphologies and the visual design of graphical user interfaces (GUI). Nevertheless, the contribution of designers, as well as artists, can also go beyond the aspects of product design in favor of critical reflections on the role of technology in society.
The wide diffusion of robots in many aspects of daily life is defining new scenarios in which many tasks are getting automated, artificial intelligence is being employed also in the personal and private sphere, and social interactions are extended also to machines.
These phenomena are pushing writers, artists, and designers to speculate about the new opportunities supported by the introduction of robotics technologies, as well as their possible controversial effects and risks.
Peculiar, in this regard, is a book by Nourbakhsh called "*Robot Futures*" (2013). Although the author is a roboticist, the book presents a series of speculative reflections about possible futures in which humans and robot coexist and are deeply interconnected. By referring to some topics of the current research on robotics, such as gaze-tracking, telepresence, and nanorobotics, the author imagined a series of exasperated scenarios. For instance, regarding telepresence, the author imagines a possible future scenario in which each human can have multiple physical avatars that physically attend events instead of the real person. This enables each person to be simultaneously in more than one place and to interact with different people at the same time. Each story is presented as an exasperated scenario with the intent of rising reflections on the ethical implications of robotics.
Similarly, Demers and Vorn, artists and researchers, investigated the theme of symbiotic interaction between humans and robots, through a performance called "*Inferno*" (Vorn, 2015), that is being staged in many art festivals around the world. The performance consists of an active participation of the public that is invited to wear mechanical suits, like exoskeletons, some of which might be controlled by the human while others control the human. The performance, designed around the theme of hell, introduce the use of robots as leading force to which man must adapt.
The theme of human-robot relationship was also addressed by Tresset and Leymarie in their artwork "*Paul the robot*" (Tresset and Leymarie, 2012). In this project, the authors focused on the concept of robots as human slaves, resulting from the utilitarian approach to robot's design, and subverted it by generating a condition in which humans are robot's slaves. Paul, in fact, is a drawing robot that needs humans to perform some unskilled tasks, such as changing the paper for its drawings.
A more ironic approach to the speculation of possible scenario can be found in the work by Auger and Loizeau (2009), and by Automato (2015).
Auger and Loizeau designed a series of five domestic robots called "*Carnivorous Domestic Entertainment Robots*". The peculiar characteristic of these robots is that they feed on different living organisms for functioning, such as a clock that generates the energy that it needs by digesting flies. The robots were designed for exploring the theme of adaptation and domestication of robotic technologies, and for pointing out the potential influence of design on human-robot interaction studies as a discipline that encourages a focus on the complex nature of everyday life (Auger, 2014).
Similarly, the design collective Automato, explored the relationship between existing and familiar practices and technological advancements, through the project "*Teacher of algorithms*" (Automato, 2015). They imagined a scenario in which smart objects are not finished entities that can learn and evolve their behaviours according to the observation and interpretation of human habits. In this scenario, they described the emergence of a new role: the teacher of algorithm.
By making an analogy between learning objects and pets, the design collective imagined that even objects might be trained and evolve in an inappropriate way, thus, the training activity might become a specialized work. In the video that describes the project, this job of training objects is carried out by a man, a sort of mystical figure that shows how he can train objects like a robotic vacuum cleaner by using dust and hitting it with a stick, to make it turn.
The power of this project resides in the soundness of the proposed scenario. The current knowledge

Fig. 1.2 - A screenshot from the video "Teacher of algorithms", a project by Automato.

about certain technologies is combined with the concreteness of daily life, without the eager of creating futuristic and catastrophic imaginaries. Little malfunctions were used as incipit of a storytelling that, in the end, reveals a tight relationship between man and machines.

1.1.3 Historical outlines on robotics and pop culture

Speculative scenarios about novel conditions of coexistence between humans and robot are today, more and more object of investigation for writers, artists and designers. In particular, technological developments are currently enabling the automation of many activities and practices of daily life, a phenomenon driven by the desire for optimization and efficiency, that open up challenges from a philosophical and ethical point of view.
However, although these investigations are becoming more and more relevant and popular today, the history of robotics and its developments was always tightly bound also to artistic and humanistic disciplines.
Contemporary robotics, in fact, is the result of an "evolutionary" process that, by focusing on the challenge of replicating human beings and biological abilities, led people to reflect and investigate human nature, perception and identity. Thus, understanding robotics ask for a reflection on the relationship between the man and the man-made, whose origins can be traced to the ancient times.
From west to east ancient cultures, such as ancient Greece, Roman Empire and ancient India, many legends tell the stories of mechanical entities that were serving, entertaining, or challenging people (Logsdon, 1984). One of the first known examples from ancient Greece is the legend of *Talos*, a giant bronze statue of a man designed for patrolling the island of Crete (Merlet, 2000). Similar examples of automata can be found in Asian ancient literature, such as in *Liezi*, a Chinese text dated 300 BC (Mavridis, 2015). The most relevant aspect of these legends is that they reveal the presence and diffusion of the concept of automata, since ancient times, revealing this human interest in investigating the relationship between the created things and the role of creator.
Moving from myths and legends, early forms of actual automation can be found already in the work of *Heron of Alexandria*, a Greek mathematician, engineer and inventor, who wrote a series of manuscripts illustrating and describing a series of automatic devices such as a puppet theater controlled by strings, drums, and weights (Nocks, 2007). Especially regarding entertainment, in fact, automata achieved a great success over time, such as in the case of the automata by *Al-Jazari* (Mavridis, 2015). This Arab inventor designed and built several machines for entertaining the guests of the royal court, like water powered clocks, fountains, perpetual flutes and many more (Nocks,

2007).
Over time, automata became more and more diffused, especially in the design of scenographies and gardens for the courts (Fornari, 2012). In particular, in the eighteenth century, they become extremely popular and advanced, thanks to the marvellous work of personalities like *Jacques Vaucanson* and the father and son, *Jaquet-Droz*.
The former played a crucial role in the history of automation because of his work on devices for improving the quality of work in various sectors, such as an apparatus for the automatic weaving of brocades, and a machine for producing an endless chain (Bedini, 1964). However, what made him popular was the design of automata like the *Flute player*, able to play eleven melodies, and the *Digesting duck*, able to eat, drink and digest (Bedini, 1964). Similarly, *Pierre and Henry-Louis Jaquet Droz*, designed and developed some of the most spectacular automata preserved over time, namely the *Writer*, the *Artist* and the *Musician* (Bedini, 1964).
In this period, automata were experiencing a similar success even also in other parts of the world, especially in Japan. Peculiar, in this sense, is the *Kamezaki Shioni Festival,* a ritual that employed automata since the late fifteenth century (Hornyak, 2006). These automata, known as *karakuri*, consisted of small puppets with gears, rods, and silk cords controlled by hidden puppeteers, and seemed to be acting autonomously.
Both in western and eastern cultures, the mastery and popularity achieved through the development and diffusion of more and more advanced automata played a crucial role in opening the way to the automation of production processes. As stated by Bedini (1964):

"*several of the basic inventions produced for these attempts to imitate life by mechanical means led to significant development culminating in modern automation and cybernetics*".

In parallel with these technological advancements, the figure of automata continued to be largely present in literature and pop culture. Among the most popular examples can be found the story of a golem by *Judah Loew*, the Rabbi of Prague, the *Pantamerone* by *Giambattista Basile*, and the story of *Olympia* by *E.T.A. Hoffman* (Logsdon, 1984). These, as well as other examples from literature, reveal that already in the seventeenth century, the role of automata and its relationship with people was an object of investigation. In fact, although they were conceived to serve and protect humans, at some point in each of these stories the automata slip out of human control. These narratives addressed issues that are still crucial today: the theme of autonomy and of human control over technology.
The idea of automata as machines created by men to serve their needs, which at a certain point become autonomous and rebel against their creator, lasted over time. It was also at the basis of *R.U.R.* (*Rossum's Universal Robots*), a theatrical play by *Karel Ćapek*, staging the first time in 1920 (Naughton, 1984). In this play, the author described a society in which people live alongside with artificial men, created to work and serve, which in the end, rebel against the creators and take control of society. These artificial men were called *robots*, a word derived from the archaic Czech "robota", meaning obligatory work performed by medieval serfs (Hornyak, 2006).
Although the most evident legacy of this work is the term robot (Naughton, 1984), a great contribution of this play is represented by the philosophical and ethical reflections regarding the very nature of human beings (Kinyon, 1999).
This negative vision related to the diffusion of automata that might slip out of human control and take over society, however, was not shared by the eastern cultures. In particular, in Japan, the automata were mostly seen from a positivistic point of view, as a technical challenge and also the R.U.R. by Ćapek, replicated in many countries, was received very differently. In fact, reported by Hornyak (2006), a Japanese translator who attended the play in Tokyo commented as follow:

"*I think the author's intent was to show people controlling the ultimate science, yet not losing human love – that's where the future of humanity lies*".

This different approach toward automata can be traced to the different evolution that these had, over time, in the two different contexts. In the nineteenth century, in Europe, the automata moved from being technical wonders to fairground attractions, as in the case of the chess player by von Kempelen (Riskin, 2003), while in Japan, the development of humanoid automata kept on

prospering towards more and more functionalizing advancements (Fornari, 2012).
Although humanoid robots are still being developed both in many countries all over the world, from that time onwards, the divide between the western and the eastern approach started to grow. Starting from the first Japanese humanoid robot, *Gakutensoku* (Sharkey and Sharkey, 2009), the opposite approach became evident.
Gakutensoku was designed and developed by a biologist and writer, Makoto Nishimura in 1928 (Sharkey and Sharkey, 2009). It consisted of a robot Buddha, a giant golden man that could move the upper part of the body and move the eyes, and was able to write Chinese characters, sitting on an altar-like desk (Hornyak, 2006). As reported by Hornyak (2006), it was designed as an "ideal man" resulted from the marriage between art and science.
The first robots from the United States and Britain, instead, were mechanical in appearance and utilitarian (Hornyak, 2006). *Televox*, the first American robot developed in 1927 by the *Westinghouse Electric and Manufacturing Co.*, was designed for work and, more specifically, for replacing the human in a specific task (Sharkey and Sharkey, 2009). It was actually designed as a box of electronic components able to activate commands through a telephone mechanism.
Similarly, *Eric*, the first robot from Britain, although more humanoid than *Televox*, was also mechanical looking and designed as an artificial labourer that was enabling an operator to speak through from a remote location (Hornyak, 2006).
Despite these cultural differences, the development and diffusion of robotics, over time, pointed out the importance of addressing the implications of human-robot coexistence, in which the purpose, the functioning and the appearance of a robot are all playing a crucial role.
In this regard, literature and pop again culture addressed the role and identity of robots providing sources of inspiration and reflection that, over time, affected their design and the philosophical debate about them.
From the idea of a slave that rebel to its creator and threaten humanity, robots became complex identities with their consciousness. For instance, Isaac Asimov, in his books *"I robot"* and "*The rest of the robots*", introduced the laws of robotics and the moral dilemmas experienced by robot with consciousness. This anticipated the contemporary debate about robot's moral judgement, attribution of blame and, more in general, about roboethics (Veruggio and Operto, 2008).
Different and positive visions of robots were introduced, over time, both in Eastern and Western pop culture through comic books and movies. In this regard, the case of *Tetsuwan Atomu* (known as Astro Boy), a robot boy hero, is emblematic. This figure emerged after the Second World War, embodied a thinking at robots as a possible salvation for Japan and became a medium to express a critic of humanity (Hornyak, 2006). In fact, although endowed with great strength and intelligence, Astro Boy is an emotional and moral agent, able to suffer.
The idea of a robot as neither perfect nor invincible, but nevertheless helpful and important to humans was then presented also in Western pop culture. One of the most famous examples is provided by the *Star Wars* saga. *C3-PO* and *R2-D2*, in fact, have clear limitations both in terms of strength and abilities, but despite these, they play a crucial role as positive helpers in the story. Similarly, a more contemporary example of movie presents a weak and limited robot called *Wall-E* who, however, is elevated at the role of hero by its virtues and tenacity in saving the future of human existence. In this animation movie, the humanization of the robots is achieved through the design of human-like behaviours, rather than appearance.
Thus, the role of the robot evolved over time together with its possible identities and features, both in pop culture and real products, two dimensions that systematically affected each other. Differences in Eastern and Western culture can still be noticed, such as in the extremely human-like androids by *Hiroshi Ishiguro* that represent an emblematic example of Japanese robotics, with no counterpart in Western countries. Nevertheless, the emerging scenarios of coexistence between humans and robots ask, in any case for investigation on the emerging relationships and their possible consequences.

1.1.4 Robotics' interest toward design

As mentioned in the previous paragraph, the real developments of robotics and pop culture,

literature and art about robotics influenced each other systematically over time.
This is still happening today and the design and development of robots are becoming more and more open to contaminations from various disciplines.
This is also manifested by the growing mutual interest between robotics and disciplines like design and artistic practices.
If on the one hand, artists and designers are showing an interest toward robotics and its implications for society, on the other hand, robotics is more and more manifesting an interest toward design and its methodologies.
This interest has emerged in various ways, such as the organization design tracks in robotics conferences, scientific workshops focused on the design implications of robotics, and special issues in robotics journals.
Regarding the conference tracks, the IEEE International Symposium on Robot and Human Interactive Communication (Ro-Man) is dedicating tracks to design-related aspects of robotics from many years, especially to the "*Innovative robot design*" and to the "*User-centred design of robots*". nevertheless, these tracks are a couple out of a total of about forty tracks.
A greater estimation of the growing interest in design in the robotics conferences can be noticed regarding the ACM/IEEE International Conference on Human-Robot Interaction (HRI). In 2015, in fact, the conference dedicated one out of five tracks, to the "*Enabling Designs*" (HRI, 2015), with Jodi Forlizzi as theme chair. This track was dedicated to "*contributions that describe new robot designs, including new robot morphology, behaviours, or services*". It was specifically required to provide a detailed description of the process and of the resources and materials involved in the design of the robot. Particular attention was also required for the documentation of the design choices, such as formative evaluations, design iterations, and heuristics, and to the description of how such new designs enable human-robot interaction.
The following year, the track was renamed as "*Human-Robot Interaction Design*", and Guy Hoffman was theme chair. As reported in the conference website (HRI, 2016), the first part of the description of the track was similar to the previous one, namely "*research related to robot design from a broad spectrum of design practices, including form, interaction, and service design*". The second part, instead, was pointing out the interest toward "*a variety of design methodologies, including iterative prototyping, qualitative and quantitative evaluations, user-centered design, expert interviews, interdisciplinary design, video and animation prototyping, improvisation, crowdsourcing, Wizard-of-Oz, as well as novel methodologies for HRI design*", which, compared to the one of the previous year, seems to put emphasis on the making process.
In the following two years of HRI conference (2017 and 2018), the track kept the same title, but the description changed slightly, by naming the research to which the track is dedicated as "*design-centric contributions*".
Similarly, in the recent years, some scientific workshops focused on the design contribution and implications for robotics.
For instance, during the HRI conference in 2015, a workshop was dedicated to the theme "*Design skills for HRI. An introduction to human-centered design topics and practices*", organized by the Center for Design Research at Stanford University. The workshop was carried out as a "*hands-on introduction to human-centred design topics and practices for human-robot interaction*" (CDR, 2015). It was particularly focused on three actions: needfinding, design sketching and physical prototyping (not actuated prototypes). During the activities, participants were provided of a set of question sheets in which they had to report aspects related to the activities, the environment, the interactions, the objects, and the users that were part of a certain scenario under investigation.
Another example of a workshop is represented by the "*3rd workshop on CRI. Growing-up hand in hand with robots: designing and evaluating child-robot interaction from a developmental perspective*" (CRI, 2017), organized by the Human Media Interaction group at University of Twente. Although it was dedicated to the theme of child-robot interaction, this workshop was particularly focused on design principles and processes adopted for CRI. Among the suggested topics, in fact, the organizers pointed out some very design related ones, such as "*Developmentally appropriate robot design*", "*Interaction design challenges", and "Generative methods to include children into the design of robots*".
Also in robotics journals, the aspects of robot design gained more attention and, in some cases,

special issues were dedicated to the relationship between robotics and design.
In particular, a special issue titled "*Design in HRI: past, present and future*", edited by Holmquist and Forlizzi (2014), was published by the Journal of Human-Robot Interaction, in 2014. The primary motivation at the basis of this special issue was the fact design is considered an integral part of the field of human-robot interaction, and the relationship between the design discipline and the HRI field results in a mutual influence.
The special issue includes six contributions from established HRI researchers as wells as designers, artists and even special effects experts. The first article, by Oh and Park (2014), was dedicated to a historical investigation of morphological aspects of life-like and intelligent machines.
The second article, by Auger (2014), was dedicated to the theme of domestication through speculative projects as a practice that can facilitate the future success of robotic products in the domestic environment.
The third contribution, by Johnson et al. (2014), focuses on the theme of human-robot collaboration and it presents a design approach and a relative model that can be used for creating collaborative control of robotic systems.
The fourth article, by Šabanović et al. (2014), presents an iterative design process focused on an in-wild prototyping and testing of a robotic artefact for a real context. The detailed description of the process and the lessons learned represents a contribution to the knowledge regarding methodological issues related to the introduction of robots in realistic environments.
The fifth article, by Hoffman and Ju (2014), explores the role of expressive movement in HRI. The authors provide a description of techniques of movement-centric design that can be employed for designing robots.
The last article, by Scherer (2014), has a provocative character. The author, in fact, introduces the notion of character robot and propose a categorization of six robot characters, that are work, entertainment, companion, security, killbot, and sex robots. Each of these characters establishes an implicit moral connection with humans. The author describes also four traits of characters that can be employed for the development of social robots.
The contributions of the special issues, hence, pointed out certain aspects of the relationship between robotics and design. These are morphological aspects and character features that may guide the design and development of a robotic artefact, considerations regarding methodological considerations on the design processes, and aspects related to the compatibility, acceptability and moral implications of the introduction of robots in real environments. Thus, these can be summarized in reflections on the artefact, on the process and on the implications on the context.

1.2 A doctoral research on child-robot play

The mutual interest between robotics and design is at the basis of the research presented in this doctoral thesis.
On the one hand, in fact, the research started with the support of TIM (Telecom Italia, main Italian telco company) and carried out as part of the projects carried out at Jol CRAB, a lab focused on the theme of service robotics and connected applications of robotics. On the other hand, this interest from the robotic section of the research developed by TIM, was combined with a design interest in the chance of addressing the new challenges posed by the spread of robotics and for entering in a growing research field.
The fact of being supported by a company introduced also a focus in terms of area of investigation, namely the edutainment robotics, especially for children. This interest toward the robots for education and entertainment was motivated by the fact that these products experienced a massive diffusion in the last years. From educational contexts to private use, edutainment products are now widely diffused and familiar. Thus, of primary interest was the investigation of possible opportunities for providing connected services related to this potential network of smart products.
This research, then, focused on the intersection between three multidisciplinary fields (Figure 1.3), that are design research, human-robot interaction studies, and child studies. In particular, two areas of interest and two related research questions were identified. The research was, first of all, focused on the intersection between design and HRI studies.

In fact, carrying out research on specific areas of applications, such as on the employment of robots in children education, requires an understanding of what are the main specificities of the HRI field and how design can contribute or might need to adapt to it.
Thus, the first research question addressed in this thesis is *"what is (or might be) the role of design research in HRI?"*.
Then, a more specific focus pertains the intersection between all the three disciplines and introduces the second research question, that is *"how to design socially acceptable and desirable child-robot play applications?"*.
The first question, whose results are propaedeutic to the investigation of the second, was answered through a review of the current literature about design and human-robot interaction (Chapter 2), particularly referring to the articles published in the proceedings of the ACM/IEEE International Conference on Human-Robot Interaction, which is a leading and top quality conference for the field.
The results of this review were used to define the background knowledge and the methodological approach for addressing the second research question focused on the child-robot play theme.
The background knowledge was then integrated with a literature review about the relationship between design and child studies (Chapter 2), and with an analysis of the scenario of the child-robot play (Chapter 4).
Furthermore, existing knowledge about two other intersections was integrated into the background knowledge. In fact, the intersection between human-robot interaction studies and child studies is object of investigation for a large body of research, for instance, a group of researchers from the Human Media Interaction group at University of Twente, is carrying out research on the theme of child-robot interaction and sharing it through a dedicated website and through a series of scientific workshops (Zaga et al., 2016).
Even more, established is the field of interactions design for children, which has also a dedicated conference called "Interaction design and children conference", from 2001.

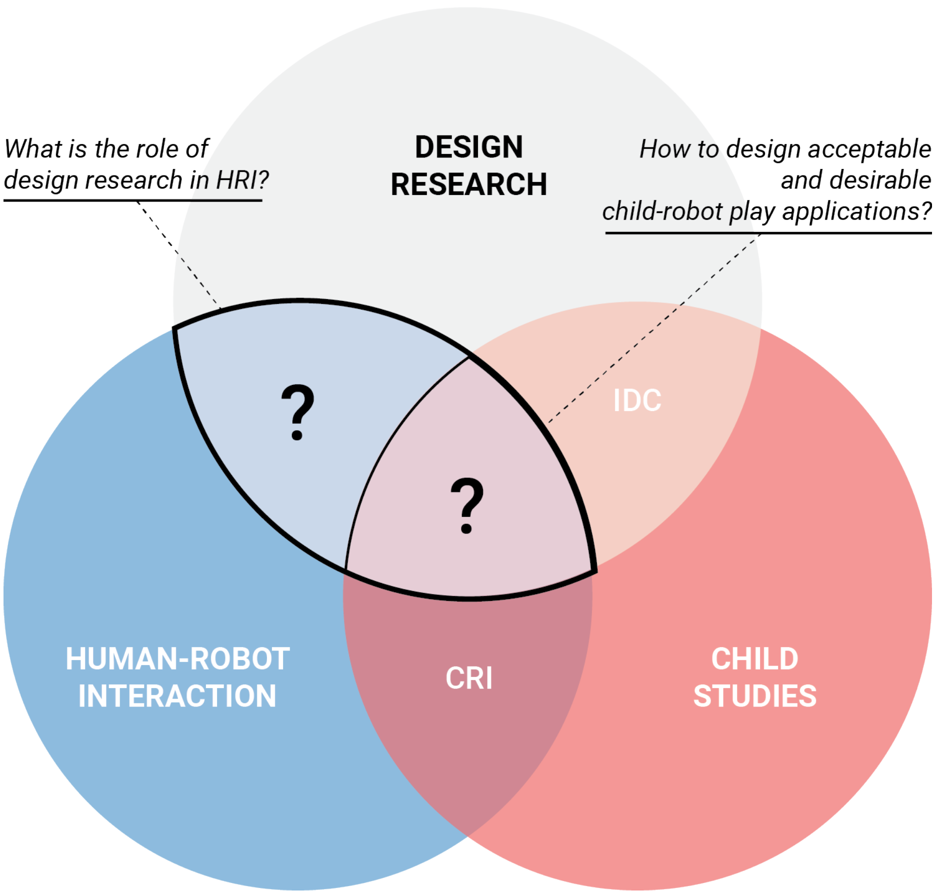


Fig 1.3 - The area of investigation at the intersection between Design, HRI and child studies

The knowledge from this area of research, at the intersection between design and children studies, is particularly relevant in terms of methodologies and processes familiar to the design discipline and also appropriate for conducting research with children.

A methodology (Chapter 3) was, then, defined by referring to the literature about both design, HRI and Human-Computer Interaction (HCI). The methodology introduces the adoption of Research through Design as the approach on which the research process was based.

Given the central importance assumed by the projects in this research approach, two chapters were dedicated to two design explorations, namely Phygital Play (Chapter 5), and Shybo (Chapter 6). The projects were reported paying particular attention to the documentation of the design process, the methods employed, and the design choices that lead to the resulting situated implementations.

The results and lessons learned emerging from the literature review, the scenario analysis and the design explorations were, then, subjected to a reflection phase through which the outcomes of the research (Chapter 7) were elaborated. These, were organized in three main levels of contributions, artefacts, knowledge and theory. Respectively, the outcomes consist of: the robotic situated implementations and their documentation, a set of operational principles, and of a theoretical framework.

Finally, a series of considerations about the limitations and future works (Chapter 8) of this research were identified.

To conclude, this doctoral thesis is aimed at contributing to the understanding the role of design in the field of robotics, and in particular in human-robot interaction studies, and to the knowledge about the implications of designing child-robot play applications.

Chapter 2

State of the Art

This chapter provides an overview of the state of the art of the intersections between three multidisciplinary themes: Design Research, Human-Robot Interaction and Child Studies. First, a definition of Design Research is provided, together with its main trends and open issues. Then, the review focuses on the contribution of Design Research to the HRI field, which can be summed up in three areas of action: artefact, stakeholders, and context. This is followed by a focus on the role of Design Research within the context of children studies, in which it is possible to identify two main design-child relationships: design as a method for developing children's learning experiences; and children as part of the design process for developing novel interactive systems. Finally, the intersection between the three fields is analysed with the aim of defining touch points, good practices and issues.

2.1 Design Research

The relationship between design and research is widely debated and various visions were discussed over the last decades. About this relationship, Nigel Cross (2001) provide a detailed historical review that starts from the beginning of the 20th Century and ends with the theories of the late nineties. The early desire for making design scientific resulted in some popular visions, that are Scientific Design, Design Science and Science of Design (Cross 2001).
As Cross explains, Scientific Design emerged as a reaction to the societal changes that were taking place after the second world war.
The change that production methods were experiencing, from craft to industry, was calling for a transformation also in the design process. As a result, design became a mix of intuitive methods and objective and rational methods, based on scientific knowledge. This movement characterized especially the 1960s, through a series of milestones that represented a turn-point in the Design discipline, such as the "World Design Science Decade" initiative by Buckminster Fuller (Fuller 1969), launched in 1961. Design Science, instead, resulted from the attempt, by many authors, to formulate a coherent, rational and univocal design method. A comprehensive description was provided by Hubka and Eder (Hubka and Eder 1987), who defined Design Science as:

"*a science that comprises a collection of logically connected knowledge in the area of design, and that contains concepts of technical information and of design methodology […] Design Science addresses the problem of determining and categorizing all regular phenomena of the systems to be designed, and of the design process. Design Science also is concerned with deriving from the applied knowledge of the natural sciences appropriate information in a form suitable for the designer's use*".

This definition shows how Design Science went beyond the use of scientific knowledge for informing the design process, that characterize the Scientific Design, and introduced the idea of design method as a systematic and organized employment of procedures. Cross, lastly, explains how Science of Design is strongly connected to Design Science, and yet profoundly different.

"*The science of Design (should be) understood, just like the science of science, as a federation of sub-disciplines having design as the subject of their cognitive interest*".

This definition by Gasparski and Strzalecki (1990) points out the substantial difference between Design Science and Science of Design, that is on the first case the attempt of "scientise" design through a systematization of the design method, while in the first case scientific methods are adopted for understanding and improving design methods.
These scientific approaches to design, however, were criticized for their limit in addressing 'messy, problematic situations' typical of the professional design practice (Cross 2001) and the idea of design as a discipline with its own identity started to spread. Owen (1998), indeed, pointed out that:

"*Design is not a science, and it is not art-or any other discipline. It has its own purposes, values, measures and procedures*."

Design has its specific approaches to conduct research. As explained by Cristopher Frayling (1993), in fact, research can be conducted into, for and through design. This early idea, provided by Frayling, was initially referring also to art research, and the role of design as a separate discipline was largely debated. For instance, Cross (1999), following the statement by Owen, provided a further clarification of the differences between design, art and science. By talking about the different ways of knowing, the author (Cross 1999) explains that:

"*the values of science are rationality and objectivity, those of art are reflection and subjectivity, and those of design are imagination and practicality.*"

Regarding the approaches to research proposed by Frayling, Zimmerman and Forlizzi (2014) provide a comprehensive description of their characterization in design. As Research into Design is intended the investigation of the human activity of design, which may be very diverse, from considering design as an artificial science, to considering it a reflective practice. Research for Design, instead, is intended to advance the practice of design. As explained by the authors, almost all the design research is included into this category, since every new method, tools, approaches, lessons learned and emerging implications can contribute to the advancement of the discipline. The last approach, Research through Design (RtD), is an approach to research focused on improving the current state of thing into a preferred state, through making new artefacts. This approach is particularly committed to the speculation of possible futures and to do so, it should be based on an emphatic understanding of the stakeholders, on synthesis of behavioral theory, and on the application of current and near current technology (Zimmerman and Forlizzi 2014). As the authors point out, the contribution of RtD can be in knowledge for design and into design.

By looking at these descriptions, a correspondence can be noticed between Research into Design and Science of Design, since both deal with the understanding of design as a human activity, and Research for Design and Design Science, because of the focus on the development of design practice through new methods and knowledge. RtD, instead, is the closest to design practice in terms of methods and processes (Godin and Zahedi 2014), but differs greatly in terms of purpose. Although the outcomes of RtD usually take the form of artefacts, these differ from the ones produced by the design practice. RtD artefacts, in fact, consist of concrete embodiment of theoretical and technical opportunities, characterized by some level of innovation and whose goal is to produce knowledge related to a problem or phenomenon (Forlizzi et al. 2008). And, as stated by Cross, the design knowledge resides in three sources, that are people, processes and products, for the investigation of which, RtD is particularly suitable.

Despite Research through Design benefits from the strength of design as a reflective practice in which a problematic situation is systematically reinterpreted and reframed (Zimmerman and Forlizzi 2014), there is still an open debate about its rigour resulting from the great variety of views on this approach (Godin and Zahedi 2014). RtD, in fact, is not a formalized approach yet, and the scientific community is asked to develop the criteria for evaluating the quality of the contributions (Zimmerman et al. 2010). In terms of methodology, Zimmerman and Forlizzi suggest that RtD should be carried out following five main steps, that are select, design, evaluate, reflect and disseminate, and repeat (Zimmermann and Forlizzi 2014). The reflect and disseminate step is, probably, the most determinant in distancing RtD from design practice. This stage is strongly connected to the ability of providing a good project documentation and a critical analysis of the work within the framed problem. In this regard, many examples demonstrate the current effort of the scientific community. For instance, Pedgley (2007) pointed out four key aspects of a good documentation, that are solo effort, endurance, subject delimitation, and mobility, and suggested also a series of tools for addressing them. Another example is a web-based tool called Process Reflection Tool (Dalsgaard and Halskov 2012), developed by Dalsgaard and Halskov for the same purpose. Nevertheless, despite authors are dedicating efforts to the formalization of this approach, rigour of this kind of research is still an open issue and it has to be considered when adopting RtD.

2.2 Design and human robot interaction

"Human-Robot Interaction (HRI) is a field of study dedicated to understanding, designing, and evaluating of robotic systems for use by or with humans" (Goodrich and Schultz 2007). Given the primary goal of investigating the ways a human can communicate with a robot, this field results from the intersection of various disciplines, that are psychology, cognitive science, social sciences, artificial intelligence, computer science, robotics, engineering and human-computer interactions (HCI) (Dautenhahn 2007).

An example of themes addressed in HRI studies is provided by Dautenhahn (2007) who mentions long-term interaction; robots in education, therapy, rehabilitation and supporting the elderly; and social learning and skill acquisition via teaching and imitation. But beyond the area of application and the specific challenges, HRI studies have to deal with common problems like autonomy, exchange of information, mutual perception of human and robots, adaptation, learning, training,

and collaboration. Accordingly, as stated by Goodrich and Shultz (2007), a designer can affect five crucial attributes of the interaction between robot and humans, that are level and behaviour of autonomy, the nature of information exchange, the structure of the team in collaborative scenarios, the modalities of adaptation, learning and training of both people and robots, and the shape of the task.
By looking at the definition of HRI and at many statements that describe the issues and the research actions within the HRI research, it appears evident the crucial role of design. However, as in the case of HCI reported by Zimmerman et al. (2007), design is frequently used to describe the HRI practice, as well as designer is used as an appellation for an HRI practitioner. Thus, design is usually mentioned in a general sense, rather than with a specific reference to design as a discipline. Nevertheless, a growing interest toward design as a discipline is manifested by the work of many roboticists, who are starting to employ design practice methods within the context of HRI studies. But still, differently from the HCI field, the role of design research in HRI and its contributions are not largely addressed yet. Further investigations are, then, needed for understanding the HRI-Design relationship, and what the two field can learn from each other.
Accordingly, a review of the HRI literature was carried out with two different approaches. On the one hand, articles concerning the relationship between Design and the HCI field were reviewed. In many cases, in fact, HCI theories have proven to be valid also in the HRI field. For instance, theories about robot's acceptability are based on technology acceptance models (Beer et al. 2011) firstly applied in HCI (Dillion and Morris 1996).
On the other hand, a representative sample of articles regarding HRI was analysed focusing on the presence or absence of factors that manifests a relationship between HRI and Design.

2.2.1 The role of Design from HCI to HRI

As mentioned in the paragraph 2.2, HCI theories are often a valid basis for constructing theories in HRI. Given this fact, literature about the role of design in HCI was reviewed and integrated to the HRI literature review, in the attempt of defining the main contributions of design in this last field. However, it is firstly necessary to define what is HCI for subsequently understanding what may be the differences in the role of design in HRI.
Human-Computer Interaction (HCI) is an area of research and practice that focuses on the design of computer technology and the interactions between humans and computers (Interaction Design Foundation 2017). This discipline is the result of the strengthening of the relationship between computer science and behavioral science (Zimmerman 2003), which was fostered by the spread of computers and Graphical User Interfaces (GUI) among the general public.
The usability issues related to how people would understand and control these computer-based applications represented an opportunity for designers who started to be systematically involved in HCI teams (Forlizzi et al. 2008).
Starting from that, the design action in HCI extended greatly its contribution domain, from designing visual elements and system behaviours, to defining generalizable design guidelines for developing user-oriented screen products (Forlizzi et al. 2008).
Over time, the design in HCI started to be strongly connected to anthropology because of the implications of the context culture for the design and development of new technology. The presence and the contribution of designers in the HCI field become so substantial over time that Jonas Löwgren, in the nineties, started to distinguish the contribution of engineering design from the one by creative design (Löwgren 1995).
The role of design as a substantial part of HCI was subsequently reaffirmed by many HCI practitioners. For instance, Daniel Fallman stated that HCI has to be understood and acknowledged as a design-oriented field of research (Fallman 2003). As he explains, in fact, HCI researchers are regularly involved in the design of prototypes used for testing and evaluating ideas, and often their projects result in artifacts used by the general public.
Dix et al. (2009) in their contribution about Human-Computer Interaction dedicate an entire chapter to the Interaction Design basics and their role in HCI. In this chapter, they define design as an activity characterized by the aim of achieving a goal within the presence of constraints, through a process that involves five main steps: requirements, analysis, design, iteration and prototyping, and implementation and deployment.

The authors point out two fundamental aspects that have to be investigated by design in HCI, that are users and scenarios.
However, despite design practice and thinking have been largely integrated in the HCI education and research, there is still little agreement about the role played by design research (Forlizzi et al. 2008). To address this issue, Forlizzi et al. (2008) elaborated a model for interaction design research in HCI based on a Research through Design (RtD) (Frayling 1993) approach. Their model focuses on the central role of making for addressing wicked problems arising from complex groups of phenomena, rather than isolated phenomenon.
The goal of interaction design researchers, according to the vision proposed by this model, is to answer these problems through transformative artifacts able to transform the current state of the world into a preferred state. Thus, the authors emphasize the contribution of design research for HCI as an ability to understand the real world and making artifacts able to produce a change. It has to be noted, however, that the artifacts resulting from this research approach differ from the ones of the design practice in the fact that their development produces knowledge, rather than commercially viable products, and that they represent novel integrations of theory, technology, and needs, rather that incremental improvements of existing solutions.
By referring to these contributions, it is possible to summarize the role of design to HCI in two main areas of action, that are: making technological artifacts, and understanding people and socio-cultural contexts. This can be considered valid also for the HRI field. As showed by the analysis conducted on the proceedings of the HRI Conference, the design presence in HRI is strongly connected to the design and development of robotic artifacts, and to the interest for understanding human perception and behaviours toward robots. Nevertheless, HRI research cannot result from a simple adaptation of HCI research to robots (Breazeal 2004).
HCI and HRI, in fact, differ in at least four key aspects: there are different possible levels of interaction for humans; the physical nature of mobile robots requires them to have awareness of the physical environment; robots have a dynamic nature that can affect their functioning; and robot might have to function in harsh conditions, depending on the environment (Scholtz 2002). In this regard, Breazeal (2004) explains that certainly HRI-like studies may be beneficial in HRI for investigating and addressing several design issues, regarding morphology, aesthetics, skilfulness, perceptual capabilities, communicative expressiveness, and intelligence. However, as the author points out the substantial differences introduced by the robots require HRI studies to be focused both on the human perspective and the robot perspective.
The human interaction with robots, in fact, do not only take place in the case a particular task is required, as it happens with computer-based applications. Robots, for carrying out their tasks, will share the same physical and cultural context with people, generating a condition of coexistence (Salvini et al. 2010) rather than of availability. This highlight the fact that in HRI the processes of making and understanding are not only valid but even more emphasized.
On the one hand, since this coexistence condition is without precedents, there is a growing need for involving people in the design process, not only for getting information but also for creatively contributing to the development of culturally robust robots (Šabanović et al. 2014). On the other hand, the peculiar nature of robots, as physically embodied agents with some degree of autonomy, requires a great focus on the actual designing and making of robots and robot-based applications situated in real contexts. The attitude of society toward robotics, in fact, is still greatly based both on promises, potentials and expectations (Weiss et al. 2011), and on prior experiences and knowledge through media (Kriz et al. 2010).
As a consequence, two main differences emerge in the contribution of Design Research for these two disciplines. On the one hand, the need for designing culturally robust robots implies processes of mutual shaping (Šabanović 2010) between robots and society, for which design culture could play a strategic role, because of its interest in framing phenomena, seeking for problems and opportunities, and iteratively developing solutions that embodies a critical thinking (Zimmerman and Forlizzi 2014). On the other hand, the need for actually designing robots and robot-based applications generate differences in the skills required to designers, such as mechanical design, computational thinking, and staging strategies.

2.2.2 Design presence and features in four years of HRI conference proceedings

The current relationship between HRI and Design was investigated through the review of a representative sample of articles from the HRI field. The articles under review consist of 157 full papers published in the proceedings of the Annual ACM/IEEE International Conference on Human-Robot Interaction (ACM Digital Library 2017), published in the last four years (2014-2017).
These proceedings were selected because of the fact that HRI Conference is among the best conferences about HRI, it is totally dedicated to this field, and its very low acceptance rate (around 25%) guarantee a very high quality of the published contributions. Although this little sample of papers cannot stand for the whole research on HRI of the last four years, it is very helpful to get an overview of the current trend, the overall distribution of Design related HRI research and some of its main contributors and areas of interest.
The papers were reviewed and cataloged retrieving general information, such as title, year, authors, affiliations, and countries, and looking for a set of 15 indicators (table 2.1), which may manifest a weak or strong relationship between the HRI studies under examination and design.
These indicators consists of generic references to design, activities that may be in support or evaluation of design, such as interviews and questionnaires, and activities and approaches

INDICATOR	INDICATOR	DESCRIPTION
Design	WEAK	This indicator is counted when the word is mentioned in the paper in relation with the actual design of a robot or robot-based applications, or referring to the implications of the study for the future design of robot or robot-based applications. The papers that mention it for indicating a study design or design of algorithm are excluded.
Human-Centred Design / User-Centred Design	STRONG	This indicator is counted when the authors make explicit reference to one of the two nomenclatures. Implicit adoption of such approaches are not counted.
Participatory Design	STRONG	This indicator is counted when the authors make explicit reference to participatory design.
Co-Design	STRONG	This indicator is counted when the authors make explicit reference to co-design.
Questionnaire / Survey	WEAK	This indicator is counted when the questionnaire/survey is intended for evaluating a designed artefact, or for getting knowledge that presents explicit implications for the future design of robot or robot-based applications. The papers that mention it for more general purposes are excluded.
Interviews	WEAK	This indicator is counted when the interview is intended for evaluating a designed artefact, or for getting knowledge that presents explicit implications for the future design of robot or robot-based applications. The papers that mention it for more general purposes are excluded.
Observations	WEAK	This indicator is counted when the observation is intended for evaluating a designed artefact, or for getting knowledge that presents explicit implications for the future design of robot or robot-based applications. The papers that mention it for more general purposes are excluded.
Focus Group	STRONG	This indicator is counted when the focus group is intended for evaluating a designed artefact, or for getting knowledge that presents explicit implications for the future design of robot or robot-based applications. The papers that mention it for more general purposes are excluded.
Workshops	STRONG	This indicator is counted when the workshop is intended for evaluating a designed artefact, or for creatively engaging potential users, or for getting knowledge that presents explicit implications for the future design of robot or robot-based applications. The papers that mention it for more general purposes are excluded.
Brainstorming	STRONG	This indicator is counted when the authors make explicit reference to brainstorming as part of the design process.
Focus on appearance, aesthetics and morphology	WEAK	This indicator is counted when the authors present a focus on appearance-related issues that is related to a designed artefact, or can inform the future design of robot or robot-based applications.
Sketches	STRONG	This indicator is always counted when mentioned by the authors.
3D models	STRONG	This indicator is counted when the 3D models are used for investigating possible robot design alternatives.
Animations	STRONG	This indicator is counted when the animations are used for investigating possible robot design alternatives.
Prototypes	STRONG	This indicator is counted every time an author mention it referring to a physical artefact or a GUI, and provide a description of the process.

Table 2.1 - List of the indicators used to analyse the set of papers.

typical of design, such as the adoption of participatory design or actions like sketching and prototyping.
At a first sight, the emerging data seams to rebut the previous statement about a growing interest towards design from HRI. As shown by table 2.2, in fact, the number of design-related papers actually decreased by 13%, from 2014 to 2017. However, a closer look at the indicators reveal a greater increase and the emergence of approaches specifically focused on design. First of all, the number of design-related papers with indicators that reveal a strong relation to design slightly decreased in 2015 and 2016, but resulted increased by 5% in 2017. A deeper analysis of the indicators reveals an increase in the number of indicators mentioned in the various papers. Table 2.3 illustrates the mean number of indicators mentioned by the papers over the four years. As shown by the numbers on top, the mean of indicators increased consistently over the years, moving from 1.94 to 2.94 indicators per paper, with a peak of 3.2 in 2016. Furthermore, by looking at the mean of the strong indicators a constant and significant growth can be appreciated. In fact, the mean of strong indicators per paper increased from 0.22 to 0.76, which is more than the triple. However, despite these data seams to show a constant and distributed increase in the number of indicators per paper, the standard deviation reveals great differences between the single papers.

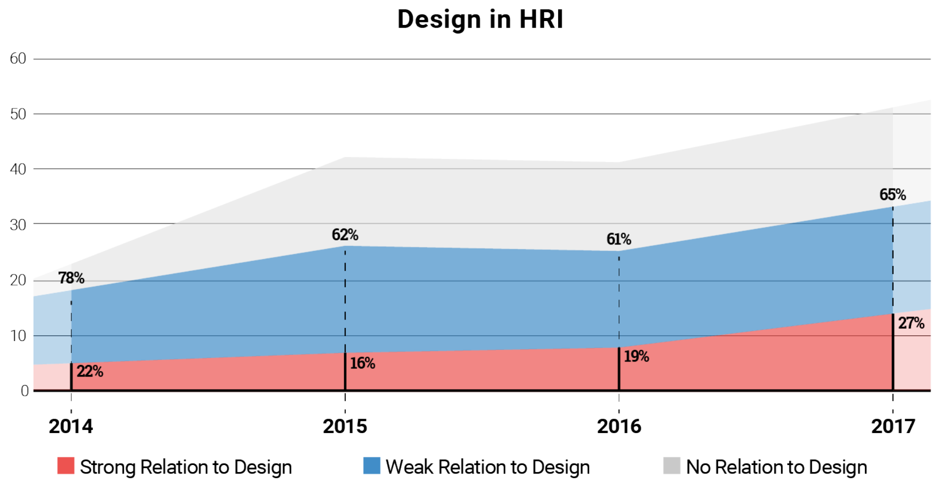


Table 2.2 - Design in HRI. The graph shows the trend of Design presence in the HRI field over the last four years calculated according to a series of indicators that refer directly or not to design.

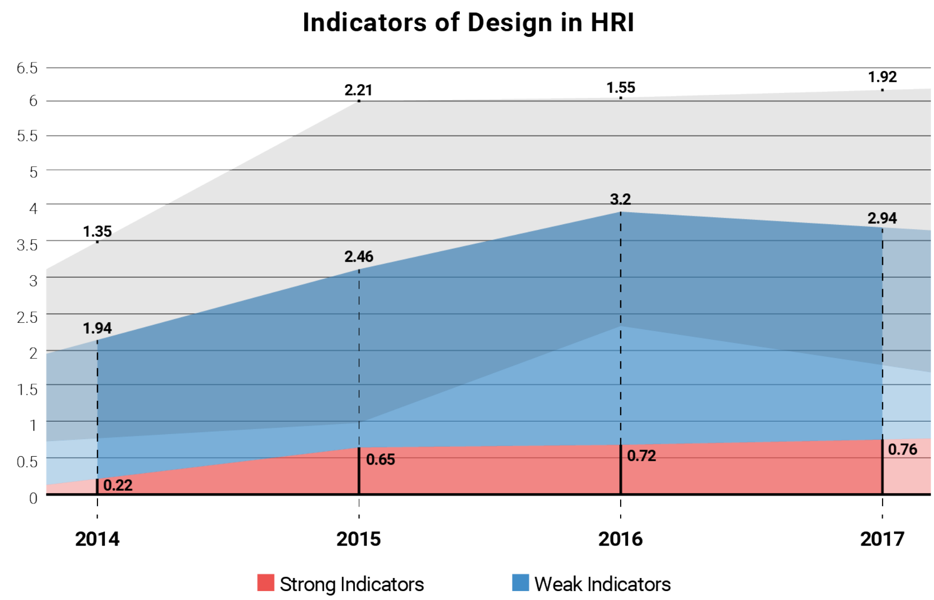


Table 2.3 - Indicators of Design in HRI. The graph shows the mean number of indicators mentioned by each paper over the four years, with a distinction between strong and weak indicators. The grey area indicates the standard deviation of the total mean.

Table 2.4 - Distribution and protagonists of Design in HRI.


W. Ju
Physical Interaction Design and Ubiquitus Computing
S. Šabanović
Culturally Situated HRI
J. Forlizzi
Interaction Design in HCI
F. Mondada, P. Dillenbourg, S. Lemaignan
Robotics and HCI for Learning and Instruction
G. Hoffman
Joint Activities between Humans and Robots
STANFORD UNIVERSITY
INDIANA UNIVERSITY
CARNEGIE MELLON UNIVERSITY
EPFL
IDC HERZLIYA
The distribution and protagonists of Design within the field of Human-Robot Interaction Studies
RED SPOTS
Strong HRI-Design relation
BLUE SPOTS
Weak HRI-Design relation
SPOTS SIZE
The size indicates the University relevance according to the sum of values of the authored papers. The value of a paper is the sum of relation indicators multiplied for weak (0,5) and strong (1) coefficients.
UNIVERSITY NAMES
The names showed in the map represents the most relevant universities in terms of HRI-Design relation.

By looking at the single data, in fact, it is possible to notice differences in the number of indicators that can be summarized in three main grouping: papers with 0 indicators, papers with 1-3 indicators, and papers with 4 or more indicators, which includes also an extreme case of a paper in which 10 of the indicators were mentioned. This highlights how the presence of design in HRI over the years increased in “specialized” approaches, rather than a homogeneous distribution.

In order to better understand these emerging specialized approaches, other data, such as authors names, and affiliation, were taken into consideration.

The affiliations were used to get geographical data and visualize the distribution of the strongly related paper in the form of a proportional symbol map (Warf 2010) . The map (table 2.4) shows a list of locations corresponding to the affiliations associated to each paper that presents a relation to design. The blue spots stand for the affiliations to which belong the papers with a weak relation, while the red spots represent the affiliations to which belong the papers with a strong relation. In some cases, the same affiliation presents both a blue and a red spot. The size of the spots is calculated by summing up the number of papers published in the four year at the conference, each of which is multiplied with a factors determined by the sum of its indicators, whose value is 0.5 for weak and 1 for strong. In this maps the data aggregated and temporal distribution is not addressed.

As a result, the map shows that the presence of design in HRI is concentrated in four areas: United States, Japan, Israel and Europe. Differently from the first three, in Europe the presence of Design in HRI is distributed in various countries. Overall, United States appear to be the country with the highest distribution density of Design in HRI. However, this data reflects also the large American dominance both on the organizing committee and on the paper published every year in the HRI Conference .

Looking at the spots size, five major affiliations emerge: Carnegie Mellon University, Indiana University, Stanford University, École Polytechnique Fédérale de Lausanne (EPFL), and IDC Herzliya.

Since the size of the spots is the result of both the number of papers related to design and the quantity and weight of the design indicators, these universities correspond to the specialized approaches emerged from the analysis of the indicators’ trend. However, these affiliations do not correspond in every case to a shared approach among a research group. In some cases, in fact, it is the result of the individual effort of some researchers. This fact can be better understood by focusing on the recurring names of the authors.

A list of authors was then compiled with the data from the papers with a strong presence of design indicators.

This list allowed to identify some recurring names affiliated to the five universities mentioned above, that are Wendy Ju, Selma Šabanović, Jodi Forlizzi, Guy Hoffman, Francesco Mondada, Pierre Dillenbourg and Séverin Lemaignan. The last three names belong to the same affiliation, the Computer-Human Interaction in Learning and Instruction (CHILI) lab at EPFL. The emergence of more that one author from the same affiliation, suggest that the large presence of Design in HRI constitutes here a shared approach. The same can be presumed for the Center for Design Research, the group guided by Wendy Ju. In fact, despite she is the only one author that appear several times in the papers from Stanford University, the name of the group openly declares the primary affiliation to the design field rather that HRI. Differently from these two is the case of Forlizzi, Šabanović and Hoffman. They actually represent those cases in which the work of single authors contributed decisively to the relevance of their affiliation in the map of Design in HRI.

Therefore, the data emerged from this literature review confirm the growing interest toward design methods and approaches from the HRI field, and the presence of authors and research groups who actually adopt them as fundamental part of their approach to HRI research. However, the specific roles and functions that Design assume in HRI studies still requires a further investigation. To this end, information about areas of application, usage contexts and robot used were extracted from the set of papers strongly related to design.

By observing the data, summarized in table 2.5, it is possible to notice that the vast majority of papers presents studies which are not intended for specific areas of applications. These rather explore some aspects of HRI that can affect human perception and attitude, and consequently can determine the

34 papers
with strong relation with design

Area of Application		Context of Application		Artefact	
23	generic / HRI aspects	27	no context	14	custom robot
3	healthcare robotics	4	home	10	existing robot
3	assistive robotics	2	educational context	4	existing robot + custom parts
3	educational robotics	1	car	3	robot sketches & simulations
1	autonomous transportation			3	No robot
1	industrial robotics				

Table 2.5 - Overview of the data regarding the areas of application, contexts and artefacts employed in the HRI studies presented in the papers with a presence of strong design indicators.

efficacy of the interaction. Knowledge about some of these aspects can be used for designing more effective robot's behaviours, such as the findings about proactivity vs reactivity by Fink et al. (2014), or the results of the study by Sauppé and Mutlu (2014) about deictic gestures. In other cases, the focus is on the design of specific elements that can be subsequently used in the design of robotic applications. For instance, Kinoshita et al. (2017) designed, prototyped and tested a gaze system for interacting with multiple people simultaneously. Other studies focus on the development of effective systems for the control and programming of robots, such as the study by Fischer et al. (2016) who compared three different ways of controlling robots for identifying the best solution in terms of efficiency, effectiveness and usability.

Nevertheless, a third of the articles presents works developed for specific areas of applications, that are healthcare robotics, robotics for learning, autonomous transportation, assistive robotics, and industrial robotics. These all share a common aspect: the central role of people in the application and interaction. This points out service robotics as the area of robotics in which design might play a significant role.

In the healthcare context, for instance, the design of robotic solutions can be focused on the development of solutions for improving motor rehabilitation of the patients, such as in the work by Derry and Argall (2014), and in another case for enhancing clinicians' skills, as proposed by Moosaei et al. (2017). Thus, in this area of application, people, who are asked to accept robots in their personal space, are largely involved in the design process. Also, in the educational context robots are mostly used for enhancing learning activities. Robot's social behaviours can be designed increase motivation towards learning, as in the study by Lubold et al. (2016). Robots can also be designed as ubiquitous, versatile and practical tools for enabling an undefined number of learning activities that engage actively children and opens up a design space for educators, such as in the case of Cellulo (Özgür et al. 2017).

The case of assistive robotics may seam very similar to the healthcare robotics, however the design of robots in this area of application is aimed at supporting people autonomy, such as in the case of guiding robots for blind people (Azenkot et al. 2016), or in the case of domestic care robot for supporting elderly in daily life activities (Caleb-Solly et al. 2014). Also in the case of industrial application, robotics is addressed in these papers for supporting and enhancing people at work. For instance, Stenmark et al. (2017) designed,

developed and tested an iconic programming interface for industrial robots by focusing on their potential non-expert users.
These findings are consistent with the existing HRI theories which point out that the use of robots can be aimed at enhancing human skills and activities (Kidd 1992), supporting and empowering people (Chen et al. 2013), especially in the case of special conditions like disability, and replacing human in performing certain tasks, which can have both a positive and a negative impact (Kidd 1992; Veruggio 2006).
In this regard, the papers strongly related to design mostly present robotic applications aimed at enhancing and empowering people, rather that replacing them. Therefore, it can be assumed that design plays a greater role in applications focused on human needs, while in the case of automation of human activities its role is smaller.

main categories: studies without robots, studies with robot sketches or simulated robots, studies with existing robots, studies with existing robots integrated with custom parts, and studies with custom robots.
The studies that do not required the use of robots consist mostly on theoretical contributions that aim at guiding the design of robots and robotic applications. The article by Huber et al. (2016), for instance, introduces a theoretical framework for researchers and developers to incorporate ethics in the design of social companion robots. Similarly, the article by Cheon and Su (2016)presents a value-sensitive design approach for designing humanoid robots that go beyond the engineering dominant bias. Differently the studies with sketches of robots and simulated robot, with 3D models and animations, are aimed at investigating factors influencing HRI and their results can be

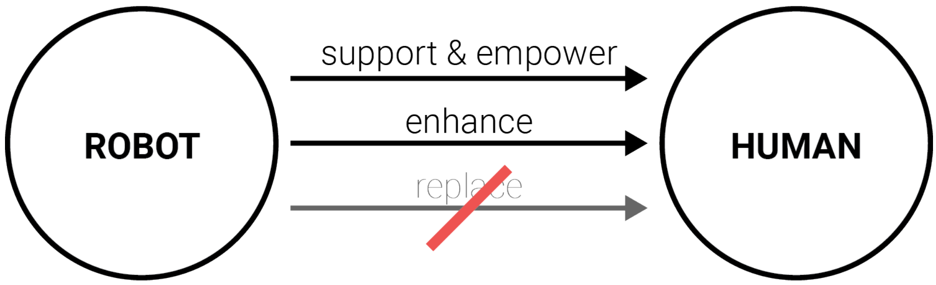


Fig. 2.1 - Robot's actions towards humans in papers with a presence of strong design indicators.

Different from these examples is the case of autonomous transportation for private use, namely autonomous car. In this case, in fact, a typically human activity is being automated. In this scenario, the person in the car assumes a new role which cannot be observed and analysed through the current usage scenario. The focus of the studies in this case can be on investigating perception and behaviours of people in hypotetical interaction scenarios, such as in the study by Wang et al. (2017) in which the authors simulated an autonomous driving scenario by adopting a Wizard of Oz protocol. However, also in this case the people are at the center of the investigation, since the purpose is to investigate new private transportation experiences for them, rather that exploring technical solutions.
Regarding the types of robots employed in the studies, it is possible to group the papers in five

for informing, with specific knowledge, the actual design of robots and their applications. In the study by Rueben et al. (2017), for instance, 3D animations of a PR2 robot were used to simulate and communicate a series of usage scenarios for investigating privacy issues with potential users. Malle et al. (2016), instead, used a series of sketches for understanding how robot appearance affects people's moral judgement. Similarly, the studies that employ existing robots are usually aimed at investigating some specific factors influencing the HRI, such as a study with Nao robot for investigating the role of deictic gestures in human-robot collaboration scenarios (Sauppé and Mutlu 2014), or a study conducted with variations of the realistic robot Repliee Q2 for investigating how appearance affect unconscious social attention (Li et al. 2015).
In studies where existing robots are combined with

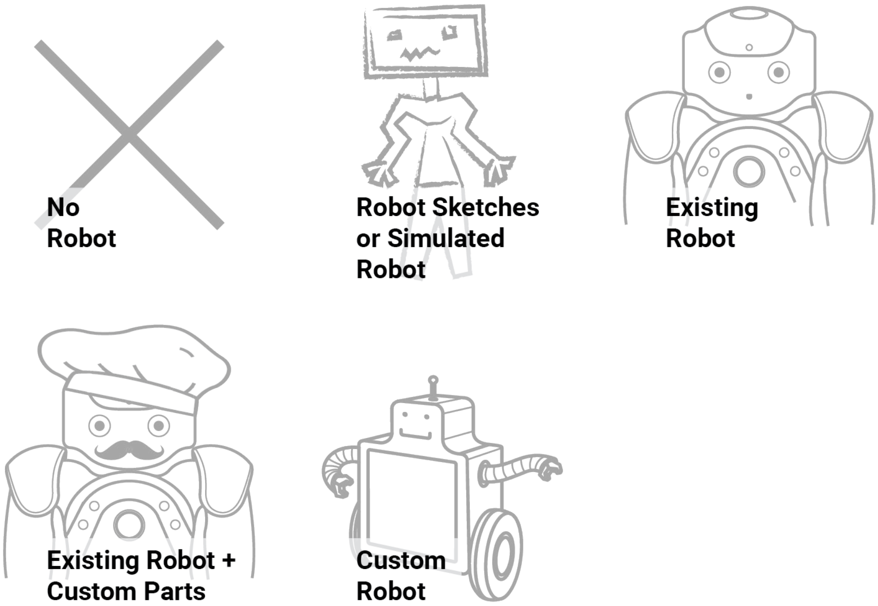


Fig. 2.2 - Five categories of robots used in HRI studies.

custom parts, the intent is often to investigate those factors of HRI mostly related to the appearance and behaviours of the robots, as in the study by Fraune et al. (Fraune et al. 2017) in which three iRobot Create robots were dressed up with three different bodies (made of cardboard and cloth) and associated with different behaviour styles for investigating the effects of the group behaviours on people perception and attitude toward them. These share the same aim with many studies that employ custom robots. For instance, Martelaro et al. (2016) worked on the expressivity and vulnerability of a custom robot for increasing the sense of trust, disclosure and companionship. However, the studies that employ custom robots result particularly interesting when the designed robot is the actual protagonist of the research. Whether it is designed as a tool for enhancing children's learning, such as Cellulo (Özgür et al. 2017), or as a social agent that may affect people behaviours, such as Kip1 (Hoffman et al. 2015), the robot itself is the object of investigation. Nevertheless, a research process focused on the design and development of a novel robot can also generate knowledge about general aspects of interaction that can contribute to the HRI discipline at various levels.

The last type of information reported in the table is the usage context which, however, only in few articles is mentioned. These, which mostly match with the areas of applications, are: home, hospital, car, and educational context, e.g. school. Moreover, among the eight cases that mentioned a context, only five of them actually situated their research in the actual context of use. Özgür et al. (2017) carried out several learning studies with their set of Cellulo robot with children and teachers in different schools. Wang et al. (2017) have been testing with a real car in the streets of the campus. Finally, the real houses of people involved in the studies become test fields in the research by Lee et al. (2017), about assistive robotics for elderly, and in the research by Fink et al. (2014) who designed a robot that interact with children in free play scenarios.

To sum up, these last three types of information reveal how the presence of design in HRI is often connected to two main aspects: the central role assumed by people in the research and the interest of the research toward specific features of the artefact. Regarding people, the focus of the studies is usually on establishing and putting into action the conditions for empowering them and enhancing their activities through robotics. In these studies, design methodologies can be adopted with two purposes. On the one hand, these are aimed at investigating the peculiarities of the potential users, focusing on aspects like attitude toward technology, existing practices, and needs, for informing the design process. On the other hand, design methods are used to evaluate and refine the proposed solutions, mostly by addressing usability aspects.

Concerning the artefact, design methods are usually employed for designing, developing and evaluating robots, especially focusing on their appearance, behaviours and interaction modalities with people. Also in this case, factors affecting usability play a crucial role, however, focusing on robots as social agents highlights the importance of further aspects, such as fluidity and credibility of the behaviours. Accordingly, the design and development process are often enriched with non-conventional sources of inspiration, such as theatrical techniques and animation. Contrariwise, little attention is still paid to the specific contexts of use and rarely the projects takes the form of situated implementations, in which design methodologies could play a crucial role.

Although the limited sample of papers used for this study do not allow to represent the totality of Design presence in the HRI field the main affiliations, authors and characteristics emerged can be taken as a useful reference to investigate more in detail what is the role played by Design in the HRI research processes.

2.3 Child Studies and Design

In order to understand the implications of designing for child-robot play, a review of the current state of the intersection between design and child studies is also needed. I fact, over the last decades, the design practice paid much attention to children products. Currently, a good review of the Italian contribution to the design-children relationship is provided by "*Giro Giro Tondo*" (Annicchiarico, 2017), an exhibit inaugurated on April 1st, 2017, in Milan. This exhibition includes not only products, such as games, furniture, and books, but also a review of various educational experiences and exemplary educators of the Italian history. Such collection is aimed at describing the world of children, which is characterized by two main dimensions: play and learning (Samuelsson et al. 2006). These two dimensions stimulate each other and in some cases can represent an inseparable entirety, especially in preschool age (Samuelsson et al. 2006). In play, in fact, the pre-schooler child can create the mental structures to connect objects to meaning, while at school age play is converted to internal processes and abstract thoughts (Vygotsky 1967). Thus, by playing, children have the opportunity to unconsciously develop and learn those habits necessary for their intellectual growth (Bettelheim 1987).

This play-learning dualism is also reflected by the two main relationships noticeable between child studies and design. On the one hand, the relationship is oriented to the development of new product/systems for children and *design is a mean*. On the other hand, the relationship is oriented to the development of learning experiences for children and *design is part of the experience*.

2.3.1 Children as Design Recipients

As *design as a mean* is intended the employment of design methodologies for the development of novel products for children.

With new technologies becoming an integral part of more schools and homes, there is a rise in the need for even greater effort on the development of new, creative and exciting technologies for children (Druin 1999). However, designing product for this specific users' category requires a deep understanding of their different nature compared to adults. Children, in fact, do not only differ in terms of abilities and knowledge, but they also have their own culture, norms and complexities (Berman 1977). The market interest toward understanding children as specific consumer group (Cook 2009) together with the growing awareness about the biased opinions of adults toward children's needs and preferences (Druin 2002) encouraged the adoption of participatory practices with children. Especially in the HCI field, by the mid 1990s the participation of children in the technology development process grew (Druin 2002). As reported by Druin (2002) children can assume four different roles in the design of novel interactive systems, namely *users*, *testers*, *informants*, and *design partners*.

As explained by the author, in the first case, the child is a *user* of a technology that was designed and distributed for commercial or research purpose. The child interaction with the intended technology is usually observed and analysed by adults for understanding the technology impact on child's learning experience. In other cases, instead, children can be involved in testing prototypes of emerging technologies. When the child assume

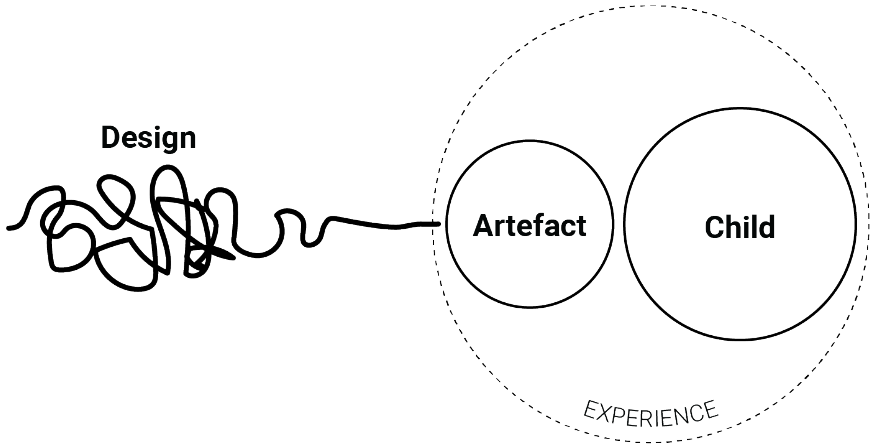


Fig. 2.3 - Conceptual schema of children as Design Recipients.

the role of *tester* he/she can help to improve the proposed technology before the commercialization or diffusion.
Otherwise, if participatory actions take place at various stages of the design process, before and after the technology development, the child plays the role of *informant*. In this case children may be observed while interacting with existing technologies or be asked to give some inputs though various hands-on activities. Finally, similar to the role of informant is the role of the child as *design partner*. In this case, the child is involved throughout the whole design process and actively contributes at the same level of other stakeholders. This role is aimed at producing a significant impact from the contribution of children on the technology.
Designing for children presents also a series of other challenges that affect the whole design process, from analysis to evaluation. In some cases, in fact, the design methods need to be adapted or even replaced by others, and even the final product needs at least an adaptation to the differences of children, e.g. in terms of language understanding and level of attention (Hanna et al. 1998), just to name few.
A first kind of methodologies adapted for children is represented by the ones used in the analysis stage of the projects. If with adults the investigation of the intended scenario can be carried out by directly asking information and opinions to the potential users, such as questionnaires, with children this approach is not effective. In the specific case of questionnaire, in fact, understanding and interpreting questions, as well as in formulating appropriate responses is challenging for children, who are influenced by developmental factors, e.g. language ability, and temperamental factors, such as self confidence (Read and McFarlane 2006). Maćkiewicz and Cieciuch (2016) addressed this issue of classic questionnaire as inappropriate tools for conducting research with children. In particular, the authors focused on the children's difficulty of dealing with abstract concepts presented through questionnaire, especially in the case of personality assessment studies. To address this issue, they present the *Pictorial Personality Traits Questionnaire for Children*, a figure-based adaptation of a personality questionnaire. The effectiveness of pictorials as an effective strategy is reaffirmed by the use of them by many researchers. The analysis of the scenario, however, can be performed through a variety of different methods, each of which presents different challenges.
Druin et al. (1998) for instance, adapted the *contextual inquiry* (Beyer and Holtzblatt 1997) methodology for avoiding the emergence of uncomfortable feelings in children, who while observed and questioned about their actions, can easily get distracted if the interlocutor takes notes while talking to them. To address this issue, the authors changed the data collection method, consisting of an observation of the users performing typical activities in their own environment with a researcher asking question and taking notes. Alternatively, they propose a change from a single researcher-interviewer to a team composed by an interlocutor and two note-takers (Druin et al. 1998).
The same challenges and need for adaptation are also present in the case of methodologies in which children are engaged in hands-on activities

for exploratory purposes. For example, Gielen (2013) adapted the *contextmapping tools* (Visser et al. 2005) for children, by taking into account children's differences in cognitive skills, socio-emotional skills, and motivations to participate in the activities.
Similar considerations guided the work by Bernhaupt et al. (2007), who adapted *cultural probes* for conducting studies with children.
Regarding the design phase of the projects, children can affect the process in two ways. On the one hand, children's peculiarities are addressed to define the requirements and features of the proposed system. For instance, Druin et al. (1998), in their studies, found out that children have some specific expectations towards technology, and tend to notice certain features.
Regarding the expectations, children want the new interactive systems to give them control, enable social experiences, and give them the opportunity to express themselves. After interacting with technology, instead, children tend to notice what is cool, how easy it is to learn, how does it look like, and how much multimedia and multisensory experience it provides. The differences between adults and children may also represent opportunities rather than challenges. As explained by Ros et al. (2011), in the case of social robots, children respond much more readily and strongly than adults, making the desired interaction much easier.
On the other hand, when children are involved in the process, the participatory design sessions have to be adapted to them. Druin et al. (1998), in fact, adapted participatory design (Vaajakallio et al. 2009) techniques through the use of low-tech prototypes, made of paper, glue, crayons, and other familiar materials. Similarly, Vaajakallio et al. (2009) adapted the idea of the *Make Tools* (Sanders 1999) for co-designing with children. They designed a toolkit composed by ready-cut pieces with symbols that can be used for exploring design ideas by building and transforming configurations of these. Also sketching can be specifically adapted for exploring design ideas with children. Walsh et al. (2010), for instance, developed a technique called *Layered Elaboration*, which enable teams of adults and children to collaboratively draw storyboards about design ideas.
Similar to the ones of the analysis stage are the challenges in the evaluation of the projects. Many are the examples, in fact, of existing evaluation methodologies adapted for children or new methods specifically designed for them. For instance, as in the case of analysis, the issues regarding questionnaires and the relative strategies, such as the use of pictorials, are the same also for evaluation.
Other activities like iterative laboratory testing can be easily adapted by the conducting researcher. As reported by Hanna et al. (1998), when observing children interacting with technology, the researcher intervention can be reversed from suggesting the intended use to trying to find out what children want to do with that. Furthermore, self reporting methods submitted after the experience, such as interviews and questionnaires, resulted to be less effective in the identification of problems if compared to techniques like *Think Aloud* (Donker and Markopoulos 2002). In this method, children, while interacting with a technology, are asked to mention anything related to three questions regarding the interaction, that the experimenter showed them in advance and kept visible for them for the whole interaction session.
Some specific self-reporting techniques are also adopted for assessing certain aspects of the interaction, such as fun. For instance, the *Fun Toolkit* (Read and MacFarlane 2002) includes a series of tools for fostering children's self reporting, that are the *Smyleometer*, a visual analogue version of a five point Likert Scale, the *Fun Sorter,* a table in which children are asked to order the games that they tried from the most fun to the worst, and the *Again and Again*, a table in which children are asked to indicate if they would like to do the activities again, by writing yes, no, or maybe. In many cases, however, data collection methods based on children's self-reporting can be limited in terms of effectiveness, because of various reasons like distraction, mutual influence in group interaction, and desire to please the experimenter, just to name few. Thus, self-reporting methods can be replaced or integrated with observational techniques, especially when it is necessary to assess aspects like engagement and arousal.
Observations can be performed directly during the activity, by combining the actions of researchers who lead the interaction and the ones who focus on observing and taking notes. This kind of approach is particularly suitable for those situations in which

the activity cannot be video recorded, for privacy issues. Conduction tests with children, especially in-wild, calls for special attention to the sensitiveness of the participants' data, and addressing legal and administrative issues becomes crucial (Ros et al. 2011). In these cases, direct observations can be carried out by taking advantage of knowledge and tools of other disciplines, such as Developmental Psychology, in which it is common to observe children playing, interacting and behaving in real world environment, such as the *System for Observing Children's Activity and Relationships during Play* (SOCARP) (Ridgers et al. 2010).
If recording is permitted, however, more objective data can be collected and also analysed after the activity, with a consequent reduction of the adults' presence in the test environment. First of all, video recordings of the tests can be coded after the experience for assessing the presence, frequency and duration of certain behaviours. This can be done through several video-coding software, such as *EthoLog 2.2* (Ottoni 2000), the *Observer XT* (Zimmerman et al. 2009), and *Boris* (Friard and Gamba 2016). Even more objective data can be collected, during the tests, by using physiological measurement tools. For instance, emotions can be assessed by getting data about cardiovascular responses (Mauss and Robinson 2009), electrodermal responses (Mauss and Robinson 2009) or vocal expressions during the interaction (Vieira and de Silva 2017). Attention can be measured by detecting facial expressions (Levialdi et al. 2007), eye blinking rate (Chen and Epps 2013), or gaze detection (Chen and Epps 2013).

2.3.2 Design as a Learning Approach for Children

The second type of relationship, *design as part of the experience*, stands for the employment of design methodologies and processes as part of active learning activities.
Although it is now becoming a common practice, the introduction of design in educational environments is the result of a change that occurred over more hundred years of debate in which several disciplines, such as psychology, philosophy, sociology and education investigated the nature of learning. Especially in the last decades, the various disciplines pointed out that the experience is an inseparable aspect of learning (Ackermann 1996).
Piaget (1945) explained in his theory how "*knowledge is not a commodity to be transmitted*", and situated cognition scholars expressed the idea that "*to know is to relate*" (Ackermann 1996).
Knowledge, then, is rather constructed through the experience and the interaction with materials, and children are "active builders of their own mental structure" (Papert 1980).
Within the framework of these studies, play was also brought at the centre of the debate about education as a crucial aspect of human learning together with the importance of artefacts (Ackermann 2004). By playing, children have the opportunity to unconsciously learn those habits necessary for their intellectual growth (Bettelheim 1987).
Furthermore, play has the particular function of letting children deal with new objects and situations by recalling existing schemas, blocks of intelligent behaviours, in a process that Piaget calls assimilation (1945). Thus, toys, daily life objects and the whole surrounding environment represent an expansion of the individual abilities for building knowledge (Ackermann 1996). Through play, in fact, an artefact has the chance to become an "object-to-think-with" (Papert 1980), whether they are computers (Papert 1980), robots or non-technological objects, such as a pendulum (Papert 1990). Consequently, direct experience, physical materials and play were brought back to educational contexts within the framework of various educational approaches.
Among the most popular approaches stand out *game-based learning* (Whitton 2012), *project-based learning* (Bell 2010), and *creative learning* (Resnick 2014), just to name few. Although these approaches present differences, especially in their orientation toward play or design, many common aspects emerge.

Game-base learning is an approach facilitated by the use of a game (Whitton 2012). This approach can result in very different learning experiences, starting from the fact that it can be carried out with physical objects, digital environment, or a mix of the two. One of the factors, that determine the effectiveness of the game-based approach, is that learning take place within a meaningful context (the game), to which the things that need to be learned are directly and clearly related. These

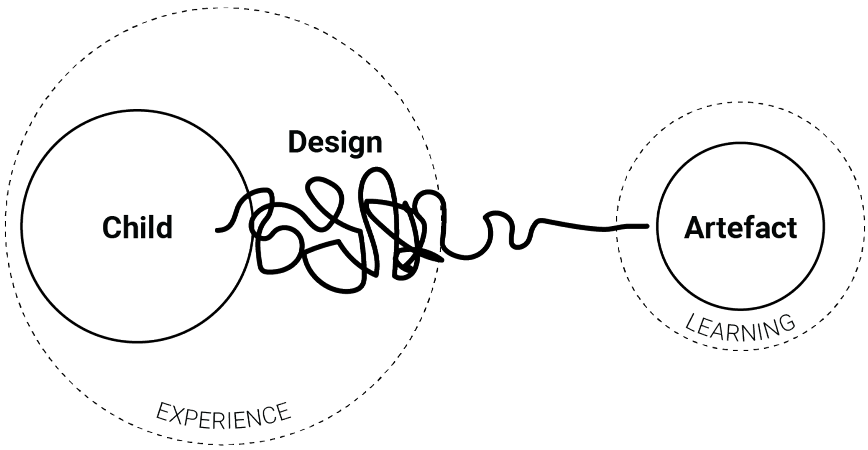


Fig. 2.4 - Conceptual schema of Design as Learning Approach for Children.

can be, then, quickly demonstrated, applied and practiced (Van Eck 2006).

Project-based learning is a student-driven, teacher-facilitated, approach in which children, in teams, can solve real-world problems, planning their learning, organising their research, and implementing a multitude of learning strategies (Bell 2010). As explained by Bell (2010), through this approach, children gain many benefits. Form a self-organization point of view, they develop responsibility, independence, and discipline, while form a social perspective, they can learn collaboration skills. Furthermore, by defining their own queries, they carry out self motivated investigations with real-world connections.

Creative learning is an approach that became popular through the research conducted at MIT (Massachusetts Institute of Technology) Lifelong Kindergarten research group, and it is characterized by four main components: projects, peers, passion, and play (Resnick 2014). Although it doesn't adopt explicitly game strategies, rather a playful (Resnick 2006) approach, it somehow gathers together the contributions of the various constructivist approaches to learning. This approach became popular in the last years and it is now mainly associated to the figure of Mitchel Resnick and the work carried out at MIT, however it is rooted in a wide body of research which has been growing for decades.
In 1970, in fact, Torrance and Myers (1970), in their work "*Creative Learning and Teaching*", provided a comprehensive definition of creative learning processes as:

"*...Becoming sensitive to or aware of problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; bringing together available information; defining the difficulty or identifying the missing element; searching for solutions, making hypothesis, and modifying and retesting them; perfecting them; and finally communicating the results.*"

Compared to traditional learning, intended as a transfer of information, the design of creative learning experiences for children is a complex challenge. "Designers" (intended as every professional involved in such project) are asked not only to define which artefact to use. They are rather requested to investigate the ways the artefacts may enable children to relate them to their experience of the world, with the final intent of constructing new knowledge.
In this regard, decisive was the contribution given by the research and the activities carried out at the Lifelong Kindergarten of MIT, over the last twenty-five years. Here, researchers investigated ways to expand the range of concepts that children can learn through the direct manipulation of physical objects (Resnick, 1998). To do so, they developed a series of what they call "manipulative materials" which embed computational capabilities inside traditional toys, such as blocks, beads and balls.
As reported by Resnick (1998), their work was guided by three underlying principles: encourage design projects, leverage new media, and facilitate personal connections.
Resnick, however, points out the fact that the introduction of new media is aimed at fostering

creative thinking, not at developing creative technologies, and that the media per se can not ensure a playful-learning experience (Resnick 2006) . Decisive aspects appeared to be the capacity of meeting children's interests, the ability to support different play styles, and the use of familiar objects in unfamiliar ways (Resnick 2006).
The most popular example of robotics applied for playful learning, developed at MIT, is LEGO Mindstorm (Martin et al. 2000).
Launched by LEGO in 1998 (Martin et al. 2000) , the Mindstorm Robotic Invention System is a product line that combines programmable bricks with sensors, actuators and LEGO technics elements, for engaging children in playful learning activities. This product resulted from a series of initiatives and researches that were carried out at MIT Media Lab in the nineties, such as an annual challenge called *LEGO Robot Design Competition* (Martin 1994), and, especially, the *Programmable Brick* project (Resnick et al. 1996).
The LEGO Mindstorms is nowadays quite diffused and used in several contexts, and their use for playful learning activities is getting popular. Furthermore, several robots for teaching computational thinking are nowadays spreading, such as *Thymio* (Riedo et al. 2013), *Cubetto* (Firth 2014), and *KIBO* (Sullivan et al. 2017).
Apart from activities related to technology, the design-based approach to learning is spreading also in several initiatives, also at local levels. In Italy, for instance, the *PACO Design Collaborative*, an open and non-profit organization based in Milan, started a series of initiatives, namely design jams, workshops, and school programs, for introducing project-based learning in children's education (Pierandrei and Marengoni 2017), through a project called *The Design School for Children*.
Similarly, the *Innovation Design* research group from Politecnico di Torino, in Turin, from 2016 is carrying out a project that involves high school students in a project-based learning initiative. In this project call *GreenTeam* (Di Salvo et al. 2017), the students, divided into teams, are asked to address an issue related to sustainability, and to answer it through the development of a project.
These various experiences in which design is a learning approach, whether they include technology or not, share the central role of projects as learning activities, the personal and unpredictable contribution of children, the co-presence of playfulness and seriousness, and the fact of being intrinsically motivating.

2.4 Conducting Design Research in Child-Robot Interaction Studies

The role of design for the development of child-robot play applications can be defined by referring to the findings of the HRI Conference proceedings review, to the knowledge coming from the HCI literature, and to the review of the literature about design for children. This contribution can be summed up in two main areas of actions, namely understanding and making, which respectively focus on the stakeholders, the context, and on the

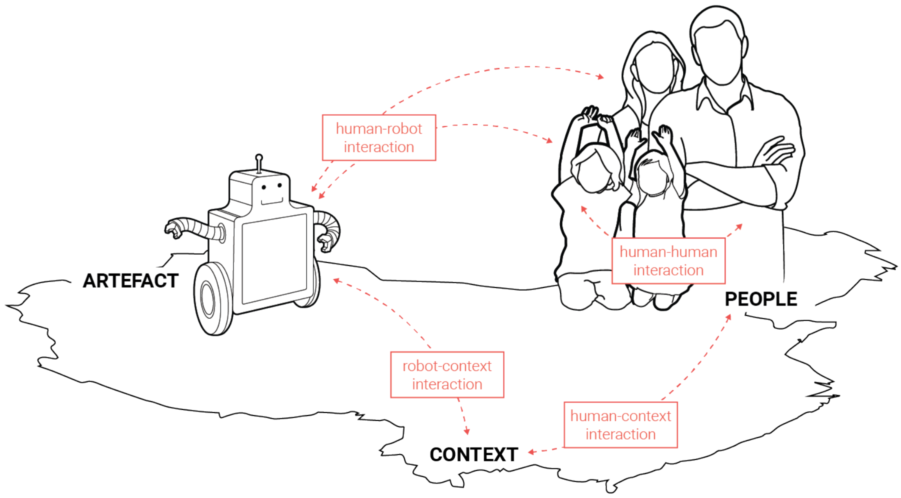


Fig. 2.5 - Conceptual schema of the main elements affected by the design contribution to HRI.

artefact, and the interactions between them.

2.4.1 Stakeholders

As pointed out in the analysis about the areas of application emerging from the proceedings review, understanding people perception, practices and values is crucial for enhancing their activities and supporting their autonomy, which is the purpose of most of the robot-based proposals. As a consequence, focusing on people becomes a central aspect of the design process.
Differently from many HCI studies, in HRI research it is crucial to take into account a wide spectrum of people rather than just primary users, because of the coexistence condition introduced by robots. For this reason, the term "stakeholders" is used in the description of actions related to the understanding of people. As stakeholders, in fact, are intended any group or individual who can affect or is affected by a project, referring to the definition by Freeman (2010).
As a matter of fact, the efficacy of each project results, on one hand, from motivations, visions and methods of whom develop it, while, on the other hand, it depends on many user's acceptance factors. Given this fact, it becomes of primary importance to identify all the actors that can potentially interact with the project, and the different factors that may influence their attitude and response to a potential proposed solution.
A key action for that is represented by stakeholders mapping (Mathur et al. 2007), which results in graphical visualizations that allow to rise awareness on implications and consequences that a project might have (Bryson 2004).
In the specific case of HRI projects for children, it becomes necessary to take into account both children and adults, who can assume a different role according to the context. The relevance of a certain category of adults, who can be parents, relatives, teachers and educators, therapists, doctors, and so on, vary according to the intended application and the relative context of use.
Children and these adults' categories represent the primary level of interest in the design of robotic applications for children, and they are usually consisting in individuals. Nevertheless, a series of other actors, that can have a great influence on the project, need to be identified. These, usually, consist of collective entities, organization and institutions that determine the legal, administrative, cultural and social norms with which the project has to deal.
Other key design actions, focused on the stakeholders, deepen specific aspects of perception and people's attitude towards robots. In particular, participatory design methods, such as observations, interviews, questionnaires, hands-on workshops etc, are often adopted with various aims. They can be employed to get knowledge about different aspects of robot's acceptability, such as in the questionnaire-based study by Choi et al. (2008), aimed at identifying positive and negative aspects of edutainment robots according to parents. In other cases, these can aim at observing emerging interactions, e.g. an ethnographic study with users performed in an elderly care center in Japan by Sabelli et al. (2011). Furthermore, participatory design can engage creatively the stakeholders, to co-create robotic solution, encouraging the aforementioned mutual shaping between society and technology (Šabanović 2010).
According to the differences between adults and children, some of these methodologies result more suitable for one stakeholders' category rather than another. For instance, activities like hands-on workshops and observations are particularly appropriate for conducting studies with children, while questionnaires, focus groups, and interviews need at least an adaptation. Thus, when preparing a study, the researchers should take into account these differences paying particular attention to what kind of data is needed and which may be the best strategy to obtain that. For instance, objective data about children's habits can be easily obtained by asking to parents, while subjective data, such as emotional responses to certain experiences, cannot be obtained without directly involving children.

2.4.2 Context

The second level of stakeholders, the collective entities, however, brings out a body of knowledge that, in addition to be determinant for the way in which individuals would establish their relationship with robots, allows to understand the implications of the context.
The same participatory design actions, in fact, can also be focused on the understanding of physical

and socio-cultural factors that determine the specific nature of the context for which a solution is intended. This second level of the design contribution, in fact, can be characterized by actions like context mapping (Stappers 2003), immersive investigations (Donahue 2003), interviews and observations, that aims at understanding the current state of the examined context, as well as to develop design proposals, that usually take the form of scenarios (Rosson and Carroll 2009) or storyboards. However, despite some studies are starting to carry out systematic investigation of the context for which the robot is intended, this is not yet a common practice.

As showed in the proceedings review, few papers mention and situate their solution in a context of use. This findings reaffirm previous results reported in a study by Baxter et al. (2016) according to which the vast majority of HRI studies, presented at the HRI conference, is usually carried out in lab environments and often with non representative samples of participants.

Nevertheless, the importance of understanding and situating robotics in society is acknowledged especially from some authors, and their specialized approaches. For instance, Šabanović dedicated an entire article to the investigation of the relationship between robotics and society, focusing on the importance of the socio-cultural context, proposing, not only ways to improve the acceptability of the robots, rather good practices for the mutual shaping of them and society (Šabanović 2010).

As already mentioned regarding actions focused on the stakeholders, in fact, a mutual shaping of robots and society can be fostered through some key actions suggested by the author, that are evaluating robots in society, by running tests in wild; systematically studying the potential context of use; design from the outside in, iterating between real world observations, technology design, and interactive evaluations; and designing with users, by actively engaging community members and potential users. Other authors also address socio-cultural implications of robotics, through different kind of situated studies, such as a long-term study with a social robot in elderly people's homes, conducted by de Graaf et al. (2015).

Thus, when designing child-robot interactions, it is a good practice to take into account typical children's environments, such as homes, schools, after-schools, or children's hospitals, according to the type of project.

However, the researchers have to be aware of both benefits and challenges related to situating their studies in real contexts. On the one hand, running tests and systematic studying a real children's contexts can be a good practice for increasing the external validity of the data produced (Baxter et al. 2016).

Often, in fact, even if the results of the studies carried out in lab can be replicated in wild, these tend to greatly differ in size and direction (Mitchell 2012). On the other hand, real contexts present very challenging environments and their complexity can significantly impact on the level of control of researchers on the object of investigation (Baxter et al. 2016). Legal and administrative issues can greatly affect a study, determining what methods and how can be adopted. This is particularly evident in the case of studies with children because of the public nature of their environments.

These contexts, in fact, characterised by higher level of safety standards, usually imposes the requirement of certifications on the materials employed (Ros et al. 2011), which, for instance, does not easily match with the use of custom robots. Another common issue in children's environments is confidentiality (Ros et al. 2011). This issue very often results in the impossibility, for researchers, of video recording the activities or employing physiological measurement tools. However, these limitations, together with the need for investigating existing practices, calls for alternative strategies, which may take the form of a *Shadowing* observation (McDonald 2005), a *Think Aloud* (Donker and Markopoulos 2002) session, or *Hands-on Workshops*, in which the knowledge is extracted from the materials elaborated from children.

2.4.3 Artefact

When focusing on the artefact level, the design actions consists mainly in the application of design practice methods for the design and development of novel robots and robot-based applications. Regarding the design process, many case studies present it with detailed descriptions, which allows to identify some recurring actions.

As common in the design practice, the first ideas are usually explored and shared through sketches and 3d models, as shown in the studies by Lee et al. (2009), Luria et al. (2016), Hofmann et al. (2015). Then, a key role is played by the prototyping actions. From low-fidelity to high-fidelity prototypes, tangible artefacts, that appear or behave as desired, allow fast testing and iterations (Šabanović et al. 2014). Usability testing represents another common action in the design of novel robots.

Vandevelde et al. (2017), for instance, developed a robotic toolkit, that is easy to build, by doing multiple design iterations and regularly testing with non-expert users. In addition to these, non-conventional design methods are starting to be often adopted in the design of robots.

The need for communicating animacy and believable behaviours of robots is pushing designers to adopt "staging" strategies. These are usually based on studies on puppetry, theater, and animation, such as the techniques developed by Disney for conveying animacy documented in the book "*The Illusion of Life: Disney Animation*" (Thomas et al. 1995).

An exemplary example is represented by the researches conducted by Guy Hoffman, which is strongly characterized by the adoption of staging strategies for the design of novel robots. In his work, in fact, staging strategies are a crucial part of the design process. For instance, in the *Mirror Puppeteering* (Slyper et al. 2015) project, an easy and affordable method was developed for animating robots with a puppeteering technique. In other projects, like *Vyo* (Luria et al. 2016) and *YOLO* (Alves-Oliveira et al. 2017), instead, different staging techniques were used. In these projects, nonverbal behaviours were designed combining the use of animation sketches, embodied improvisations by professional artists, and movement simulations through puppets.

When the design action is focused on developing a robot for children there are at least two aspects that the designer needs to take into account. On the one hand, children have different capabilities compared to adults (Hanna 1997), and, according to the age, they may find more difficult to interact with interfaces (Hanna et al. 1998). On the other hand, they respond much more easily and strongly to robots (Ros et al. 2011), compared to adults, and they have certain preferences in terms of robot's appearance, such as cartoon-like features, bright colours to enhance behaviours, hybrid appearance that combine human-like and machine-like features (Woods 2006).

As mentioned at the end of the previous paragraph, in addition to new methods, the differences of robots compared to other artefacts are pushing designers to acquire new skills. This can be explained by referring to the three main aspects addressed in the design of robotic artefacts: morphologies, non-verbal behaviours, and interaction schemas (Luria et al. 2016).

Regarding morphological aspects and non-verbal behaviours, in fact, designers are asked to deal not only with aesthetical challenges but also with robot's mechanisms. This aspect, traditionally entrusted to mechanical engineers, is particularly challenging because of the robot's peculiar ability to move that does not only serve to perform tasks, rather it can support action coordination, communication of robot's internal states, and produce an impact at the emotional level (Hoffman and Ju 2014). Thus, movements and the related mechanisms are a fundamental part of robot's expressivity.

Regarding interaction schemas, instead, which are strongly related to the purpose of a robot, designers are asked to employ another important skill, that is *computational thinking* (Wing 2017). Despite on the one hand, computational thinking is acknowledged as a fundamental skill for everyone (Wing 2006), it is currently experiencing a great popularity mostly in children education.

On the other hand, the massive spread of computational technology and its increasing emergence as design material (Hallnäs and Redström 2002), is pointing out the importance of developing computational thinking skills also within the context of various disciplines, among which, design. For instance, Carnegie Mellon University applied it to mathematics, biology, chemistry, design, economics, finance, linguistics, mechanics, neuroscience, physics and statistical learning (Wing 2017). Also design schools are starting to introduce it in the curriculum, as in the case of the Copenhagen Institute of Interaction Design (CIID 2017).

Furthermore, by looking at the definition of computational thinking by Jeannette M. Wing (2017), it appears evident why it is particularly

relevant in specific case of design within the field of robotics.
She defines it as:

"*the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent* ."

Thus, computational thinking is needed by designers not only for dialoguing with engineers, but rather for being able to creatively and appropriately answer to the needs emerging from the understanding of the context and the stakeholders, through the opportunities offered by the current technology.
It appears evident that the various levels of design actions are deeply interconnected. Despite some project might focus on more specific aspects of human perception, while others more on contextual challenges, every project has some implications at all the three levels.
However, among the three, the employment of design practice methodologies at the level of the artefact, especially through the development of custom robots, is the most diffused design contribution to robotics because it answers to the HRI field interest in designing novel robotic systems.
Given this focus on the artefacts combined with the need for participatory design aimed at understanding aspects of human perception, a Research through Design approach seems particularly suitable for conducting Design Research within the field of HRI studies. Research through Design, in fact, is defined as the employment of methods, practices, and processes of the design practice with the intent of generating new knowledge (Zimmerman and Forlizzi 2014).

Chapter 3

Methodology

Given the primary interest of understanding the role of Design Research within the field of Human-Robot Interaction studies, a preliminary investigation was dedicated to the identification of an appropriate approach to research. The analysis of the current literature reported in the previous chapter, allowed to identify the *Research through Design* approach as the most appropriate.
Thus, a brief overview of this approach is provided in this chapter with the intent of introducing the theoretical foundations on which this thesis refers.
This brief introduction is followed by a *research methodology* based on the current state of Research through Design, and the roles and practice of design in HRI, emerged in the previous chapters. Given the adopted approach, this methodology is strongly characterized by the presence of projects as study methods. These, in turn, are characterized by a common *project's methodology*, also reported in this chapter.

3.1 The Research through Design Approach

As introduced in the previous chapter, Research through Design "*is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge*" (Zimmerman and Forlizzi 2014).
As explained by Godin and Zahedi (2014), this approach is the closest to the design practice as it is based on design aspects of creation as research, and design researchers conduct investigations through the creation of new products, and the experimentation of new materials and processes. As a consequence, prototypes play an essential role in RtD (Stappers and Giaccardi 2017), and, in many cases, are adopted as main tool for investigation (Keyson and Bruns 2009).
Nevertheless, the RtD approach is not solely focused on the design and development of artefacts, it rather entails a series of different methods that are common both in design research and practice.
RtD, in fact, originated by different experiences, such as *Rich Interaction Design*, *Participatory* and *User Centred Design*, and *Critical Design* (Zimmerman and Forlizzi (2014), carried out mostly in the UK, in the Scandinavia, in the Netherlands, and in the US (Stappers and Giaccardi (2017). As reported by Zimmerman and Forlizzi (2014), in the Netherland, RtD came out from the experiences such as the research carried out at the *Rich Interaction Design Lab*, which combined design practice methods with experimental psychology research, through design workshops. Similarly, in Scandinavia, the spread of IT systems highlighted the need for understanding users' behaviours, both in production and consumption. *Participatory Design* and *User Centred Design* provided answers to this need, by combining research practices from anthropology and sociology with design. RtD has also its roots in the *Critical Design* approach become popular thanks to the *Royal College of Art*, in the UK. In this case, particular effort is dedicated to the problem selection, exploration of many possible forms, iterative refinement, and the reflective writing. In the US, instead, the emergence of RtD was strongly connected to the effort of design researchers on investigating design within the field of HCI, its role and the knowledge it can produce.
Thanks to these experiences, RtD is now starting to be widely acknowledged among designers and non-designers. And, despite in many cases it is not explicitly mentioned, this approach today represents a variety of designerly ways of doing research (Stappers and Giaccardi 2017), such as Experimental *Design Research* (Brandt & Binder 2007), *Design Research through Practice* (Koskinen et al. 2011), *Interaction Design Research* (Zimmerman, Forlizzi, Stolterman 2007), just to name a few. This variety of visions and approaches is directly related to the still existing difficulties of the design community in identifying for RtD the right words, models, and practices (Stappers and Giaccardi 2017).
About this issue, Stappers and Giaccardi (2017) pointed out the main challenges of this approach by providing a list of the most recurring, and unanswered, questions, that concern: the type of knowledge produced by RtD; the role of the artefacts; the projects' methodologies; the dissemination of the produced knowledge and the audience engagement; the relationship of RtD with other research approaches; the role of design practice in RtD; and the belonging of RtD to certain academic contexts rather than others.
These open questions are also reflected on discordant methodologies and processes adopted in RtD. For instance, Keyson and Bruns (2009) suggest that RtD should be carried out through the following steps: methods' selection (inputs), hypotheses' formulation, design iteration 1, artefacts/interfaces design, pilot studies, evaluation, design iterations, artefacts/interfaces design, pilot studies, evaluation, final iteration, final experiment.
Zimmerman and Forlizzi (2014), instead, suggest a methodology summarized in five main steps: select, design, evaluate, reflect and disseminate, repeat.
The two methodologies differ for various aspects. First of all, the focus of the first methodology is on the development of artefacts and the various steps are functional to that. In the second case, the artefact represents one of the methods along with the act of identifying problems and opportunities (select). But most of all, the two methodologies diverge in the fact of contemplating a final step of

the research (first case) and not contemplating it (second case).

The intended outcome for Keyson and Bruns (2009) consists of deep insights about interaction issues and knowledge that could guide subsequent design actions. These outcomes are expected also by Zimmerman and Forlizzi, which, however, introduce two key aspects: reflection and repetition. The reflective phase of the research, in fact, allows to move from the concrete to the abstract dimension, from actionable insights to theories. A possible cyclic dynamic of research, instead, is suggested by the "repeat" step. Although iterations are present in both methodologies, the repeat of Zimmerman and Forlizzi highlight the fact that research through design is not intended to deliver a final output, rather open up new research opportunities and provide different interpretations of a same problem.

Despite the differences between the various methodologies adopted, there is a general agreement about the overall objective of RtD, that is not the production of artefacts themselves or how these are made, rather the investigation of what these could be and how these might move the current state of things into a preferred state (Godin and Zahedi 2014). Furthermore, this objective does not only belong to the RtD approach, rather to the design discipline in general, as pointed out by Simon (1996) who stated that design is "*a process by which we [devise] courses of action aimed at changing existing situations into preferred ones*."

3.2 Designing for Robot Acceptability

Designing hypotheses of robotic solutions that might have a positive impact on the context and the people for whom the project is intended is a complex challenge. If, on the one hand, designing artefacts and experiences is familiar to the design discipline, on the other hand, dealing with the specific possible effects of robots in society asks designers to pay particular attention not only to a potentially positive impact on society (Jonas 2007), but also to ensuring the acceptability of the proposed solution (Salvini et al. 2010). A large body of research, in fact, was dedicated over the years on investigating the factors affecting the acceptability of technology, and various models were proposed for evaluating it.

Acceptability was defined by Dillon (2001) as "*the demonstrable willingness within a user group to employ information technology for the task it is designed to support"*. This concept, often recurring in human-robot interaction (HRI) studies, is addressed from two different perspectives: accepting (or rejecting) users, and accepted (or rejected) technology (Dillon 2001). Referring to accepting users means to take into account all those human characteristics that might influence acceptability, such as cognitive style, personality, demographics and user-situational variables (Dillon 2001).

Referring to accepted robots, instead, means to address those aspects that characterize them, such as relative advantage, compatibility, complexity, trialability and observability (Roger 1995). In particular, many studies deal with the issue of acceptability focusing on preferred robot's behaviours (Milliez et al. 2016) or characteristics, such as voice (Eyssel et al. 2012) or typology (Kwak et al. 2014).

The theme of acceptability is not a novelty in research, and several acceptance models were elaborated over time, especially in HCI. These, commonly meant for evaluation, depict the issue of acceptability from different perspectives. Already in 1989, Davis (1989) proposed a Technology Acceptance Model (TAM) in which two main characteristics affects acceptance: perceived usefulness and perceived ease of use. This was followed by a series of other models that attempted to describe the complexity of acceptability through different variables. The Technology-to-Performance Chain model (TPC) (Goodhue and Thompson 1995), for instance, introduced individual characteristics as influencing factor, together with task and technology characteristics. A further contribution in this regard is brought by the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003). This model, in fact, shows how technology characteristics, such as performance expectancy and effort expectancy, and human characteristics, such as attitude and social influence, are influenced by human peculiarities, such as age, gender, experience and voluntariness of use. This model

was widely used and adapted in HRI studies. For instance, Heerink (2010) adapted and extended the UTAUT model by explaining the intention of use not only in relation to functional aspects, but rather to social interaction aspects, such as trust and anxiety.
Another model developed specifically for robot acceptance is the USUS (Weiss et al. 2009), an acronym that stands for the main aspects addressed: usability, social acceptance, user experience and societal impact. According to this model, robot's acceptability can be evaluated taking into account these four aspects, for each of which, the model provides a list of key factors. Compared to the other, this model addresses human characteristics more deeply. For instance, it reports factors such as quality of life and education with regards to the societal impact, and forms of grouping and attachment, that refers more to the social acceptance. These aspects appear to be particularly relevant for HRI, rather than for HCI, because of the embodied interactions that robots allow and the social presence that they represent.
Looking at both case studies and models, it is possible to notice that the concept of acceptability is usually taken into account for evaluation. In particular, in the case of project involving the design of novel systems, this affects mostly the test phase. However, as mentioned by Dillion (2001), the main aim of understanding robot acceptability is to influence the design process to ensure that the resulting solutions are likely to be accepted. In fact, the knowledge about acceptance factors and the application of these as design drivers should lead to an adaptation of technology to human needs. These factors, as showed by the models, refer to different aspects of human-robot interaction scenarios, from physical to societal dimensions. In particular, the importance of "high level" factors are highlighted by Vincente (2010). He stresses that the adaptation of technology to human needs implies reflections also at organizational and political level, since these involve moral, legal and ethical implications. Šabanović (2010) proposes a further step foreword regarding the relationship between robotics and people. She suggests that there is need to design for robot and society mutual shaping, that can occur through iteration between social analysis and technology design.
Many projects that are aimed to design acceptable robotic solutions conduct preliminary studies to identify acceptability factors that, subsequently, are used as design drivers. However, even if in these cases acceptability issues were considered during the whole process, these were addressed as specific aspects rather than as complex system of relations. In fact, acceptance of a robotic system cannot be achieved analysing single factors, or a single type of factors, because even a small aspect can bring unexpected consequences. For this reason, human perception and psychological implications become crucial for both acceptability and prevention of negative drawbacks. Robots, whom abilities often bring requirements not compatible with real contexts or appear to be in competition with existing practices, have to be designed within the context of use where these psychological implications can arise. This, however requires to face the unpredictability of real environments, where there is need of continuous adaptation from robots. Furthermore, the long term consequences of the social relation between human and robots are not predictable.
This multitude of issues, that highlight the complex nature of the emerging systems, can be analysed through the classification of socio-technical systems problems, by Norman and Stappers (2016). They define as DesignX problems all those issues that relate to psychology of human behaviour and cognition; social, political, and economic framework of complex socio-technical systems; and technical issues that contribute to the complexity of design problems. Therefore, designing for robot's acceptability means to embrace complexity and to deal with these problems, at multiple levels. Designers are required to be aware about the unpredictability, non-linearity and impossibility to fully control these systems. Despite the models can appear simplistic since they describe acceptability through rigid structures with highly defined boundaries, the variety of factors that they highlight can be used as design drivers. In particular, by taking into account some of the most recurring factors that affect acceptability, it is possible to identify four main categories: functionality, social ability, appearance (Beer et al. 2011) and ethics (Vincente 2010). The functionality factors refer mostly to how a proposed solution works and what is its scope. For instance, this category includes some factors such as perceived usefulness (Davis

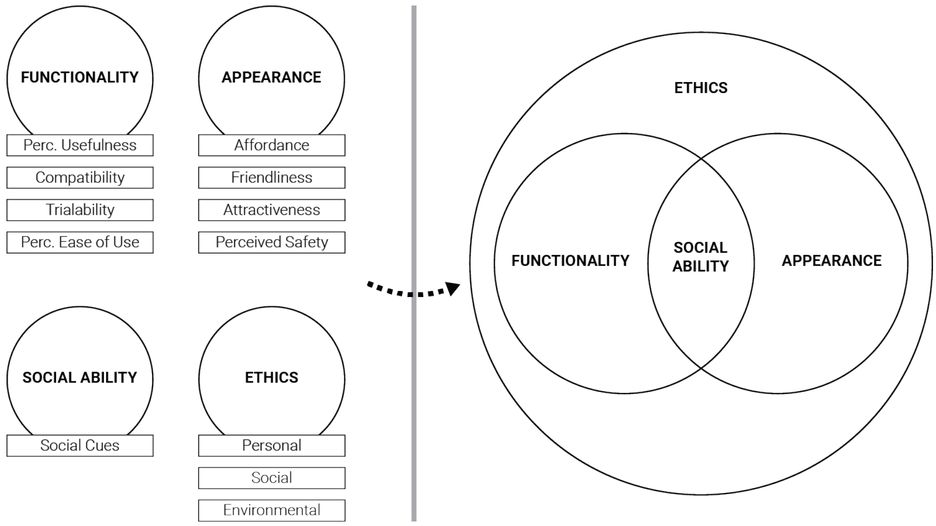


Fig. 3.1 - Recurring factors affecting acceptability are organised in four main interrelated aspects.

1989), compatibility, trialability (Roger 1995) and perceived ease of use (Goodhue 1995). Social ability, instead, refers to those specific qualities of a robot that communicate sense of animacy, in particular the ability to show social cues (Beer et al. 2011). Regarding appearance, instead, Salvini et al. (2010) highlight the crucial role for acceptability played by factors such as affordance, friendliness, beauty and perceived safety.

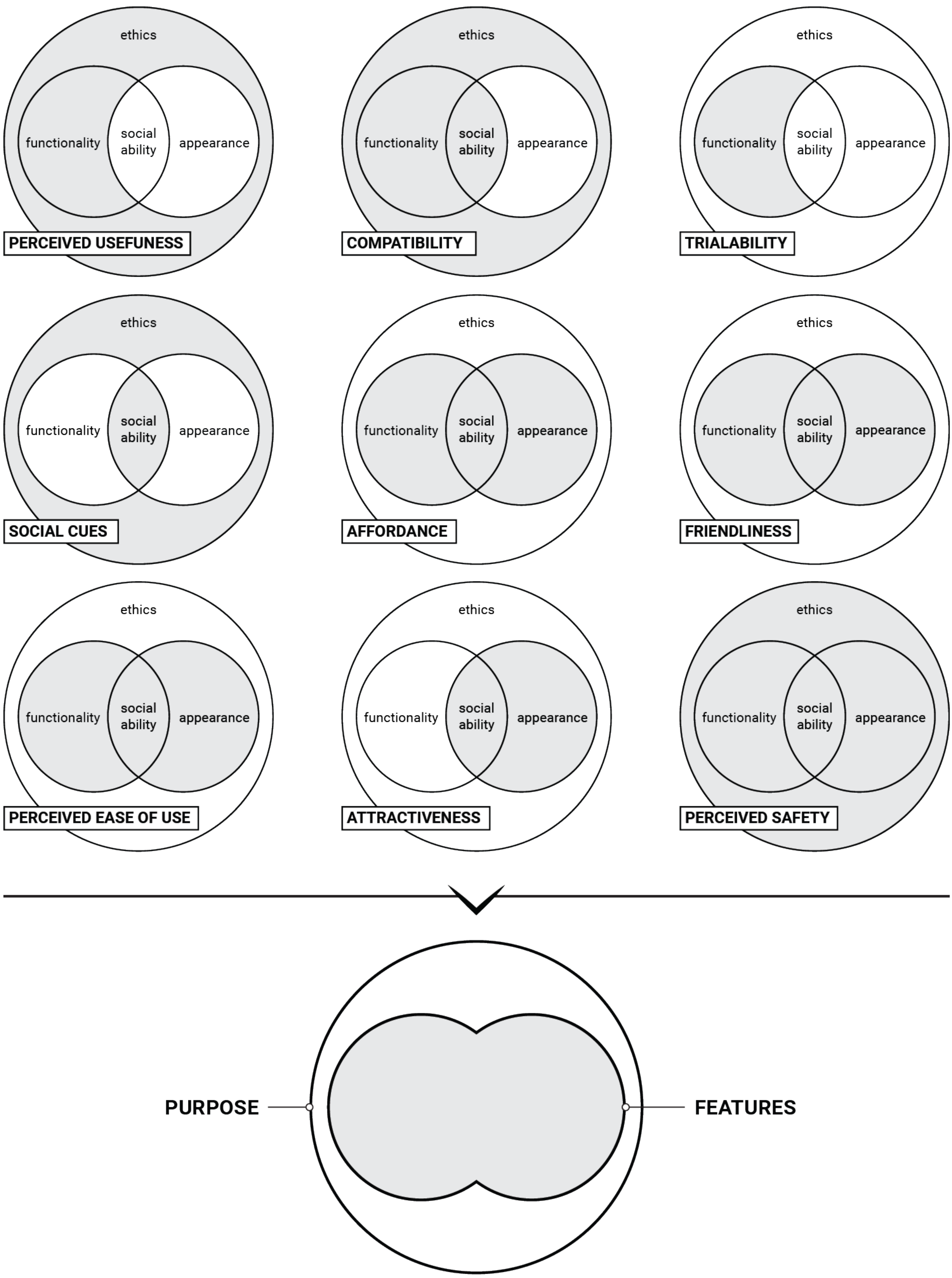
As mentioned before, however, these factors have to be addressed as interrelated parts of a complex system, rather than a set of elements since every factor interacts and affects other categories. To this end, the four main categories of factors were arranged in a single framework, shown in figure 3.1. At the center of this were located two intersecting circles: one representing the functionality and another the appearance. The intersection between the two stands for the inescapable relation of their mutual influence, that recalls the traditional form-function dichotomy (Landowski and Marrone 2002). As a matter of fact, the function of an artefact contributes to the shaping of its appearance, at least in its constitutive parts. Vice versa, the appearance is not only crucial for gaining attractiveness, but it can also affect the perceived usefulness of an artefact by determining the way it communicate its function to people. Between these two categories stands the social ability that a robot may have. It is located in this hybrid space due to the impossibility to distinguish its functional role from its appearance. The social abilities and their manifestation in terms of appearance determines the belonging of a robot to a typology rather than another, each of which enables different functionalities and usage scenarios. For instance, Kerstin Dautenhahn (2002) highlights how non-humanoid mobile robots are more suitable for autism therapy rather than humanoid or zoomorphic robots since the complexity of appearance and behaviour can result overwhelming for autistic children.

These three categories, functionality, appearance and social ability, are then included in a larger circle representing ethics. Ethics, that can affect acceptability at personal, social and environmental level, is implicated by every design choice. From the definition of the function, that might conflict with human activities and alter human relations, to the choice itself to adopt robotic technologies instead of alternatives that might be less impactful from the economical and the ecological point of view. Thus, in most of cases, ethical implications call for reflections about the cost-benefit relation entailed by the adoption of a new technology.

This relationships of interdependence between the four categories can be further understood by focusing of the single factors, synthetically summarized in figure 3.2. Every circle shows how every factor affect the main categories of the framework.

For instance, referring to perceived usefulness in the context of cultural heritage, telepresence

Fig. 3.2 - Relationship of each recurring factor with the four main aspects.


ethics
functionality
social ability
appearance
PERCEIVED USEFUNESS
ethics
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COMPATIBILITY
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ATTRACTIVENESS
ethics
functionality
social ability
appearance
PERCEIVED SAFETY
PURPOSE
FEATURES

robotics might be used to attract greater public on site by offering an innovative service to explore hidden areas of the heritage, as in the case of the project Virgil (Germak et al. 2015), in Italy. In this context it could be perceived as highly useful due to the existing issue of inaccessibility of heritage in the country (Istat 2013). In this case it could be considered also ethical in the extent of which it increases accessibility for people, it doesn't intake human-human relationships and it enhance the environment in which it is located. On the contrary, in a different context like Australia, this solution might result unnecessary and with little benefits compared, for instance, to allowing remote exploration of a museum for children from rural areas, as in the case of the National Museum of Australia (Csiro 2016).
Regarding the compatibility, instead, despite the usefulness or not of the function, a solution might be considered acceptable on the basis of the value system of the cultural context. For instance, robot companionship for children could be acceptable for Korean parents while would highly rejected from European parents (Choi et al. 2003) despite their use for educational purpose. This phenomenon could be examined by reflecting on how the educative functions are usually carried out in the two contexts (which could affect perceived usefulness and ethics), and on the presence or not of forms of social abilities and life-like characteristics applied to other tools (which could determine the acceptance or rejection of social cues).
The specific ability to show social cues, besides, raises a variety of ethical and moral issues related to the unpredictable consequences of an emotional bond with robots (Scheutz 2011). Thus, despite these can increase the efficacy of human-robot interaction, by allowing natural communication modalities (Breazeal 2003), the presence of social cues necessarily call for attention on psychological and social, and then, ethical issues.
Conversely,otherfactorsbelongingtotheappearance category, such as affordance or friendliness, do not raise great ethical issues. However, these can play a crucial role for acceptability because of their great influence on how people perceive and engage with robots. In particular, the affordances allow people to understand the possible actions offered by a system and to behave accordingly. A robot that fails in providing affordances of its functions might be underestimated, misinterpreted and considered unsafe. Similarly, the familiar appearance or behaviour of a robot can recall existing artefact or functioning, helping people to understand it and to establish positive interaction.
These few examples show how the various acceptability factors, shown in figure 2, are related and influence each others. Nevertheless, observing the main relations between the factors it is possible to identify two main level of the framework: some factors refer more to the general purpose of a project, while others to its specific qualities. The general purpose represents the aim of a project, the issue that is being addressed and the value that it could generate. The specific qualities consist of the strategies this purpose is achieved, the details of the project. So, designing for acceptability requires a continuous reflection on both specific qualities and the general purpose of a project, by referring to the related factors.

3.3 Research Methodology

Given the practice-based nature of the Research through Design approach, this research was characterized by three key elements: background research, design, and reflection. An overview of the methodology is shown in figure 3.1.
The background research consisted of the literature review presented in the previous chapter and literature, which was consulted throughout the research.
Similarly, an analysis of the child-robot play scenario, also part of the background research, was carried out from the beginning of the research and regularly updated, taking into account new edutainment robots, new trends in children education and play, and new general phenomena. The findings of the background research were used firstly to inform the two projects, developed as key studies for the research.
These projects, developed with a specific methodology described in the next paragraph, assumed the role of methods through which were investigated aspects of design processes, robot design, and implications of developing robotic solutions.In the reflection phase, the projects were documented and subjected to a critical analysis with the aim of producing sharable knowledge.

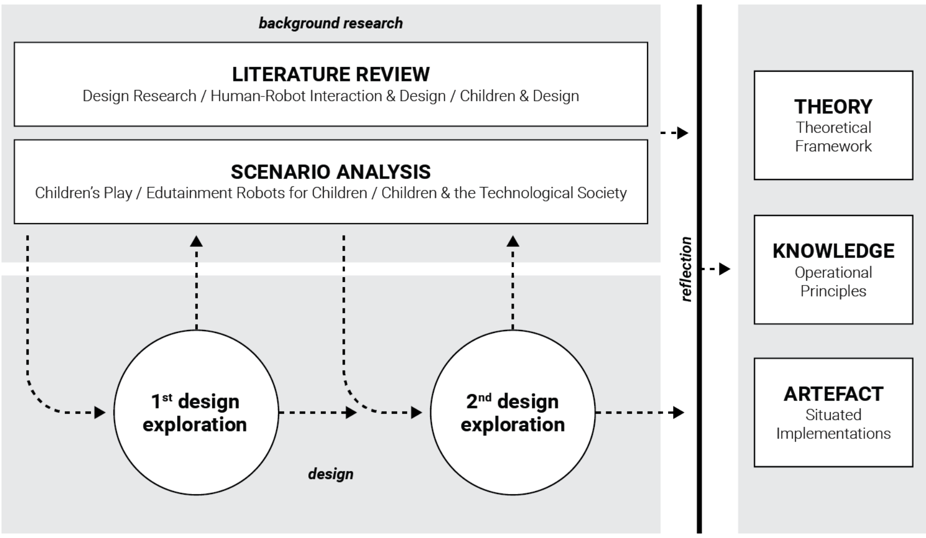


Fig. 3.3 - Research Methodology.

As explained by Cross (1999), in fact, "to qualify the work of the design practice as research, there must be a reflection by the practitioners on the work, and communication of some reusable results from that reflection". To this end, the outcomes of this research were subdivided in three main levels, referring to Purao (2002) who provided a useful classification of the kinds of outputs that Design Research may produce. According to the author, the outputs can be grouped in three main levels of contributions: artefact, knowledge, and theory. Thus, the outcomes of this research consist in situated implementations, at the artefact level; operational principles, at the knowledge level, and a theoretical framework, at the theory level.

3.4 Project's Methodology

In addition to the research methodology, a specific methodology was defined for guiding the projects as research "tools". This was formulated by taking as reference the reflections on acceptability and the two key aspects of RtD methodologies, namely investigating through designing artefacts/experiences and exploring design hypotheses that might have, a positive impact on the context and the people for whom the project is intended. About that, Forlizzi (2013) suggested an approach for creating the design conditions to foster them. According to the author, in fact, this can happen by framing the system for which the design action is intended. This framing should consist of three main actions: moving the approach from problem solving to problem seeking, moving from sketching to modelling and abstracting relations, and, finally, moving the focus from prototyping solutions to investigating how certain solutions may perturb the system.

Besides putting emphasis on the importance of defining the problem and understanding relations, the author introduces the key concept of system as a behaving entity that is perturbed by the introduction of new technologies.

Although she was referring to technology in general, this vision is particularly relevant in the field of human-robot interaction studies. Service robots, in fact, are expected to operate in changing, real-world environments (Scholtz 2003) collaborating or just co-existing with humans (Salvini et al. 2010). In this scenario, understanding acceptability to prevent negative drawbacks plays a central role, but it is not easy. In fact, on the one hand, aspects of human perception, psychology and culture add up to technical challenges. On the other hand, robotics is commonly adopted mostly for its potential and promises rather than being problem-driven (Weiss et al. 2011) rarely addressing existing practices, socio-cultural norms, and values (Sabanovic 2010). This co-presence of technological, human and contextual factors highlights the complex challenges posed by the HRI field, whose problems falls under the definition of *wicked* (Rittel and Webber 1973) or *DesignX* (Norman and Stappers 2015) problems.

Designing for child-robot play, thus, do not only pertain the ideation and development of novel artefact, rather the understanding the complex

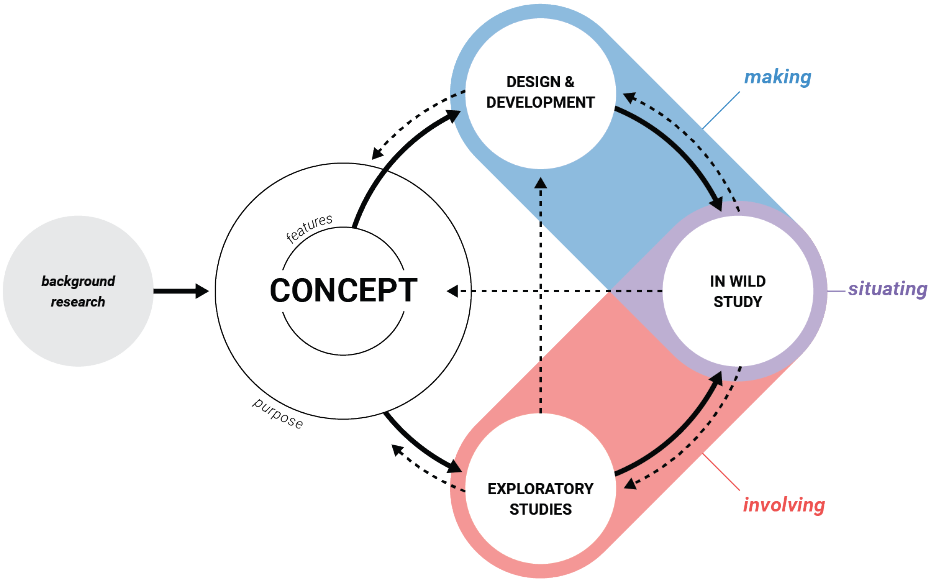


Fig. 3.4 - The methodology defined for guiding the development of the two projects carried out during the research.

socio-technical system for which a robotic artefact is intended.The complexity of these systems and the different nature of the influencing factors require a shared effort among multiple disciplines. In this, designers can contribute both through the actual development of novel artefacts and through the established human-centered practices by investigating the experience of the people and highlighting how the factors of a system affect them (Norman and Stappers 2015).

According to these considerations, a methodology was defined by referring to the suggestion by Forlizzi (2013), and the common practices emerged from the literature review about both Design Research and HRI.

The proposed methodology, illustrated in figure 3.4, is characterized by five main steps. Firstly, knowledge coming from the background research, that correspond to that of the research in general, showed in figure 3.1, is used to inform the project and define a theme.

On the basis of this knowledge, a design concept is defined, focusing on both the purpose of a hypothetical solution, and its features. These two aspects of the concept, which encloses hypotheses on how robotic artefacts might produce a positive effect, are, then, explored through two parallel actions: design and development of a robotic solution that focus more on the features of the project, and exploratory studies with the potential users and other significant actors for digging in the project's purpose and its relevance. Although these two actions are carried out in parallel, the results of the second are intended for both generating new knowledge on the theme and informing the design and development of the proposed solution. These two actions, then, converge on a crucial phase: in wild studies. In this phase, the proposed solution is adapted for a credible usage scenario, in a real context where representative sample of people can interact with it.

Compared to other methodologies adopted in HRI, this is particularly characterized by the effort of systematically combining making, involving and situating actions.

The *making* actions, corresponding to the design and development and adaptation for in wild studies, are particularly focused on the robotic artefact, which includes aspects of morphology, interaction with users and behaviours.

The *involving* actions, instead, require the participation of representative samples of people, according to the project purpose. These are aimed at investigating the socio-cultural context with a focus on the potential users and their possible attitude towards robots. Thus, the involving actions can be both explorative, with the aim of generating knowledge that may inform the making processes, or evaluative, with the aim of validating design choices and assumptions, generating new knowledge and identifying issues for future iterations.

Finally, as *situating* actions are intended those at the intersection between making and involving, aimed at investigating the socio-cultural context with a focus on the physical and cultural environment, that can determine great differences in the meanings assumed by robotic applications.
Thus, this methodology was applied in two different projects: *Phygital Play* and *Shybo*, described respectively in chapter 5 and chapter 6. The two projects addressed different themes and were developed through slightly different processes, although both consistent with the overall methodology structure.

Chapter 4

The Scenario of Child-Robot Play

Developing projects focused on child-robot play requires not only to be aware of the current state of the research in the field but also to understand the current scenario in which this type of interaction takes place. Differently from other robotic areas of application, in fact, child-robot play is widespread today, and it is represented by the edutainment robots' category.
It is then necessary to analyse what is edutainment robotics for children, what are its common features, how it relates with the child play types and developmental stages, and which role these products play or might play in the current society.
Accordingly, this chapter provides an introduction to what is play for children and its main typologies. This is followed by an analysis of the most common edutainment robots for children and their features, through a sample of twenty-seven products. Then, an overview of the current relationship between children and technology is provided, with the intent of understanding the role played by edutainment robots in society. From this analysis emerged two themes, and relative design opportunities, that are "*physically active play*" and "*objects-to-think-with*". Finally, the chapter ends with a framing of edutainment robotics as a phenomenon, that should be used as a reference in the development of child-robot play projects.

4.1 Child's Play

Play was defined as "*a minimally-scripted and open-ended exploratory activity in which the participant is absorbed in the spontaneity of the experience*" (Ortileb 2010).

In the last century, the importance of play was largely debated, especially regarding its role for children's development. In particular, a great contribution was provided by Piaget (1962), according to whom, play leads children from activity to representation, passing through sensory-motor explorations first, and through symbolic and imaginative play, after.

and acquiring thereby a feeling of virtuosity or power". The importance of play for the development of the child, was reaffirmed by many other authors, including Vygotsky (1967), and Bettelheim (1987).

Although Vygotsky believed that play is not the predominant form of activity for children, he claimed that it is essential for their development. In play, in fact a child push himself "*above his average age, above his daily behaviours*", because play is "action in the imaginative sphere, in an imaginary situation" and it is "*the creation of voluntary intentions and the formation of real-life plans and volitional motives*", all aspects that represents the highest level of development in preschool children.

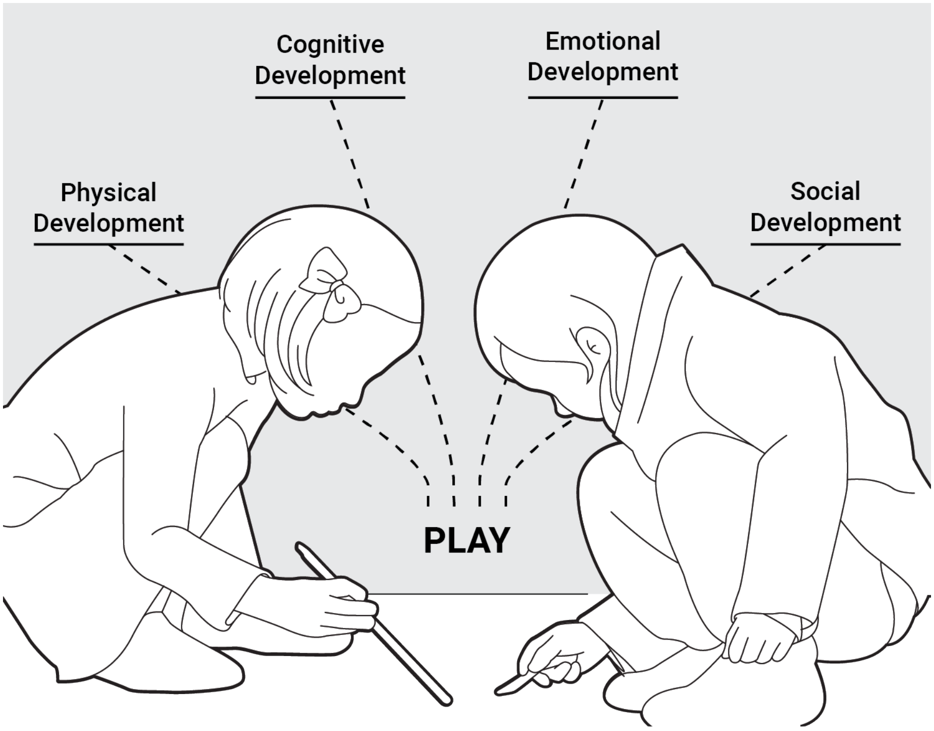


Figure 4.1 - Play and child development.

Play, in fact, allows children to create meanings for their symbolic representations of the world, through a process that he calls assimilation. This process, consists on the act of using existing schemas (the building blocks of intelligent behaviours) to deal with new objects and situations. Especially in the initial stages, play represents also a process of relaxation from the efforts required to children for accommodation, namely the adjustment of existing schemas to new objects and situations.

In play, in fact, children can keep performing activities "*for the mere pleasure of mastering them*

Furthermore, he pointed out the fact that pleasure, in play, resides in resisting to impulsive actions and subordinating one's own behaviours to rules. In fact, despite the early forms of play are almost identical to sensory-motor behaviours (Piaget 1962), through play, the child gradually free himself from the situational constraints emerging from perception. He gets the ability to disconnect the meanings from the objects with which are usually connected, for creating his own meaning/object structures and imaginary situations (Vygotsky 1967).

Also Bettelheim (1987) reaffirmed the importance of play, stating that "*play is the child's most useful tool for preparing himself for the future and its tasks*" because it "*teaches the child, without his being aware of it, the habits most needed for the intellectual growth*". He also pointed out the difference between play and games. Although the two are often considered synonymous, play refers to the young children's "*activity that is characterized by freedom from all but personally imposed rules*", while games, associated with a more mature age, are usually "*competitive and characterized by agreed-upon, often externally imposed, rules*".

4.1.1 Play Types

According to Piaget (1962), play types evolve in accordance with the child's developmental stages. The author (Piaget 1952), in fact, formulated a theory according to which the cognitive development of the child consists of four main phases, characterized by the acquisition of different abilities.

The first, called *sensorymotor* stage, correspond to the infancy of the child, namely the first two years of life. At this stage, the child, that explores the world through sensory and motor activities, gradually acquire the concept of object permanence.

The second stage, that goes from the age of two to six/seven, is called *preoperational*. At this stage, the child's intelligence is manifested by the use of symbols, a more mature language, memory, and imagination. Nevertheless, the thinking is mainly non-logical and egocentric.

This phase is followed by the *concrete operational* stage, that goes from the age of six/seven to eleven/twelve. At this point, the child has acquired logical thinking and uses systematically symbols associated to objects.

The last phase, called *formal operational* stage, correspond to the adolescence and adulthood, and starts around the age of twelve. At this stage, the child has acquired the ability of using logically symbols in relation with abstract concepts.

Referring to these stages of cognitive development, Piaget pointed out the fact that play move from primitive forms, strongly connected to sensory-motor behaviours, to more abstract forms, in which play becomes a symbolic transposition of things in the child activities without contextual limitations. Furthermore, he stressed the role of socialization as the process through which individual symbolic imagination is gradually adapted to collective rules.
Many author, then, provided categorizations of play types, such as Moyles (1989), who identified three main groupings of play types, that are *physical play*, *intellectual play*, and *socio and emotional play*; and, more recently, Gielen (2009), whose work is focused on design for children's play.
Referring to Vermeer (1972) and Vedder (1977), the author identified six main paly types: "*playful movements*, *sensopathic play*, *playful handling of objects*, *construction play*, *fantasy and role play*, *success and team play"*.
Alternative categorizations can also be found in specialized reports from foundations, companies and associations. Among these, a useful categorization was provided by the LEGO Learning Institute, in the report "*The future of play. Defining the role and value of play in the 21st century*" (Gauntlett et al. 2011). In this report, play types emerged from literature were grouped in five main categories: "*physical play, play with objects, symbolic play, pretence/socio-dramatic play,* and *games with rules"*. *Physical play* includes active exercise play, rough-and-tumble, and fine motor practice. These three play modalities foster both physical development, though motor skills and coordination, but also emotional and social skills.

Play with objects consists of children's exploration of the world through the objects they have around them. Through manipulation and construction, this type of play can foster physical skills. But most of all, playing with objects, stimulate children's creativity, thinking, reasoning, and problem solving skills. This type of play is also strongly related with physical, socio-dramatic and symbolic play.

Symbolic play refers to the activities related to the communication that foster children's technical abilities to express their ideas, feelings and experiences. This can take the form of language, drawing, collages, music and others. The importance of symbolic play resides in the fact that it enables children to represent their knowledge and to gradually increase their vocabularies.

Pretence/socio-dramatic play includes all forms of pretence play, typically solitary in the child's first years, and social and cooperative at the age of 4/5 years. High quality of pretend play can foster cognitive, social and academic development.

PLAY TYPE	TOY TYPE
Physical Play	Mirrors, Mobiles, & Manipulatives Push & Pull Toys
Play with Objects	Blocks, Interlocking Building Materials
Symbolic Play	Arts & Crafts, Audiovisual Equipment, Musical Instruments
Pretence & Socio-Dramatic Play	Dolls & Stuffed Toys, Play Scenes & Puppets, Ride-on Toys, Dress-Up Materials, Small Vehicle Toys, Tools & Props
Games with Rules	Puzzles, Card, Floor, Board, Table Games, Computer & Video Games
Educational & Academic Play	Books, Learning Toys, Smart Toys & Educational Software

Table 4.1 - Play types and some examples of related toys.

Games with rules refer to a broad range of games, including videogames, that share the presence of explicit rules governing the play activity. In this type of play, children can learn a broad range of social skills, like sharing, taking turns, understanding other's perspective and so on.

A further interesting categorization can be found in a report by the *U.S. Consumer Product Safety Commission* (CPSC) (Smith 2002). This report, focused on the relationship between children's age and toy characteristics, a list of seven types of play is provided, with a series of example toys for each category. This differ from the categorization by Gauntlett et al. (2011) mainly for the terminology and in the number of play types. For instance, in this report, symbolic play is called media play, pointing out the growing presence of different media in the toy industry. Physical play, instead, is divided in two different categories, that are construction play, and sports and recreational play. However, the most interesting difference presented by this report in the presence of the *educational and academic play* category.
Although this might represent a ground for debate about play and its purposeless nature, it is crucial to take into account within the context of this investigation about the theme of child-robot play.
Edutainment robots for children, in fact, represent a category of products in between play and learning, and are more and more adopted both in private contexts for entertainment, as well as in public educational environments, such as schools, for supporting education.

4.2 Edutainment Robots for Children

The term edutainment was formulated combining between the words education and entertainment. It emerged with the spread of the first computer-based educational programs (Lund and Nielsen 2002), and now popular through a variety of consumer products (Cox 2015), among which robots.
The term stands for all those applications that combine learning with fun in the attempt of increasing the attractiveness of educational activities and the retention of the learner attention (Okan 2012).
The term edutainment is now widely used to indicate many robotics products for children since, over time, most of robotic games and toys were developed putting emphasis on their educational potential.
Edutainment robots for children were analysed from a psychology perspective by Lund and Nielsen (2002). In their article, the authors provided an overview of the most popular edutainment robots, such as *Furby, SONY AIBO, My Real Baby, Paro seal Robot, Tama cat robot, SDR-4X, LEGO Mindstorms*, and many others. From their analysis, the authors defined three categories of edutainment robots, that are *robots with no construction possibilities*, *robots with little construction possibilities*, and *robots with extensive construction possibilities*. The categories were based on the particular interest toward the educational potential of the robots and focused on the beneficial role of manipulation for defining the robots' structures and behaviours. A further distinction of edutainment robots' categories can be done referring to toy types. Through this approach, two main robot types emerge: constructions robots, and characters robots.

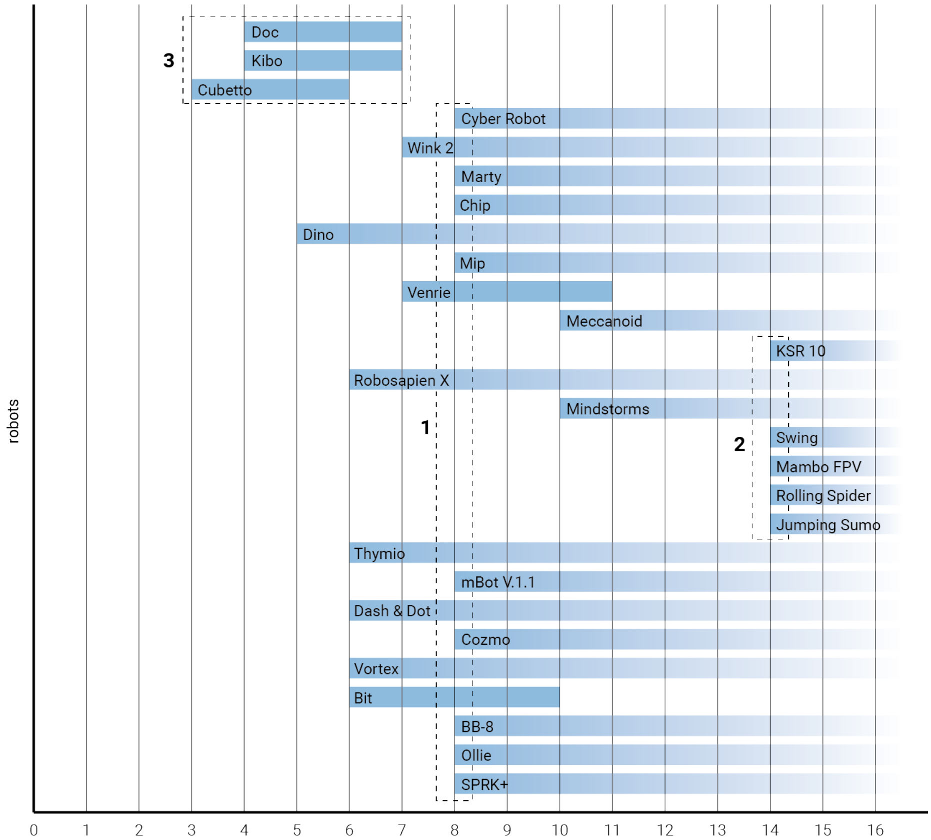


Table 4.2 - Distribution of the sample of edutainment robots according to the recommended age.

Many of the examples reported by Lund and Nielsen (2002), however, are now out of market. Nevertheless, in the last years, the market of edutainment robots for children experienced a tremendous growth. Thus, an overview of the today's most popular products is showed in table 4.3. This sample of robots was analysed and listed reporting four main characteristics: intended age, toy types, movement and control.

4.2.1 Age

By looking at the sample of edutainment robots that was taken into account, it is possible to reflect on some common characteristics and on how these relate to the aforementioned play types and related toys examples.
First of all, in table 4.3, it is possible to notice how these products appear more suitable for certain ages rather than others. A sort of threshold can be noticed at the age of 8 (1), that correspond to the minimum age suggested by many products, such as *SPRK+*, *Cozmo*, *Mbot V1.1*, *Marty*, *Cyber Robot* and others. These kind of products, in fact, may ask children to build or program the robot, which requires logical thinking and systematic use of symbols, characteristic aspects of the pre-operational stage of development. In four cases (2), the suggested age is minimum 14, such as the *Parrot* mini drones and the *KSR 10* robotic arm. However, the motivation for this high suggested age is probably different in the two cases. On the one hand, the robotic arm presents a complexity that may require a certain maturity in the child development, while on the other hand, the mini drones may be unsuitable for younger children because of safety issues, rather than learnability issues.
A third interesting point (3) is that few products are intended for children under the age of 6. Under this age, in fact, children can understand and use symbols, but they didn't acquire systematic and logical thinking yet. However, these challenges were addressed by three products dedicated to young children, that are *Cubetto, Kibo* and *Doc.*

Table 4.3 - Some of the most popular edutainment robots for children today.

SPRK+, *Sphero*

Age: **8+**
Type: **Vehicles**
Movement: **Orbital**
Control: **Teleoperated / Programmed**

Ollie, *Sphero*

Age: **8+**
Type: **Vehicles**
Movement: **Wheels, Directional**
Control: **Teleoperated / Programmed**

BB-8, *Sphero*

Age: **8+**
Type: **Vehicles / Characters**
Movement: **Orbital**
Control: **Teleoperated / Programmed**

Bit, *Ozobot*

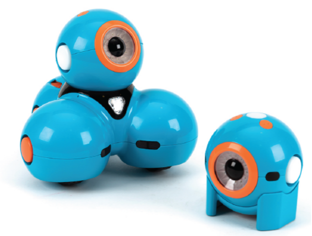
Age: **6-10**
Type: **Vehicles**
Movement: **Wheels, Directional**
Control: **Programmed**

Vortex, *DF Robot*

Age: **6+**
Type: **Vehicles**
Movement: **Wheels, Directional**
Control: **Programmed**

Cozmo, *Anki*

Age: **8+**
Type: **Vehicles / Characters**
Movement: **Wheels, Directional**
Control: **Programmed / Autonomous**



Dash & Dot, *Wonder Workshop*

Age: **6+**
Type: **Vehicles / Characters**
Movement: **Wheels, Directional**
Control: **Teleoperated / Programmed**

mBot V.1.1, *MakeBlock*

Age: **8+**
Type: **Vehicles / Constructions**
Movement: **Wheels, Directional**
Control: **Programmed**

Thymio, *Thymio*

Age: **6+**
Type: **Vehicles**
Movement: **Wheels, Directional**
Control: **Programmed**

Jumping Sumo, *Parrot*

Age: **14+**
Type: **Vehicles**
Movement: **Wheels, Directional**
Control: **Teleoperated**

Rolling Spider, *Parrot*

Age: **14+**
Type: **Vehicles**
Movement: **Flying**
Control: **Teleoperated**

Mambo FPV, *Parrot*

Age: **14+**
Type: **Vehicles**
Movement: **Flying**
Control: **Teleoperated**

Swing, *Parrot*

Age: **14+**
Type: **Vehicles**
Movement: **Flying**
Control: **Teleoperated / Programmed**

Mindstorms, *LEGO*

Age: **10+**
Type: **Constr. / Char. / Const.**
Movement: **Wheels, Directional**
Control: **Programmed**

Robosapien X, *WowWee*

Age: **6+**
Type: **Characters**
Movement: **Walking**
Control: **Teleoperated / Autonomous**

KSR 10, *Valleman*

Age: **14+**
Type: **Constructions**
Movement: **Grasping**
Control: **Teleoperated**

Meccanoid, *Meccano*

Age: **10+**
Type: **Constructions / Characters**
Movement: **Wheels, Dir. / Grasping**
Control: **Programmed**

Vernie, *LEGO*

Age: **7-11**
Type: **Constructions / Characters**
Movement: **Wheels, Directional**
Control: **Programmed**

Mip, *WowWee*

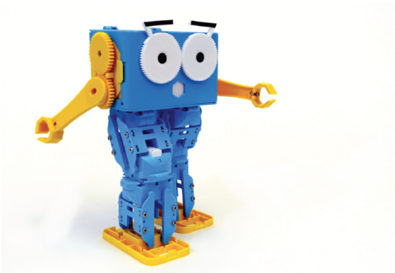
Age: **8+**
Type: **Characters**
Movement: **Wheels, Directional**
Control: **Teleoperated / Autonomous**

Dino, *Cognitoys*

Age: **5+**
Type: **Characters**
Movement: **No**
Control: **Autonomous**

Chip, *WowWee*

Age: **8+**
Type: **Characters**
Movement: **Wheels, Directional**
Control: **Autonomous**



Marty, *Robotical*

Age: **8+**
Type: **Constructions / Characters**
Movement: **Walking**
Control: **Programmed**

Wink 2, *Plum Geek Robotics*

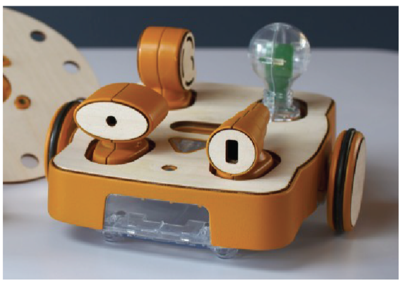
Age: **7+**
Type: **Constructions / Characters**
Movement: **Vibration, Directional**
Control: **Programmed**

Cyber Robot, *Clementoni*

Age: **8+**
Type: **Constr. / Char. / Const.**
Movement: **Wheels, Directional**
Control: **Programmed / Teleoperated**

Cubetto, *Primo Toys*

Age: **3-6**
Type: **Vehicles / Characters**
Movement: **Wheels, Directional**
Control: **Programmed**



Kibo, *Kinderlab Robotics*

Age: **4-7**
Type: **Vehicles / Characters**
Movement: **Wheels, Directional**
Control: **Programmed**

Doc, *Clementoni*

Age: **4-7**
Type: **Characters**
Movement: **Wheels, Directional**
Control: **Programmed**

Although the intended age of Cubetto differs of one year compared to the other two, they all addressed the issue of introducing programming to very young children. This challenge resulted in three different solutions that share the fact of being tangible programming interfaces.
Cubetto is provided of a wooden board that consist of a loop machine on which children can place the commands in the desired sequence. Also the commands are physical elements, made of wood and painted with different colours. *Kibo,* instead, is provided with a set of wooden blocks that represents the robot's commands. These are described through icons and present a bar code that can be read by the robot. In this case, children have to place the block for creating the desired sequence and then scan it with the robot.
The tangible programming interface of *Doc*, instead, is part of the robot and consists of a set of buttons. These, located on top of its head, correspond each to a function.

In the research presented in this thesis, the categorization, that was defined referring to the toy's types, consists also in three categories that are vehicles, constructions, and characters.
Table 4.4 shows the distribution of the robots' sample presented in this chapter, according to these three categories. The majority of robots in this sample belongs to the category of vehicles, which consists of robots strongly characterised by the ability of moving around and by a machine-like appearance. This group includes not only robot provided of wheels like *Thymio* and *Bit*, but mini drones like *Rolling Spider* and Swing, that have the characteristic ability to fly. Many mobile robots present also highly recognizable character features, as in the case of *Cubetto*, *Kibo*, and *Cozmo*. These are located in between the category of vehicles and characters. The category of characters, instead, includes all those robots that appear mainly anthropomorphic or zoomorphic, and present a cartoonlike style.

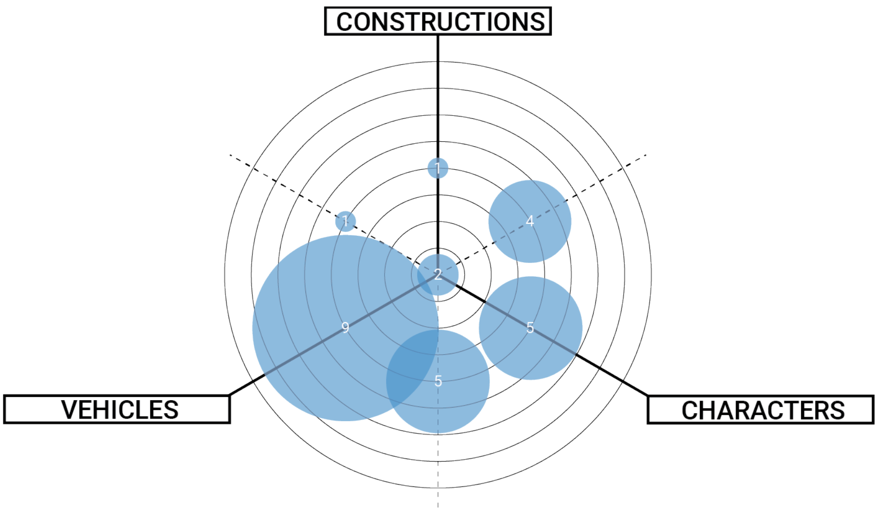


Table 4.4 - Distribution of the sample of edutainment robots according to the toy types.

4.2.2 Types

Another significant aspect of the robots is their typology. Lund and Nielsen (2002) provided their categorization based on the construction possibilities offered by the robot.
Ben-Ari and Mondada (2017), instead, suggested three categories that consist of the most representative of the robots commonly used in education, namely pre-assembled mobile robots, robotic kits, and robotic arms.

To this category belong robots like *Mip* and *Robosapien X*. Even if some of these have the ability of moving around, the character's features are stronger.
Furthermore, in general, these robots are also provided of autonomous behaviours.
The third category, namely the constructions and assembly robots includes only one product, that is the *KSR 10* robotic arm. This, in fact, consists of a robotic kit with highly machine-like features. Differently from vehicles, however, this is not

provided of the ability of moving around rather moving itself for grasping. Other products that comes in kits and have to be constructed by children, present also strong character-like features, such as a face or expressive behaviours, as in the case of *Marty*, *Meccanoid* and *Vernie*. Thus, in table 4.4, these are located in between constructions and characters. Moreover, in two cases, the robot incorporates features of all the three categories, such as Mindstorm and *Cyber Robot*.

By looking at this categorization, referred to the existing toy categories, it is possible to notice which play types are promoted through edutainment robots.

Vehicles robots can be seen as an evolution of vehicles toys, such as cars and trucks, and characters can be associated with dolls and puppets. Both categories, hence, support the pretence and *socio-dramatic play* type, through which children develop deductive reasoning, self-regulation, and cooperative and social skills. Differently from traditional products of this category, vehicle and characters robots may introduce different narratives related to a new imaginary.

Constructions robots, instead, can be naturally associated with toys like blocks and interlocking materials, which were actually at the basis of their development. Thus, this category of robots is more oriented to the support of the *play with objects* typology, that can foster the development of physical skills, creativity, reasoning, logical thinking, and problem-solving skills.

Furthermore, in addition to the fact that often the robots belong to more than one of the three categories, the way these are used can support other types of play, especially in the educational context. Their use, in fact, is often supported by other materials introducing other types of play, like *games with rules*, when robots are used in activities with boards and cards that point out rules, or *symbolic play*, when other craft materials are used by children for expressing ideas and constructing stories around the robot.

In general, all these robots can support the *educational and academic play* type. On the contrary, *physical play* is the only one type that is less supported by these products.

Appearance

The robots' typologies are directly related with their appearance. In fact, in terms of morphology, five main types of robots emerge: machine-like robots, anthropomorphic robots, zoomorphic robots, and hybrid robots that combine a machine-like appearance with anthropomorphic or zoomorphic features.

As for the types, also the appearance of the robots in the sample is, in many cases, hybrid. Marty, for instance, is characterized by a machine-like appearance, with clearly visible mechanisms and components. Nevertheless, it also has anthropomorphic features like legs, arms, and a face, whose elements are exaggerated. The same is also for Vernie and Meccanoid.

This hybrid approach is not casual. In fact, the importance of combining human or animal features with a machine-like appearance is documented by many studies, as the one by Woods (2006). Through her study, the author pointed out some design implications for robot designed for children, such as the desirability of a mixture between human-like and machine-like features, the need for considering the appearance of the whole robot, rather than just the face, the ability of cartoon-like features, and bright colours to communicate robot's positive behaviours or dully colours for negative behaviours. Cartoon-like features are also recognizable in most of the sample's robots, that in many cases present stylized faces. This is a particularly relevant features as facial configurations offers a series of advantages, like affordance, self transposition, mirroring (Fornari, 2012), attractiveness, and sense of familiarity (Blow et al., 2006). Anthropomorphic features, however, have to be balanced with an iconic style, for avoiding the risk of surface mimicry (Marti, 2014) that could lead to a mismatch between the robot appearance and its actual abilities (Fornari, 2012), which can lead to the rise of uncanny feelings (Mori, 1970).

On the contrary, the use of colour doesn't seem to reflect the duality pointed out by Woods (2006). Bright colours are mostly used in robots for young children, such as Dino, Cubetto, Kibo and Doc. Dully colours, instead, seem to be used with no relation with age, rather with the robot type. in particular, in machine-like robots there is a large use of white, grey and black.

4.2.3 Movement

Another aspect pointed out in the sample of edutainment robots is movement. From the earliest definitions of robot, in fact, movement was highlighted as a crucial aspect that characterise a robot. Longsdon (1984), for instance, defined the robot as *“a reprogrammable multifunctional manipulator designed to move material, parts, tools or special devices through variable programmed motions for the performance of various tasks”.*

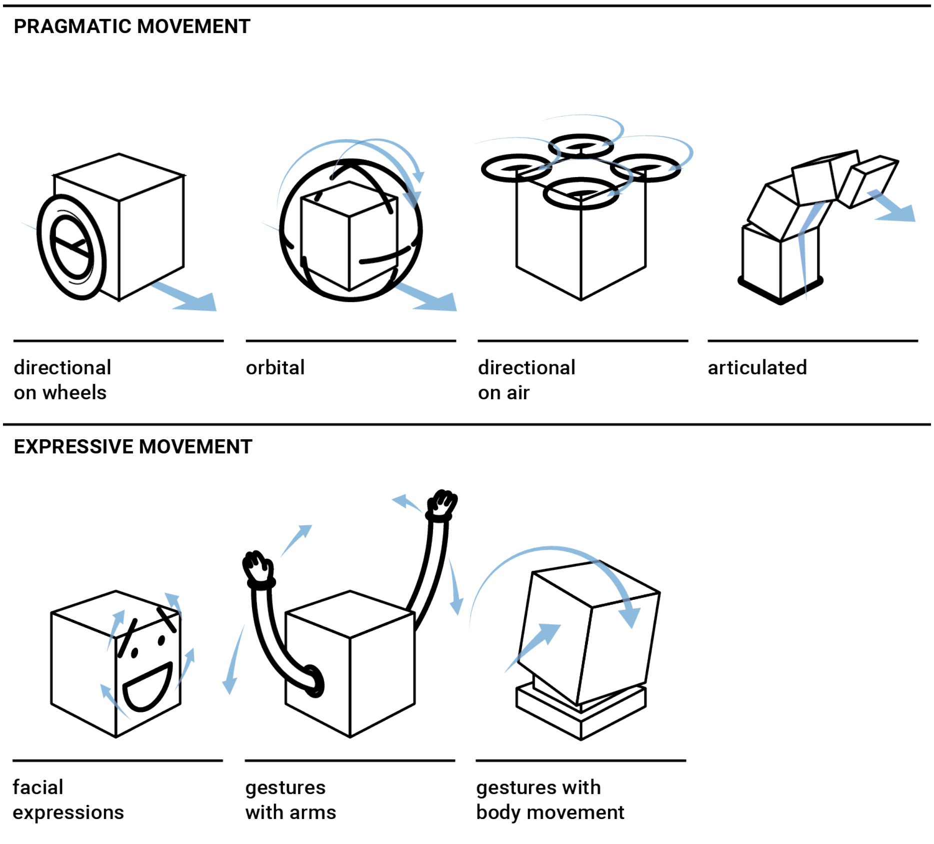


Table 4.5 - The main types of movement identified in the sample of edutainment robots for children.

Movement, however, is not only crucial for performing the robot’s tasks, but also because it is a powerful medium of expression and interaction (Hoffman and Ju, 2014). Humans, in fact, generate and interpret non-verbal behaviours for communicating information, reasons about mental states, express emotions, attitudes, accomplish rituals, and much more (Argyle, 2013).
Thus, in the case of edutainment robots, and service robotics in general, two types of movement can be identified, namely pragmatic and expressive movement (Hoffman and Ju, 2014). On the one hand, *pragmatic movement* consists of the ones performed to carry out a task, and to physically reach a goal. On the other hand, *expressive movement* is the one designed to convey a sense of animacy, communicate a status, intention and personality.
Regarding pragmatic movement, the case of edutainment robots is particular because of the unconventional nature of the task. These products, in fact, are not intended for performing tasks that are usually dangerous or that empower humans to be more independent.
Edutainment robots have, as main objective, the purpose of supporting children’s learning and enjoyment. To do so, these may have the ability of moving around, through a directional movement on wheels or orbiting, altering their pose for reaching and grabbing things, through articulated movement, or flying, which is also a directional type of movement. These are considered functional because of the fact that in the act of controlling these movements, children can learn programming

or explore remote interactions.
Expressive movements, instead, include behaviours like facial expressions, as in the case of *Marty* eyebrows, gestures performed with arms, e.g. *Mip*, *Robosapien X*, or gestures performed with minimal body movements, like a nod of the head as in the case of *BB-8*, *Dash* and *Chip*.
It has to be noted, however, that the boundaries between the two are very thin. In particular, functional movements give also expressivity to the robot.

4.2.4 Control

The fourth aspect mentioned in table 4.3, about the robots, is control. Control refer to the interaction modalities that enable humans to assign a task to a robot and cooperate with him through the execution and it is related to the robot's autonomy. Depending on the specific task the robot has to perform, it may be beneficial to transfer part of the intelligence and decision-making process to the robot itself (Piumatti et al., 2017), and this is what determine the robot's level of autonomy (LoA) (Sheridan and Verplank, 1978).
Edutainment robots, however, represent a peculiar case also from the autonomy point of view. Their task, in fact, can be supporting children's thinking, by executing their commands, or entertaining. Thus, in this case were identified three categories of control that differ from the popular scale of autonomy by Sheridan and Verplank (1978). In this scale, in fact, the autonomy, and relative control modalities, may vary from a condition of total user-dependency that consists of teleoperation, to a condition of total independence from user's actions, that is complete autonomy.
The three categories identified from the analysis of the edutainment robots' sample, instead, consist of teleoperated, programmed, and autonomous. Although all the three might seem similar to the other scale, only teleoperation is.
Autonomy, in this case, is considered as the ability of a robot to perform autonomous behaviours and to show some personality traits, which can be performed also in response to user's actions, as in the case of Cozmo or Chip. On the contrary, in Sheridan and Verplank (1978) scale it is considered as the condition in which a robot decides everything and acts autonomously, ignoring the human.
The category of programmed robots, instead, might seem a controversial since every robot requires to be programmed for functioning. In this case, however, it is motivated by the fact that the task of many robots is not to perform a specific action, rather to perform actions according to the user's programming activity. This category, in fact, includes mainly the robots intended for education, whose task depend on the user's intention and may vary each time. Regarding the control modalities, two categories can also be identified, and are human-robot direct interaction, and human-robot mediated interaction.
In the case of direct interaction, the child can interact with the robot mainly through voice and gestures, and also through on-board buttons and other elements on the robot.
On the contrary, mediated interaction, that is the one more diffused in this robots' sample, require the use of additional interfaces for controlling and communicating with the robot. These interfaces can be distinguished into tangible (TUI), such as specifically designed wooden blocks for programming, or graphical (GUI), which may vary

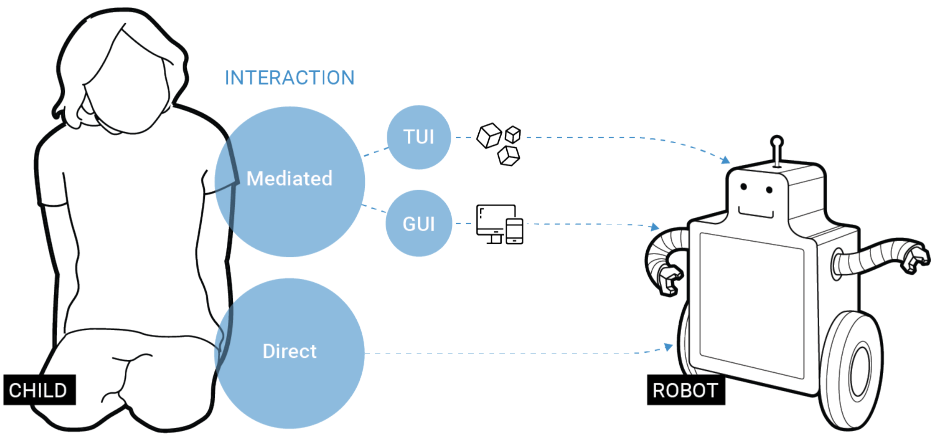


Figure 4.2 - Two main types of interaction between the child and the edutainment robots.

from gaming applications for mobile devices, to programming software mainly for computers or tablets.

4.3 The children contexts of play and interaction with edutainment robots

In order to provide a complete description of the scenario of child-robot play, also from a context perspective, a set significant places were identified and analysed from the play types and play with robot perspective.
The interaction between edutainment robots and children, in fact, can take places in different contexts, however some typical child places results more appropriate than others in this regard.
As shown in figure 4.3, a set of 10 places of child play was identified, that are: home, home's garden, courtyard, school, school's garden, public garden, naturalistic sites, toy libraries, museums, and commercial play areas. These contexts are organized in the schema according to two main characteristics, namely the fact of being a private or public context, and the fact of being an indoor or outdoor environment.
Apart from the home and the home's garden, all the other contexts can be considered public, since are characterized by the fact of being open to the participation of many children.
This fact introduces a first consideration, namely the enlarged social dimension of a public context compared to a private context. At home, in fact, a child can mostly play alone, with parents, and in the case he/she is not a single child, with peers. Nevertheless, the type of interaction is usually solo play or small group play.
In public contexts, instead, there is the possibility of solo and small group play, but also the possibility of play carried out in large groups of peers. This introduce a first design implication, that is the fact that designing for group interaction in public contexts is most of time crucial for the success of a project. This is even more relevant in contexts like schools or museums, in which play is associated to learning and it is fundamental that the whole group of children who attend the activity is constantly engaged.

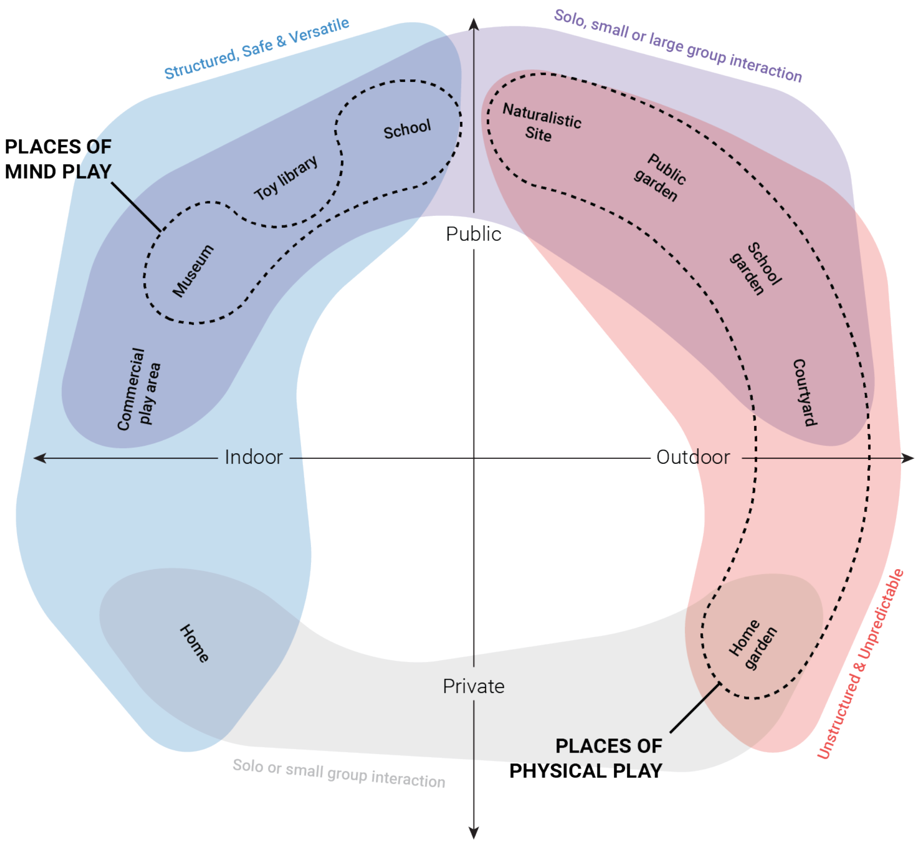


Fig. 4.3 - The places of children play. The contexts are organized according the fact of being public or private, and outdoor or indoor.

A second consideration pertain the nature of the environment and of the activities that take place in it. Indoor contexts are usually characterized by the fact of being structured and safe, thus, not subjected to weather limitations and requiring a lower level of attention and caution, compared to outdoor environments, which are usually less structured and might presents unpredictable situations. When designing activities with children, this difference needs to be taken into account. In most of cases, public indoor contexts like museums, toy libraries and schools might result the optimal solution, since they allow a good level of control on the environmental variables, safety and replicable conditions.
A further consideration, that is connected to this characteristic of the contexts, refer to the play types that can take place in certain environments rather than others. places like home, commercial play areas and toy libraries might result very versatile and open to almost any kind of play activity. Others, instead, are more suitable for certain types of play rather than others. At museums and schools, for instance, play is strongly connected to learning and the activities are designed accordingly. These two contexts, then, represents the places of "mind play", in which the cognitive aspects or play are more emphasized than others.
Most of outdoor contexts, like naturalistic sites, public gardens, school gardens, home gardens, and courtyards, instead, are more suitable for active and physical play. Activities with toys and objects are also possible, however outdoor environments result less suitable for activities characterized by a precise structure and small materials. Due to this fact, these contexts are grouped as the places of physical play. This difference between the places of mind and physical play has to be taken into account when designing for child robot play. In particular, the deign of playful learning activities with robots might results very challenging if intended for outdoor environments, nevertheless it can also be a precise design choice. The importance is to be aware of these differences during the whole design process.
By observing the current scenario of child-robot play, it appears evident the fact that edutainment robotics is mostly used in the private contexts and in the public contexts of "mind play". Many schools are now offering robot programming classes as part of the academic curricula. For instance, in many European countries, educational robotics is now being widely introduced in schools through national programs for fostering the acquisition of digital skills, such as the French Digital Plan for Education, the UK Digital Strategy 2017, and the Digital Switzerland Strategy.
Also museums, especially the ones dedicated to children, are now organizing activities related to robotics and to computational thinking.
Regarding the private context, both new companies and traditional companies are producing robots commercialized also for the private use, falling under the category of smart toys. Thus, more and more frequently, children posses their own edutainment robot with which they can play at home. In addition to these traditional contexts of child play, the interaction with edutainment robots takes place in contexts that did not exist before or that were not usually considered places for child play. To this group belong contexts like *Lifelong Learning Centres*, *Fab Labs* and other associations, and temporary contexts like fairs related to the themes of innovation and science.
The *Lifelong Learning Centres* are contexts dedicated to learning, which is considered an ongoing, self-motivated and voluntary process that take place for the whole life (Cliath et al., 2000). These are now widespread around the world and offer a variety of learning activities, many of which are dedicated to children and are related to technology.
The most popular example of this kind of contexts in the *Lifelong Kindergarten* at MIT Media Lab. This lab is the context in which the constructivist theories about learning were put into practice, especially in relation with educational robotics for children. From the studies and the activities carried out here emerged some of the most popular products for educational robotics, namely the *LEGO Mindstorms*, a programmable robotic kit, and *Scratch*, a free visual programming language.
There are many other Lifelong Learning centres founded by top university from all over the world. For instance, Tsinghua University, in 2015, founded the *Lifelong Learning Lab* in collaboration with LEGO (Grey et al., 2015). The lab organizes mostly courses for children, aged between 4 and 14 years. The courses, that usually have a duration of maximum five days, are usually characterized by a flexible structure of the activities and the technology, such

as the *LEGO Mindstorms* robots, are used to support creative challenges about societal issues.

At a smaller scale, a similar role is played by *Fab Labs*, which are small and distributed laboratories that offer space and tools for making, especially related with the digital fabrication and the open source movements. Together with offering a collaborative space and shared tools, *Fab Labs* are contexts in which courses and workshops are offered regularly. In most of cases, some of the activities are specifically designed for children, such as in the case of the *Fab Lab Torino*, in Turin (IT). In this lab, in fact, a specific program dedicated to children, called "*Fab Lab 4 Kids*", was established in 2013. This program includes a series of courses and workshops dedicated to various technologies and topics, among which activities related to robotics and programming (Fablab for Kids, 2018).

Similarly, other local entities, such as associations, play a strategic role in terms of bringing the broader public close to the themes of robotics and educational technologies, by offering courses and workshops. For instance, *Scuola di Robotica*, an Italian association that works on projects focused on the impact of robotics on society, was one of the first institutions that introduced educational robotic courses for children and professional course for teachers related to robotics, in Italy.

Furthermore, in addition to these emerging contexts, child-robot play experiences and workshops often take place in temporary events, such as fairs related to the themes of innovation and science. For instance, activities related to educational robotics are regularly included in the program of the *Science Festival* (Festival della Scienza), held annually in Genoa (IT), as well as of the *Innovation and Science Festival* (Festival dell'Innovazione e della Scienza), held in Settimo Torinese (IT).

4.4 Children and the Technological Society

Apart from its features and relationship with existing products and play practices, edutainment robotics for children is part of a broader phenomenon of change that has been underway for at least fifty years.

Already in the mid-twentieth century, the philosopher and sociologist Ellul (1964) was describing the dominant role of technology in the modern society. In particular, the author pointed out how technology and techniques were not only pervading society through machines, rather through a "technification" of all aspects of human life. Through techniques, in fact, society get clarified, arranged, rationalised, and efficient. In this scenario, the man and the machine move from being two external and independent entities, to being integrated and mutually influenced.

Consequently, the implications of this process of rationalisation of life, together with the massive spread of machines, were largely debated (Hickman, 2001). In particular, the possible effects of technology on children, seen on the one hand as an opportunity and as a risk on the other, were object of discussion and investigation. Over time, research focused on how technologies, such as television and computers, changed family dynamics and how children were facilitators of technology acceptance (Gordo López et al., 2015). Furthermore, from the nineties, this idea of children as naturally inclined to acquire a digital literacy and creatively master the new medium supported a series of reflections and projects focused on the role of technology as driver of change especially in education, as reported in the book "*The Children's Machine: Rethinking School in the Age of the Computer*" by Papert (1993). However, while on the one hand, new technologies represented new opportunities for learning, on the other hand introduced also a series of concerns. Starting from radios and televisions, the great exposure of children to these medium raised the concern that these could affect their "*knowledge of the world, attitudes, values, and moral conduct* (Wartella and Jennings, 2000). The introduction of computers enhanced the same concerns and, especially with the access to the Internet, children were also more exposed to inappropriate contents (Wartella and Jennings, 2000). In addition, a regular interaction of children with the computer revealed concerns about the possible social implications. Some studies, for instance, showed that a large use of the Internet at home may lead to a decrease in social involvement and psychological wellbeing (Kraut et al., 1998). Nevertheless, the findings regarding social and psychological effects of technologies on children are controversial. In fact, others studies reported a relation between the use of computers and an increase in self esteem (Chen and Paisley, 1985) and a facilitated social status at school (Lieberman, 1985).

Many of technology-related concern, in fact, were, and still are, often accompanied by little knowledge and familiarity about the medium. Nevertheless, risks related to children use of technology do exists and, today, robotics products are introducing new challenges. From a psychological and social stand point, the idea that a social robot may be seen as a peer by children, who can establish with them an affective relationship, introduce the possibility that this may alter or replace a child normal relationships with other children (Sharkey, 2008). Another recurring issue related to children interaction with connected toys and connected robots is privacy. As described in the final report "*#Toyfail. An analysis of consumer and privacy issues in three internet-connected toys*" (2016) by the Norwegian Consumer Council, several children's products, that are today in the market, can respond to children's voices by using microphones and speech recognition technologies. This document reported the fact that the voice data collected by such products, like *Hello Barbie* or *i-Que* the robot, is being regularly stored by the production companies. The armful potential in terms of privacy was evidenced by some cases of data leakage, such as the "*Data Breach on VTech Learning Lodge*" (2015) that reported an unauthorized external access to their database that "contains user profile information including name, email address, password, secret question and answer for password retrieval, IP address, mailing address and download history. In addition, the database also stores kids' information including name, genders and birthdates. In total about 5 million customer accounts and related kids profiles worldwide are affected."

Thus, as reported in these examples, the use of technology may bring a series of implications, such as privacy issues, concerns related to the social and psychological wellbeing of children, and exposure to inappropriate contents. Nevertheless, the peculiar nature of robots may represent an opportunity rather than a cause for concern. On the one hand, the issue of unhealthy behaviours emerging from a long exposure to screen based applications, especially in gaming, may be overcome through the introduction of robot into the game environments. These, being physically embedded entities may foster physically active play modalities. On the other hand, robots can support novel learning modalities, as also documented by the work of many authors, such as Papert (1993). In particular, robot may assume the role of objects-to-think-with (Papert, 1980) for fostering the development of specific thinking skills, such as computational, creative, and emphatic thinking.

4.4.1 Physically Active Play

As mentioned in the previous paragraph, technology today is affecting every aspect of life, and first of all play. Games, in fact, are evolving in accordance to the technological and digital developments, taking into account the spread of personal devices, wearable technologies, and distributed intelligences.

The diffusion of smart and connected products in the everyday life is also changing the way people interact with the environment and with other people, on behalf of a pervasive virtual dimension. The new generations, who were named *digital natives* (Prensky, 2001) because they were born within this technological and digital society, are strongly influenced by technology and by the Internet, especially in the way they communicate, socialize, learn and play (Prensky, 2004).

By focusing on games it is possible to notice a difference in time and modalities of play. Most traditional games, such as cards, board or word games, had a maximum duration of a few hours and the strategies to be carried out were fixed. Today's games, instead, that consist often in videogames, can take up to 100 hours of playtime and become, level by level, more complex (Prensky, 2004). Consequently, people, especially young, may spend an increasing amount of time in front of a screen. Moreover, a multitude of other activities, that can be carried out online, such as watching movies, videos, or searching for various resources can contribute to the increase of children's screen time (Mark and Janssen, 2008). Such a strong relationship with displays might increase the rise of sedentary behaviours (Must and Tybor, 2005) which were defined as the amount of time spent with minimal body movement. This, may have an impact on the physical and psycho-social wellbeing, and, in some extreme cases, studies evidenced a relationship between sedentary behaviours and the development of health issues, such as obesity or metabolic syndrome (Mark and Janssen 2008).

This phenomenon, and the related concerns, are even more relevant in contexts in which there is a growing trend of children overweight and a continuous reduction in physical activities. In Italy for instance, children spend most of their free time at home (Ipsos, 2016), have access to more and more devices (Istat, 2011), the vast majority of them do not do sport regularly, and 15% of them is overweight (Unicef, 2013). Although the correlations between technology usage and unhealthy behaviours is not always validated, and it is still object of debate, a growing interest towards physically active play

is emerging. This interest is also fostered by the growing availability of systems that enable to create play experiences that blend the physical and digital dimensions. In some cases, traditional games are evolving by acquiring digital features, while in other cases virtual games are transformed through the introduction of the physical dimension. For instance, the *Osmo Company* brought back the physical experience of some traditional games by blending digital features with physical elements. To do so, they designed a device that, when attached to an iPad, allows children to interact physically with some elements, such as Tangram pieces and to have digital feedback on the screen.
As a consequence, the exploration of the physical dimension in game environments is becoming a topic frequently addressed by researchers. In *PlayTogether* (Wilson and Robbins, 2007), for example, Wilson and Robbins designed an interactive tabletop system, which allows people to play table games (such as chess) together from remote locations. In this project the tabletop is projected on a real table surface by a commercial projector, located in front of a player who interacts with real checkers. The system is replicated in a remote location, giving the two players the illusion of physically interacting with each other. The idea of interacting with physical objects can also be found in *Twinkle* (Yoshida et al., 2010), a game interface that uses physical flat surfaces as an environment for the interaction between real objects and virtual characters. The characters are displayed also in this case through the use of a camera and a handheld projector. Projections as gaming environments are further emphasized in *RoomAlive* (Jones et al., 2014), a prototype for an immersive and augmented entertainment experience. In this game, several building blocks, composed of a projector and a camera, cover all of the room's floors and furniture, creating an interactive and responsive game scenario. Another step forward in the relationship between physical and digital is represented by the introduction of robots in the gaming environment. This aspect has been explored, among others, by Robert et al. in their research about *Mixed Reality* (2011). They developed a game scenario in which the playground is split in two parts: one half is projected on the floor and the other is displayed on a screen. In the game, some virtual characters push a ball out of the screen, where it is then projected on the floor. The interaction in the physical world happens through a robot, aesthetically identical to the characters on the screen, called *Miso*. The characters play a Pong-like game with the robot, which is guided by the user through a joystick. In this way, the game allows the embodiment of the user into the robot and the embedding of the virtual into the physical reality.

4.4.2 Objects-to-think-with

The concept of "objects-to-think-with" was mentioned for the first time by Papert (1980), in his book "*Mindstorms: children, computers, and powerful ideas*". In this book, the author was discussing the role of computers in children learning and in doing so, he pointed out that by teaching to a computer how to think, children embark on an exploration on how themselves think. They can actually learn to think like a computer, acquiring mechanical thinking skills together with the ability to recognize which situations and challenges require that, and which others ask for a different thinking style.
However, as the author pointed out it is not certainly fundamental to interact with a computer in order to acquire good strategies for learning. It is a facilitator in learning certain styles of thinking, such as mechanical, but the act of thinking with objects is actually inherent in human nature. In this regard, Piaget and Inhelder explained the crucial role of objects in the development of logical thinking (Piaget and Inhelder, 2013). From infancy, in fact, people think and elaborate concepts like numbers, space, time, and causality by interacting with objects.
This was already investigated and explained by Dewey (1910) in his book "*How we think*", in which he discussing thought, what it is, how it works, and how we can train it. Referring to learning, the author explained how it is inappropriate to separate thought from things because the goal of education should be to move from concrete to abstract, which necessitates to pass through things. By interacting with things, in fact, children are immersed in inferential processes. Things arouse suggestions and ask children to interpret them. Furthermore, these theories were formulated learning from the experiences of the first *Kindergarten*, that were founded by Froebel in 1837 (Resnick, 1998). In particular, his work represented a determinant contribution to the theories and approaches regarding the things-thinking relationship. During his work on the kindergarten, in fact, he developed a series of 20 tangible objects and materials that he called *Gifts and Occupations* (Provenzo, 2009). These were intended for introducing children to physical forms and relationships that can be found in nature, and their mathematical and logical underlying principles.
Subsequently, the relationship between objects and

thinking for learning was thoroughly explored by Maria Montessori, who developed a practice-based method, which is still popular today. In her book *The discovery of the child* (2015), the author describes the materials specifically designed for supporting various aspects of children's learning, such as sensory education, practical life, reading, writing, mathematics and others. These materials represent a system of objects characterized by some peculiar features. These were made of traditional materials like wood, metal, or paper, with different finished according to the intended activity. The system is subdivided in groups of objects that share the same physical propriety. The elements of each group are distinguished by a different gradation of the same property. In the objects, the physical properties are isolated and children can easily learn to distinguish and master them.

Some aspects of the Montessori's approach were resumed lately by Bruno Munari. Artist and designer, he developed a series of didactic activities for letting children to know and understand art and communication through the direct experience of materials and techniques that might characterise them. He shared with the Montessori approach the idea of isolating features for reflecting through the practice. In particular, the work of the author focused on the sense of touch, as documented in his book *I laboratory tattili* (*The tactile workshops*) (2016). Through the organization of a first experimental workshop, the author developed a method and a series relative communicative objects for letting children explore concepts related to form of things and proprieties of materials. These objects were developed using common materials of everyday life.

These early experiences pointed out the fact that even simple materials, if experienced in a meaningful way, can foster thinking and learning. This reflection on the role of the materials as empowering tools was reaffirmed by a statement of Papert who, referring to computational technologies, said that "*the point is not about what computers can do to us, rather what can we make with them*" (Papert, 1988). Nevertheless, computational technologies opened new opportunities for experimenting alternative methods for learning. As reported by Ackermann (2004), Papert took advantage of Piaget theories about learning, of which, experience is an inseparable aspect (Piaget, 2013), for rethinking education in the digital age. Papert (1980), in fact, explained that more than other technologies, computers can foster the construction of a different type of knowledge, because of its "mathematical nature". In particular, computers can foster the development of what Piaget (2013) called *formal thinking*, in which both the realm of reality and of possibility coexist. Computers can support the construction of knowledge necessary for becoming formal thinkers because of it can support two crucial aspects, that are combinatory thinking and self-referential thinking about thinking itself (Papert, 1980).

On the basis of this Papert theories, many project were then developed with the specific purpose of being "objects-to-think-with", especially at the Lifelong Kindergarten research group, at MIT Media Lab. Resnick et al. (1998) referred to the material that can be found in Kindergarten, such as Froebel's Gifts and Montessori's materials, as traditional manipulatives for introducing a new type of materials that they called *digital manipulatives*. The aim of these new manipulatives was to provide children with new sets of concepts that can be learned through experience. Some examples are the *programmable building blocks*, consisting of computational technology embedded in LEGO bricks; *the programmable beads*, composed by microprocessors and LEDs, for creating dynamic patterns; the *BitBall*, that can manifest "behaviours" through fading light; and the *Thinking Tags*, that are interactive badges that exchange users' data when they meet and give a light feedback representing their affinity. Computational technologies were then embedded into tangible artefacts within the framework of various projects, such as *StarLogo* (Resnick, 1996), a programmable modelling environment, *Curlybot* (Frei et al., 2000), a physically expressive computational toy, and *LEGO Mindstorms* (Martin et al., 2000), a robotic construction kit for children that became popular and diffused all over the world. This project assumed a crucial importance in the process of approaching teaching methodologies to practical activities because it was one of the main examples that made educational robots the most popular objects-to-think-with.

Today, in fact, the number of educational robotic products is constantly growing and their employment in educational contexts is becoming a common practice. Nevertheless, many other objects typologies, characterized by responsiveness and non-verbal behaviours, unveiled different types of thinking that objects might support different. In particular, Ackermann, with her research about animated toys, that can be both integrated with computational technologies or not, pointed out how an object can be a tool for reflecting on human identity. In fact, the *AniMates* (Ackermann, 2005), as she named the animated toys, are characterized by a certain level of autonomy and present an ambiguous nature, between animate and inanimate. This singular form of agency, that is both surprising and familiar, invite people to establish a relationship with them. As the author explained, *AniMates* are artificial but also credible and convivial, they seam to have their own will, and their explicit "otherness" compared to humans encourage explorations on psychological issues related to the concepts of agency and identity.

Finally, a further reflection in this direction, about the nature of thinking related to objects, was provided by Turkle (2011). In her book "*Evocative Objects. Things we think with*" (Turkle, 2011) the author discussed the co-presence of love and thought in interaction with objects affirming that "*we think with the objects we love; we love the objects we think with*". Thus, objects-to-think-with that she calls evocative objects, assumed also an emotional value. The author explained this through a series of stories from scientists, humanists, artists, and designers, which testify how people, in life, build their theories and knowledge by thinking with and about objects to which are emotionally connected. These can be any kind of objects, from knots to a radio, but, as the author suggest, a completely different thinking is required in the moment the object we think with become one that "*challenge the boundaries between the born and the created and between the humans and everything else*" (Turkle, 2011).

4.5 Edutainment Robots as a Phenomenon

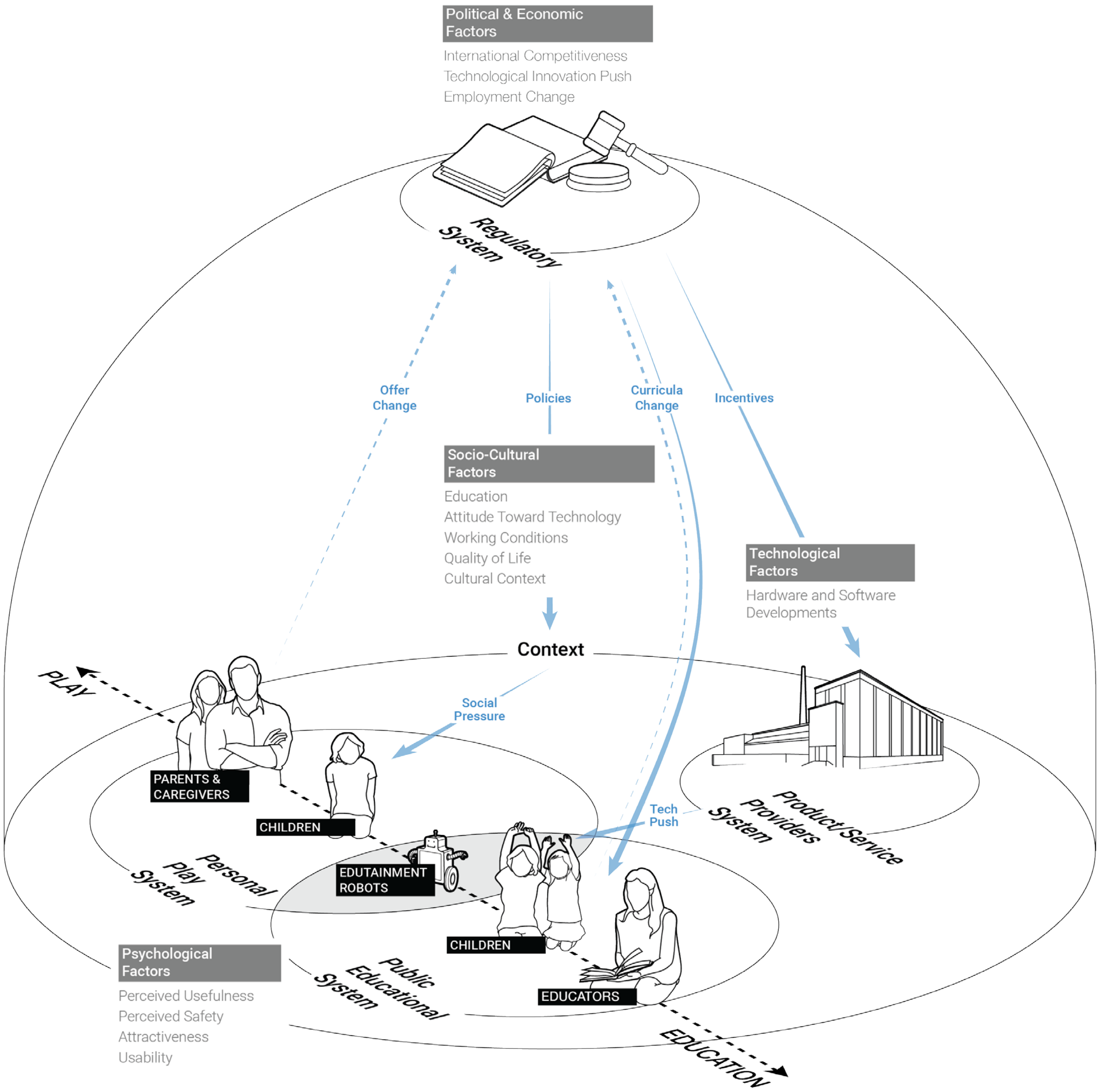
The reflections on the features of the robots, on their relationship with toy and play types, and on the current challenges of the technological society highlighted the fact that edutainment robotics embodies a complex phenomenon connected to a societal change. Thus, this phenomenon was framed by referring to Forlizzi (2013), who suggested that framing the system for which the project is intended, is a good practice for developing acceptable projects with a potentially positive impact on society. By adopting a holistic approach, it is possible to identify four main interrelated systems that affect or are affected by the spread of edutainment robot. As illustrated in figure 4.1, these products are located in a hybrid space between education and play. This space can also be seen as an intersection between the *public educational system* and the *personal play system*. The educational system includes both school education and extra curricula courses, and it is characterized by the role of educators and the presence of peers (children of the same age). The private play system, instead, refer mostly to the free time that children can dedicate to play, and it is characterized by the relationship with parents as well as the individual dimension. These two systems are the ones in which most frequently the interaction with the edutainment products take place. These two interaction scenarios require not only children's engagement, but also parent's and educator's acceptance and adaptation. In this regard, psychological factors like perceived usefulness and attractiveness plays a crucial role.

A third system is represented by *product/service providers*. This system appears independent from the first two, but still connected through the products. This differs from the previous two for the different motivations and scopes from which it is ruled. However, all the three systems are under the influence of the same *regulatory system*. This last, drove by political and economical factors, can have a great influence on the spread of edutainment robots by promoting incentives for the product/service providers and promoting curricula change for schools. For instance, the need for technological innovation and international competitiveness, as well as the need for adaptation to the employment change brought by technology, are leading governments to introduce programming classes from primary school (Hamilton-Smith, 2016; Indemini, 2014). In addition, the regulatory system, through its policies, determines the socio-cultural factors of a context, influencing the people perception, acceptability and adoption of these new products.

These socio-cultural factors are crucial for understanding how children's play and education habits are changing. In this panorama, edutainment robots can be seen as a sub-system that intersects and depends from higher systems. From these, it inherits the influence of technological, economical and political, socio-cultural, and psychological

Figure 4.4 - A framing of the edutainment robot phenomenon.

factors that determines its acceptability, adoption and diffusion. Thus, this framing should be kept in mind in the development of robotic solutions for both identifying opportunities as well as exploring different design ideas and the effects that these might have on the various systems. For instance, designing educational robots for teaching programming in school contexts implies not only the design of the robot and the interfaces, that should be easy to learn and to use by children. This, first of all, requires a significant adaptation from teachers, who are asked to acquire themselves new skills and change their approach to teaching. The didactic approach, then, is another crucial aspect. On the one hand, in fact, these products were developed on the basis of the theories from Piaget, Vygotsky, Papert, and many other authors, who pointed out the fact that learning cannot be separated from experience, and knowledge that is actively constructed by children rather than acquired. On the other hand, the scholastic system is still strongly bounded to traditional approaches and mindsets in which knowledge is "transferred" from teachers to students, and learning is quantified through scoring systems. Potentially, reflecting on these aspects may lead the design action focused on developing solutions that dialogue with knowledge and existing practices of educators, or that might foster a transition toward a less structured and quantitative approach to learning.



Chapter 5

1st design exploration: Phygital Play

A mixed-reality platform for playing with or against robots.

The Phygital Play project consists of an exploration of natural interaction modalities with robots, through mixed-reality, for fostering children's active behaviours. To this end, a game platform was developed for allowing children to play with or against a robot, through body movement. This project, started in November 2014, was part of a joint research promoted by TIM (Telecom Italia Mobile) and carried out by the Department of Architecture and Design (DAD) and the Department of Control and Computer Engineering (DAUIN).
The operative team was composed by Maria Luce Lupetti (designer), Federica Rossetto (design intern), Giovanni Piumatti (engineer), and Lucia Longo (psychologist, specialized in UX, working at Telecom Italia).
The mixed-reality playground with a robot, was also adapted and tested at "Xké? Il Laboratorio della curiosità", an educational center for children, in Turin, Italy. After this experimental application, the collaboration with this center is still ongoing.

5.1 The process

This project, as generally explained in the methodology chapter, was developed by adopting a research through design approach, that combines actions aimed at involving potential users, situating the project in a real context, and actually designing and developing an artefact.

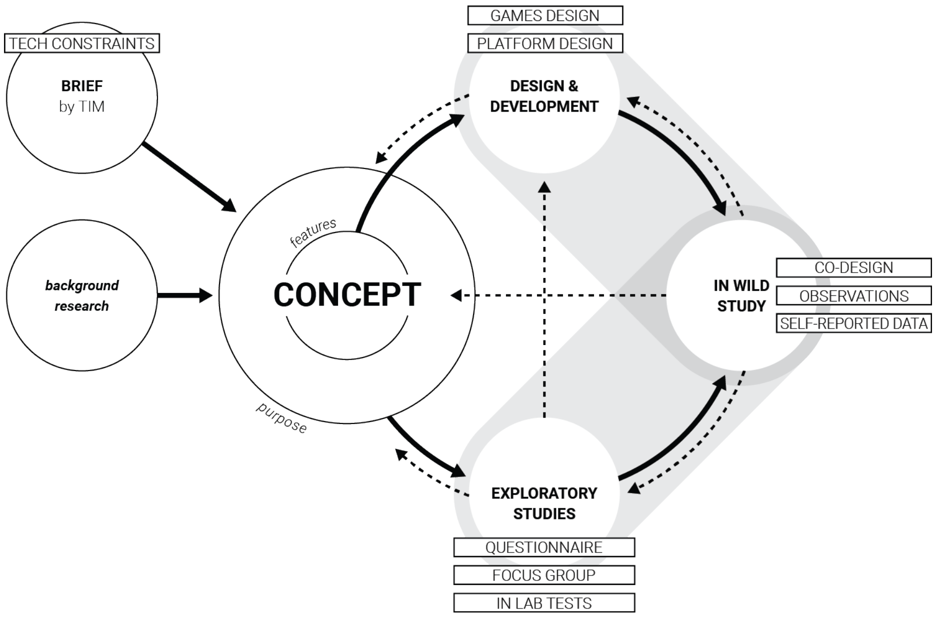


Fig. 5.1 - The process of the Phygital Play project.

However, differently from the second project, this was strongly influenced by the interests of the company, which was financing the research. As a consequence, the whole process was influenced by a decisive technology push.
The first phase of the project, in fact, was characterized by two parallel actions: a preliminary investigation, about the related research and the scenario, and a briefing from the company, aimed at identifying new design opportunities for taking advantage of the technological asset provided by them: broad-bend connection. The following step consisted on the definition of a design concept, which was elaborated through a process of co-design between a company innovation manager, designers (one primary investigator and an intern), an engineer, and a psychologist.
Once the concept was defined, two parallel types of actions were carried out. On the one hand, the designers and the psychologist collaborated to the design and development of exploratory actions, that consisted of a questionnaire for adults, a focus group with parents, and an in lab testing with children. On the other hand, the actual design and development of the novel solution was carried out by the designers and the engineer.
These actions focused both on the games design and on the design of the platform, which however was carried out mostly by the individual work of the engineer member of the team. At this stage, a preliminary setup was developed and tested in preliminary interactions with both adults and children. The following step consisted on situating and adapting the design concept and the preliminary setup according to a real context. This phase, in fact, was carried out in collaboration with the "Xké? Il Laboratorio della curiosità", an educational center for children, based in Turin.
Through this collaboration, new requirements were identified, a game was co-designed and developed, the solution was tested in wild as an experimental application, and the results were analysed with intent of generating sharable knowledge.
After the situating actions, the project was further developed from a technical point of view. Other design opportunities and contributions are still object of an ongoing collaboration with the Xké? lab.

5.2 The Phygital Play concept

The term Phygital consists of a crasis between the terms physical and digital, and stands for the growing phenomenon of contamination between these two dimensions. This hybrid scenario, and the related research, show some common characteristics that can be assumed to be crucial in the creation of a phygital gaming scenario.

witnessing a large increase, as evidenced by many projects. Indeed, in some cases portable, pocket-sized projectors have been introduced (Yoshida et al., 2010). On the one hand, projections can transform any room into a playground (Jones et al., 2014). On the other hand, cameras allow to scan the environment and to understand what happens during the gameplay, especially with the introduction of low cost, depth-aware cameras. These tools allow for continuous feedback between perception and action, making the game constantly adaptive.

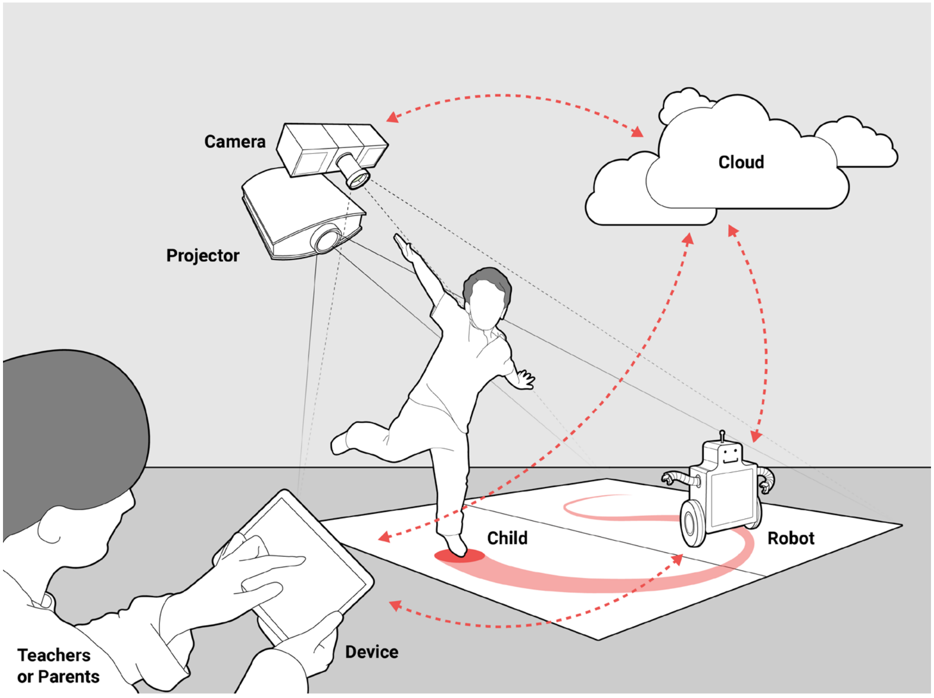


Fig. 5.2 - Phygital Play. Game platform concept.

Robert et al. (2011) defined mixed reality the process in which both the virtual and the real world are encompassed and merged, in order to produce new environments where physical and digital items coexist and interact in real-time. Especially in games, it is possible to identify two main categories of items: surfaces and objects. The surfaces, used as base for applications, are in most cases real-world surfaces (Wilson and Robbins, 2007), such as floors or walls, on top of which the playground is projected. Objects, on the other hand, can be either purely virtual or real. Mixed reality can be achieved by using a camera combined with a projector.

The use of cameras is already widespread and well established, whereas the use of projectors is now

The adaptability in the game, in addition to the camera and projector systems, is enabled by several algorithms with different functions, such as environment mapping or object and person tracking (Jones et al., 2014). These cognitive abilities are usually entrusted to a server. As such, the camera, projector and server need connectivity for communicating.

The design concept of the Phygital Play project (figure 5.2) was defined according to these considerations and the theme of physically active play introduced in the chapter about the Scenario. It consists of a mixed-reality game platform, in which, children can play with or aganst a robot, interacting through the movement of their body.

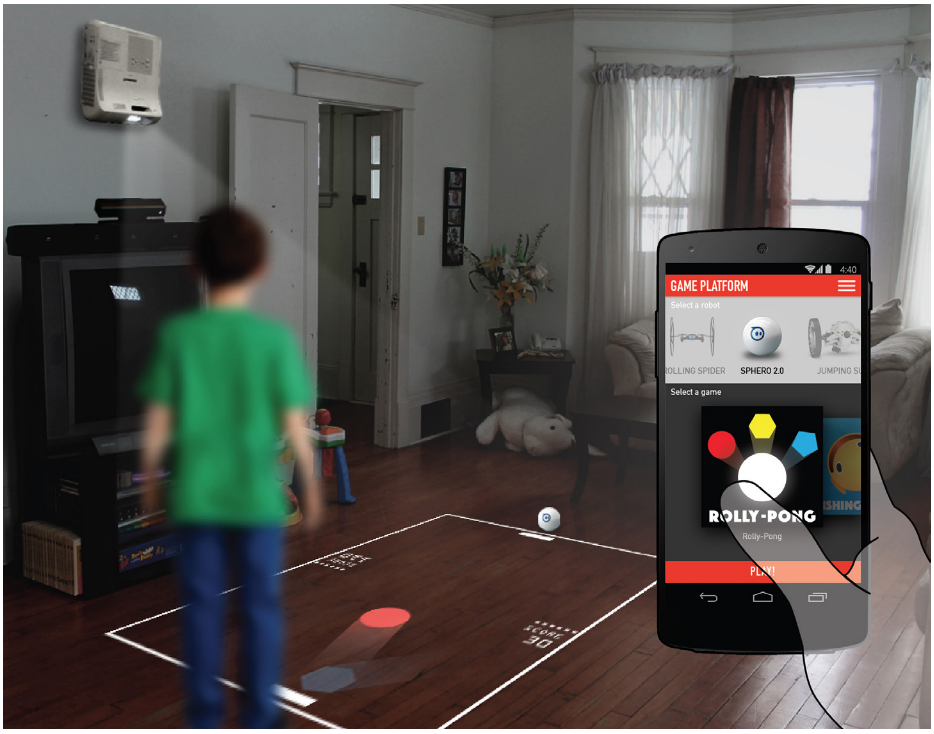


Fig. 5.3 - Phygital Play. Detail of a possible interface for the game platform concept.

According to the available edutainment robot, a different game can be selected through a dedicated app, on mobile device (Figure 5.3). After a game is selected, no screens are needed for playing. In this way, the robots peculiar characteristic of being a physically embodied agent can be used as a way to attract, engage and entertain children, who are asked to move for playing.

5.3 Exploratory studies

The explorative stage was aimed at getting inspirational data about the current scenario of children's play in Italy.
To this end, an ethnographic study was carried out: a qualitative analysis of people's everyday life, desires, and concerns for informing and inspiring the next phases of the design process (Van Dijk, 2010). This analysis was characterized by three main actions: a questionnaire for adults, and a focus group with parents.
Adults were involved for the crucial role they assume both as experts about children habits and needs, as well as final accepting users. In this regard, they were asked to discuss their perception, opinions, and concerns about the world of games, technology and children's play habits.

5.3.1 General questionnaire

The questionnaire was firstly aimed at validating the relevance of the issue addressed by the project: raise of sedentary behaviours (SB) and their relation with technology. Secondly, it was aimed at investigating preferences about games and play typologies, both for adults and children, and to get a deeper understating of what are general ideas about robots and if there are concerns about their use for children's play.
The questionnaire was composed by 31 questions, subdivided in general information, technological background, technology and relation with sedentary behaviours, games and play, and edutainment technologies, included robots. It was distributed as an online survey through the employee mailing list of Politecnico di Torino.

Participants

The sample of participants was composed by 511 people, with a prevalence of male (60% vs 40% of female). The participants overall share a high level of instruction, the 80% of them, in fact, has a degree.
However, from the age distribution point of view, the sample is diversified: there are almost 30%

General Information	Age	Do you have children
	Gender	If yes, how many?
	Education	If yes, how old are they?
Technological Background (multiple choice questions)	Which of the following device does your family own? (Smartphone, Tablet, PC, Smartwatch, Mobile game console, Home game console, TV, Other)	
	Which of these do you let your children to use? (Smartphone, Tablet, PC, Smartwatch, Mobile game console, Home game console, TV, Other)	
	If you have a home game console, which of the following? (Nintendo Wii, Xbox, Play Station, Other)	
Sedentary Behaviours (four values likert scale questions)	Do you think children spend too much time in front of screens?	
	Do you think that spending time in front of screens might lead to a sedentary lifestyle?	
	Do you think that a sedentary lifestyle might foster physical issues?	
	Do you think that a sedentary lifestyle might foster social issues?	
	Do you think that a sedentary lifestyle might foster emotional and psychological issues?	
	Do you think that games and toys should foster active behaviours?	
Game Preferences 1-3 (multiple choice questions) 4 (open answer) 5-9 (four values likert scale questions)	Which game types do you prefer? (None, Traditional, Outdoor, Videogames)	
	Which game types do you prefer for your children? (No children, Traditional, Outdoor, Videogames)	
	How do you prefer to play? (I don't like to play, Alone, In group, Both alone and in group)	
	Name three of your favourite games	
	Do you think that game apps are a good way to intertain children?	
	Do you think that game apps for children are fun?	
	Do you think that game apps for children might be potentially good tools for learning?	
	Do you think that game apps for children might foster children social isolation?	
	Do you think that game apps for children might be harmful?	
Robotics (open answer)	Do you thave a robot?	
	If yes, which one?	
	Which of these do you let your children to use?	
	Have you ever heard about edutainment robots?	
	What do you think is an edutainment robot?	
	Would you allow your child to play with a robot?	
	If you said no, why?	

Table 5.1 - Questionnaire about sedentary behaviours, play and technology.

aged from 19 to 30 years, 25% from 31 to 40 years, 26% from 41 to 50 years, 15% from 51 to 60 years, and the rest is older than 61 years. The 60% of them has children. The diversity is also observable in the number and age of children. There are participants who have a single child, as well as other who have multiple children, up to four. The age of children varies from less than one year to over 40 years.

Results

The first part of questionnaire, focused on the relationship between children and technology, revealed that, according to more than 90% of participants, children spend too much time in front of screens and they believe that this may lead to an increase of sedentary behaviours.
Concerning the effects that a sedentary lifestyle may cause, the results showed an overall agreement that these can affect children, causing physical issues (98%), social issues (84.5%), and emotional and psychological consequences (70%). Despite there was a significative disagreement (30%) about sedentary behaviours as cause of emotional and psychological issues, and some others (14%) disagree that these can be cause of social issues, the importance of promoting active behaviours for children was reaffirmed by the preferences about game types. In this section regarding the game types, in fact, participants were asked to give their

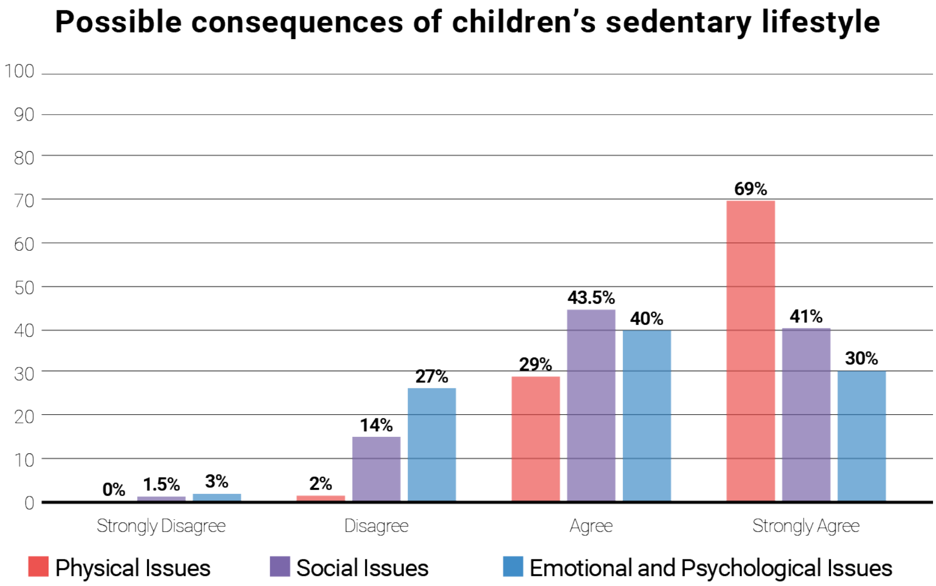


Table 5.2 - Agreement about the three possible consequences of children's sedentary lifestyle.

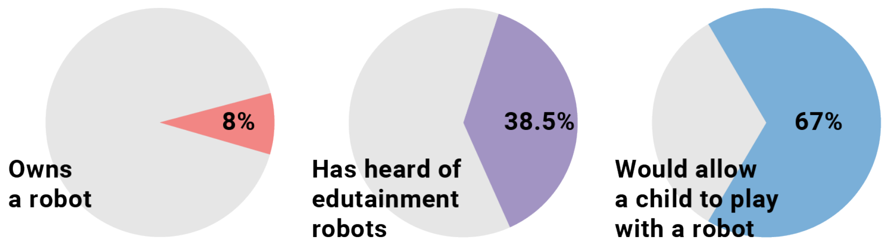


Table 5.3 - Participants owning robots, knowing about edutainment robots and attitude toward child-robot play.

preference and the preference for their children about three main games categories, traditional games, outdoor games and videogames. They were allowed to choose more than one category. The category preferred by adults is traditional games, with 75% of preference. However, regarding the game preference for children, the outdoor and sports games get higher preference: 86%. In both cases, videogames are never preferred by more than 40% of the sample. The last question of this section was an open-ended question, in which participants were invited to write which is the best game for them. Among the various mentioned, some are actually sports activities, such as football, volleyball, golf, tennis, swimming and rugby. The following section of the questionnaire concerned edutainment technologies, from mobile game apps to robotic toys. Participants were first asked to express their agreement or disagreement about some statement about videogames, both for consoles and mobile devices. The 60% of participants agreed that it is fun to play with them, and 15% of them strongly agreed. However, 25% disagrees. The disagreement increased about the following statement: videogames are a good way to entertain children. In fact, 56% of participants disagreed, and for the 10% of them, it was a strong disagreement. Negative feelings about videogames were also confirmed by a largely positive (72%) response to another statement: videogames can foster social isolation. Nevertheless, more than half of participants affirmed also that their can be learning tools.
The final questions concerned robotics.
Participants were asked to say if they have a robot and, in case, which one. The 92% of them do not have a robot and 60% do not even ever heard about edutainment robots. Most of the ones who do have a robot, hold a robotic vacuum cleaner. The rest of robots mentioned are drones, mini-drones and Lego Mindstorm. Participants were, then, asked to say if they would allow children to play with robotic games and if not, why. Most of them, 67%, stated that would allow children to play with robotic

Fig. 5.4 - Focus group with parents.

games, but 31% stated that they would allow it just under the supervision of an adult.
The percentage of the ones who were strongly contrary to robotic games for children was very low, 3%. Regarding the motivations of the contraries, most of them think that robots could encourage social isolation of children, many believe that robotic games are useless, some of them is worried by the idea of children playing with robots and some other think that robotic games are difficult to control for children.

5.3.2 Focus group with parents

This activity (Figure 5.4), was aimed at validating the purpose of the project and at investigating the scenario of children play, as well as, ideas and concerns regarding robots.
This activity, compared to the questionnaire, allowed to go deeper in the understating of the theme and to get more qualitative data. Furthermore, in this activity was presented a preliminary prototype of the game platform. Thus, the main concept of the project was directly discussed with parents.
The focus group, which lasted two hours, was carried in a lab, by a psychologist, who conducted the activity, and two designers, who observed and took notes.
The conduction by the psychologist consisted of introducing questions and arguments, moderating the discussions and assigning tasks. The focus group activity was also recorded for a subsequent transcription of the discussions.

Participants

The participants of the focus group were 6 parents, of children aged between 6 and 8 years. They were two male and 4 female. Two mothers had a humanistic background, one mother and a father had technical/engineering background, and one mother and a father had an academic/design background.

Results

In the first part of the focus group, parents talked about their children's habits, in the spare time. Although the theme of sedentary behaviors was not introduced yet, they all highlighted the importance of sports and physical activity, as well as the importance of playing outside.
By discussing about game types, they affirmed to prefer traditional games, such as board games, play-cards, constructions and fictional play.
Despite this preference, however, their children regularly spend time watching TV and playing games, especially game apps on tablets, but they try to control and limit this kind of entertainment.
One father, in particular, explained that he must limit the use of the tablet to one of his two children

because this is unable to regulate this activity by himself. In the second part of the focus group, the parents were asked to describe what is a robot for them, if they have one and what they think about the diffusion of robotic products, especially for entertaining. Their ideas about robots were vague, however, they all referred to robots as:

"*machines that can help humans performing some kinds of physical activities*."

They made reference to robotic vacuum cleaner, robotic arms for industry, and two products that actually are not properly robots: Emiglio, a toy with robot's appearance and small interactive abilities, and the Bimby, which is considered a robot for the kitchen. This highlight the fact that in general, the knowledge about the robots is still limited. Regarding possible future applications for robots, participants appeared concerned about the consequences that may arise.
In particular, a mother was worried about children playing with robots and said:

"*what if in the future, having robots as a companion, our children would start to prefer robots instead of the company of other children?*"

As a matter of fact, this concern is not inappropriate, since also the research is investigating the possible risks related to the emotional bond between children and robots (Sharkey 2008), especially for more delicate subjects, such as children with cognitive disabilities.
In the following part of the focus group, three categories of entertainment robots, and relative examples were shown to the parents, who were invited to discuss their opinions about these products.
Regarding the pet robot category there parents had divergent opinions: by some, this kind of robot was considered interesting and useful to make children familiarize with the concept of care, especially when there is no possibility to have a real pet; on the other hand, this may lead to an unreal concept of care and increase the distance between the child and the understanding of a real pet. A mother, as an example about this issue, said:

"*You can't switch off a real dog*."

The category of humanoid robot companions, instead, raised negative feedbacks from all the participants. About that, some parents explained that a robot should improve the quality of life in some ways, especially from the educational point of view, and it is not clear how a humanoid robot could do that.
A mother, however, said that if the robot would be able to perform many different activities, from educating to entertaining, it could also be a companion for children.
The last category, the "*smart toys*", included all those edutainment robots not humanoid neither pet, such as mini-drones, Sphero or Ozobot. According to the parents, this kind of robots seems to be the same as remote controlled cars, without additional functions. Thus, they underlined again that a robot should be a helper or a tool for some specific functions, because robots like these can be attractive at first, but then people can get easily bored of them.
Finally, the last part of the focus group was focused on the idea of the mixed-reality game platform.
Regarding this, the parents appreciated the purpose of the project: promoting physical play through the interaction with or against a robot in a projected playground. Moreover, they stated that the projection is completely different compared to a screen, such as a TV, despite their common virtual nature. The main difference is due to the type of engagement required to children: active in the case of projected playground and passive in the case of other screens, such as TV, computers, and tablets. They also gave positive feedbacks to the choice of using commercial robots and reinterpreting video games, giving them a physical dimension. However, they also highlighted some critical issues.
First of all, as in the case of smart toys, the platform has to provide a large variety of games for avoiding boredom and abandonment. Then, they also pointed out a fundamental aspect: a multiplayer modality. This, in fact, would be intended for both allowing more than one child to play together, and for allowing also parents and other adults to play with children.

5.3.3 Preliminary findings

The explorative stage highlighted a mismatch between the general trend of Italian children's habits and the desires and concerns of parents regarding this.
On the one hand, statistic reports show a great change in children's habits regarding technology. For instance, the use of mobile phone is increasing constantly, and at least 20% of children aged 6-10 years already have one (Istat 2011). The phone is used not only for calling or messaging, rather as a multimedia platform. The use of internet and the use of computers for gaming are also increasing (Istat 2011). In parallel, the free time that children spend outdoor is decreasing, in fact, according to a research conducted by *Save the Children*, 62% of parents stated that their children spend most of the free time at home (Ipsos 2016). A change was also observed regarding sports activities performed by children in their free time: it decreased from 83% (of 2015) to 77 in 2016 (Ipsos 2016). Compared to other European countries, in Italy the levels of physical activity are lower: less than 10% of children aged 11 to 15 years perform at least 1 hour of physical activity every day, while on average the other countries are over 15% (Unicef 2013). Italy is also one of the countries with the highest percentage of children overweight (15%) (Unicef 2013).
On the other hand, the adults involved, both parents who attended the focus group and the participants of the questionnaire, underlined the importance of outdoor play and sports, and the fact that they encourage these activities. Furthermore, regarding play, they expressed a preference for traditional games compared to the technological ones.
They also pointed out the need for limiting their children's use of digital devices, confirming the concerns about the possible consequences of children exposure to technology, including sedentary behaviours.
Therefore, from this analysis emerges a scenario in which children exposure to technology is increasing together with sedentary behaviours and related issues, while parents are worried about this phenomenon and still have a preference for traditional games and physical play. Therefore, a design challenge emerges: *can robot's physicality leverage a reduction of sedentary behaviours?*

5.4 Requirements

On the basis of the finding from the preliminary research and the exploratory studies, a set of requirements were defined for guiding the design and development phase.

Given the project purpose, promoting active behaviours, the solution should make children *play through body movement*. This purpose was defined referring to statistical data about changes in children's everyday life, and its relevance was reaffirmed by the results of both the questionnaire and the focus group.

A related requirement is, then, *avoiding the use of screens*. The screen-time issue emerged from the preliminary research and was reaffirmed by some parents during the focus group, who stated that they often have to limit their children's use of digital devices.

The game experiences should *take advantage of the robot's physicality* for promoting such active behaviours. Accordingly, robots can be part in the games, assuming the role of players or tools.

Designers, then, should develope the *games according to the robot's peculiarities*. In fact, on the one hand, using commercial robots for creating novel experiences received positive feedbacks. On the other hand, these impose certain limitations in terms of functionalities and behaviours, that make them more suitable for certain games rather than others.

Another requirement related to the game design is the *use of familiar game types and styles*. In fact, in addition to the positive feedback of parents toward this practice, previous research reports the fact that familiarity can improve usability (Hekkert et al. 2003).

The final requirement, pointed out by parents during the focus group, is to *provide different and extendible set of games*, for avoiding boredom and abandonment. Thus, the design action should focus on developing a plaform able to support an unpredictable number of game experiences.

5.5 Design and development

The design and development phase of the project was focused on refining the concept, building the platform, defining some game typologies according to the avalilable robots, and elaborating the visual design for the games. In this phase the designers contributed to all the design and development actions, consisted apart from the development of the platform, which was carried out by the engineer member of the team.

5.5.1 Platform

The Phygital Play gaming platform consists mainly in a mixed-reality playground. The main hardware components are a projector, two depth-aware cameras (Microsoft Kinect v2.0), and commercial robots. The projector is used to display a virtual playground on the floor, on which most interactions take place. The depth-aware cameras are used to track the position respectively of human players and robots. The robots themselves are controlled by the computer, according to the game logic.

5.5.2 Robots and games

The system is designed to support different kind of commercial robots for leveraging the characteristics of each available robot to create a different kind of experiences. For instance, two commercial robots available at the lab, *Jumping Sumo*, and *Sphero* are characterized by a different movement. One has a directional movement, since it moves on two wheels, while the other has an orbiting movement. For this reason, *Jumping Sumo* appeared to be more suitable for games where a precise direction in movement is needed, such as a *Pong*, while *Sphero* is more suitable for games where the motion is given by the body movements of the player. Therefore, two different kinds of games were designed accordingly: a pong-like game and a catching game (figure 5.5).
In the first game, the robot assumes the role of opponent. Like the traditional pong, the playground consists of a rectangular field divided into two areas. On one side plays the human and on the other side the robot. The aim is to make the projected figures bounce on the other side of the playground.
In the second game the player, with ones body movements, controls the robot that is located in front. The aim is to catch projected figures (fishes) that regularly appear in the playground. Both games have a duration of one minute. This is due to two reasons: on one hand these types of game are typically designed as short matches in which the player gets a score; on the other hand, short matches are more suitable for tests with a large number of children. Regarding control, hence, the depth-aware camera allows players to use the body as a “joystick”. Using the positions and gestures to control the robot, as well as other elements of the

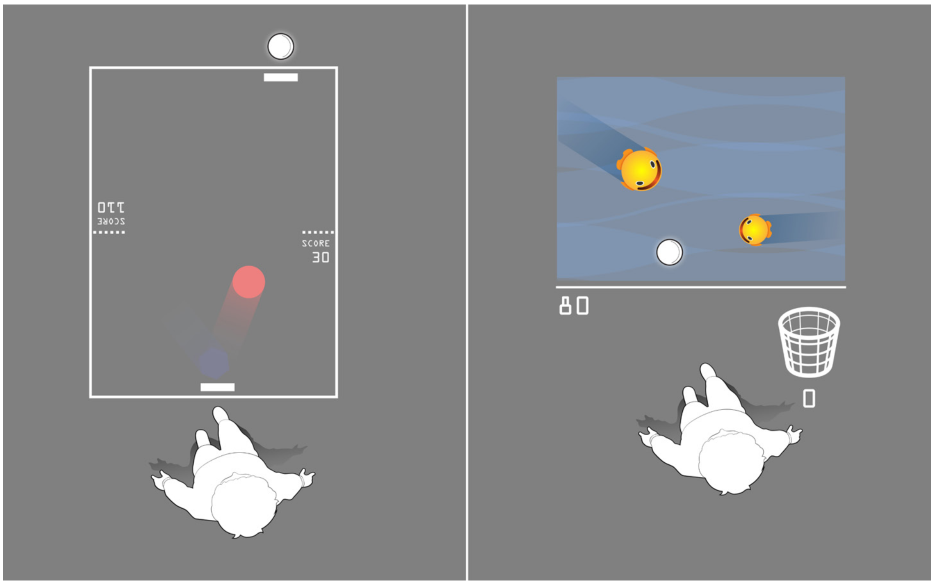


Fig. 5.5 - On the left: pong-like game in which the robot is an opponent. On the right: catching game where the robot is a tool with which the player catches the figures.

Fig. 5.6 - First prototype of the Phygital Play platform. A researcher is playing a pong-like game

Fig. 5.7 - Second prototype of the Phygital Play platform. Two researchers are playing a pong-like game. The size and the timing were updated.

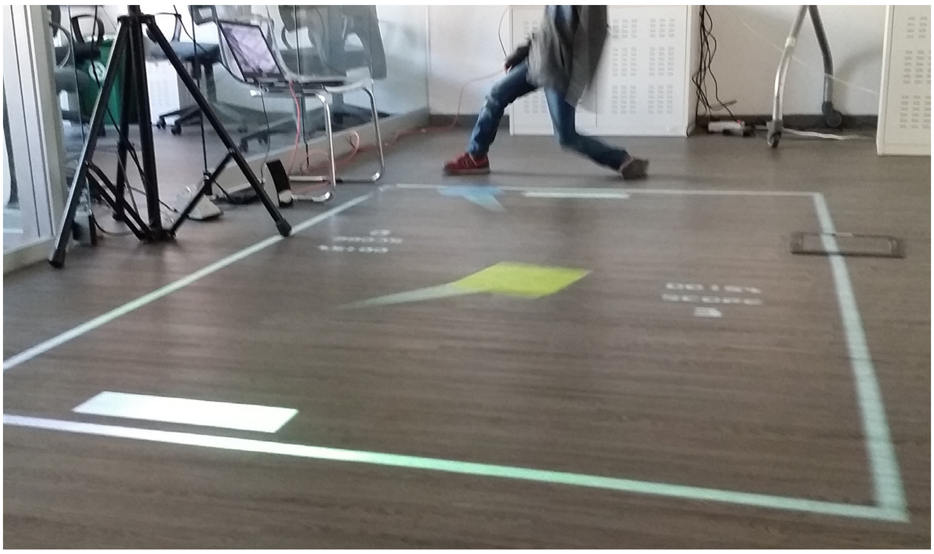


Fig. 5.8 - Third prototype of the Phygital Play platform. A child is playing a pong-like game. The visual design was completely updated.

games, is crucial to obtain an active engagement in the game. However, the developed games used only the position of the player, to control a projected bar in one game, and the robot in the other game.
Posture and gesture tracking will be further explored in future developments.
From the visual design point of view, mixed-reality games call for special attention to visibility issues. In fact, the unpredictable nature of the support, namely the floor, and the lighting conditions can greatly interfere with the game usability (Beardsley et al. 2005). Thus, the use of bright colours and high contrasts are crucial. Accordingly, the games were designed using mainly primary and secondary colours, and avoiding the use of coloured backgrounds. As well as by figure-ground relationship (Graham 2008), visibility is also affected by factors of elements composition, such as simplicity (Kultima 2009). Thus, the number of game's elements and their characteristics were simplified to reduce player's cognitive load (Kultima 2009) and increase game intuitiveness.
Furthermore, the simplicity principle also matches with the willingness to create familiar games. Especially in the case of the pong-like game, the visual design is based on the original design of the pong game. This way of transposing games from a virtual to a blended reality was a concept emerged and appreciated by parents involved in the focus group.

5.5.3 Preliminary setups and tests in lab

A preliminary setup was developed together with the Pong-like game. The robot, however, was not implemented yet. This early version of the platform, however, allowed to run some structured and unstructured experiment in lab. These were crucial for addressing some usuability aspects, such as timing, visibility, and intuitiveness, just to name few.
Informal trials of the platform were carried out in lab and in a demo session of a conference (Lupetti et al. 2015). In both cases the participants were researchers, aged between 25 and 60 years.
The comments and the observations of these unstructured tests were used for improving both technical and game design aspects through multiple iterations.
It was possible to identify some limitations determining the quality of the gameplay. First of all, the size of the projected playground was initially too small, resulting in a little amount of movement required to the player. Secondly, some specific characteristics of the game design where influencing the platform usability. Low visibility was mainly caused by a too complex game graphic design. Thus, the game was redesigned with less elements, high contrasts and the use of primary and secondary colours. Playability issues, instead, were mainly caused by the rhythm of the game. Thus, the game was improved by reducing the downtime length, simplifying the game logic and increasing the fluidity of the game.
A more structured testing session was organized in the lab for observing again the usability and playability of the solution, and testing a draft version of the observation forms. The participants were 19 children aged between 4 and 9 years, of which just 3 were female. They were involved as children of employees of the company that promoted the project.
In this occasion, particular attention was paid on how to introduce the activities to children, how long every activity should be, gameplay aspects and if the observation procedure was appropriate and effective. To this end, the activities were performed simulating a potential experiment for real educational contexts.
Children were welcomed by a researcher, who also introduced them to the theme of robotics through storytelling and a drawing activity, held in a room. One at the time, the children were conducted to another area of the lab were first were invited to drive *Sphero* and make it jump over small ramps. Then, they were invited to play with the mixed-reality platform.
Every child was guided and introduced to games by a psychologist of the lab (conductor), while a designer was entrusted of the observational activity (observer). This last activity was performed by observing directly children behaviours and reporting specific aspects in a form, composed of a structured set of questions and parts for free comments. Some of the structured questions corresponded with the questions that the psychologist was asking to children in the form of a semi-structured interview.
Despite the non-representativeness of the sample (for age and gender distribution), this test

highlighted crucial aspects, such as limitations of the observational forms, the necessity of a greater coordination between conductor and observer, and some difficulties in the game. On the basis of these, the observational forms, the activities and the game experience were improved.

5.6 Situated application of the Phygital Play platform

Involving representative samples of participants and situating the project in a real context represents good practices for designing solutions that relates to real issues and context dynamics. Thus, the last part of the project was dedicated to building a collaboration with "Xké? Il Laboratorio della curiosità", an educational center for children, in Turin, Italy.
The educational center was considered a particularly suitable context for the study, since it daily engages school groups in educational activities introduced to children playfully. Their activities are usually organized as tours, in different areas of the center, where every school group is accompanied by two people, expert on education, science and group management. The experts' main tasks consists in introducing a scientific concept to children, make them interacting with tools to understand these concepts, and coordinating the group. Their daily experience with children was, then, considered extremely valuable for enriching the project, and the context appeared an appropriate environment for introducing a platform as a part of existing practices.

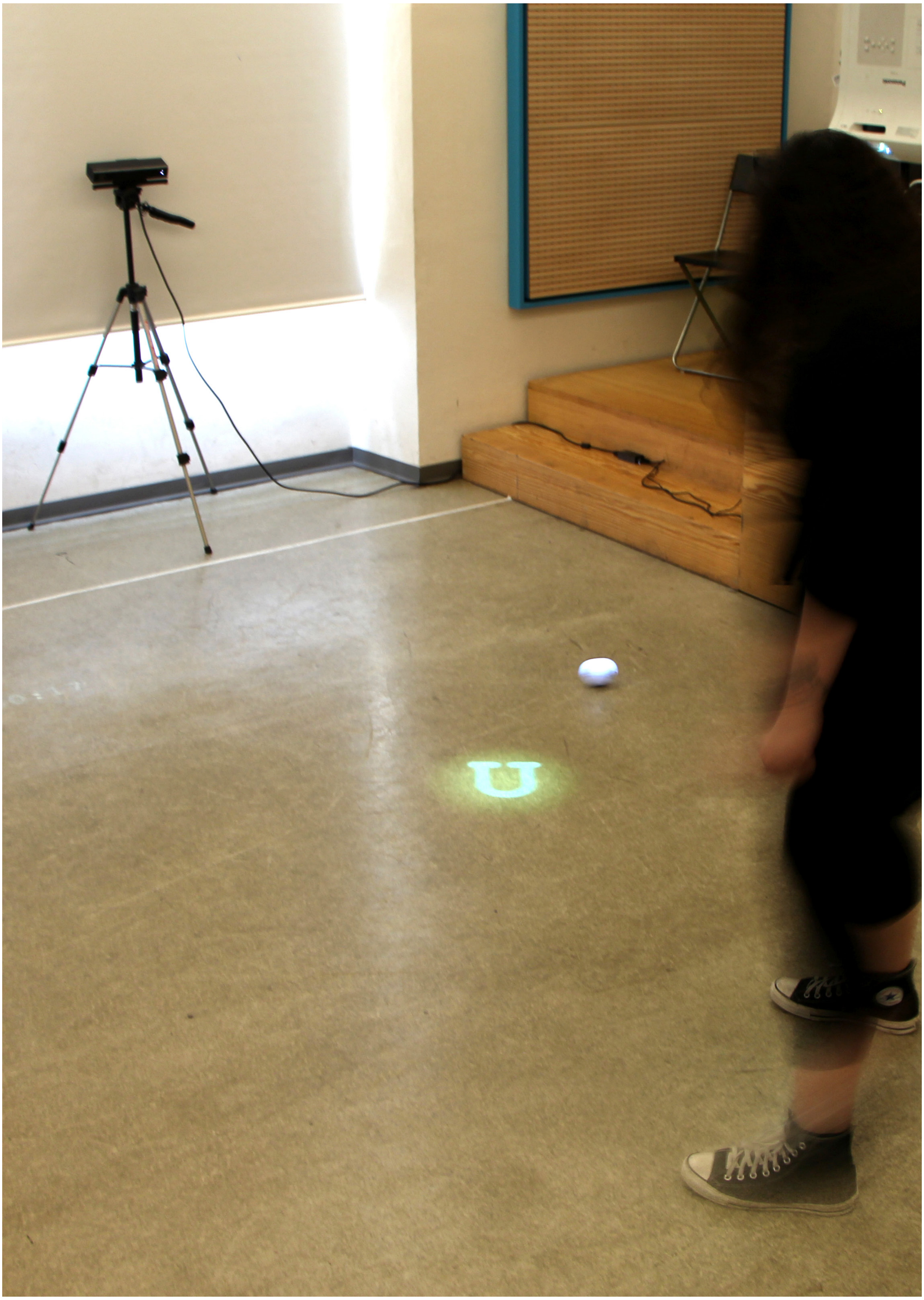
5.6.1 Game co-design

The situated implementation was carried out by customizing the catching game, in which was implementad *Sphero*, a spherical robotic toy that can be controlled via an application for mobile devices, developed by the *Orbitix* company.
The new version of the game was co-designed with the experts of the educational center in which the platform was subsequently tested. It was customized around the theme of coordinates and remote communication of the posion in space, for creating a common topic, around which different experiences could be organized. The main rule of the game was to catch the projected figures that appear in the playground. The figures, that moves around, can be caught only by making the robot roll over them. If the child goes over the figures with a foot, for instance, it does not work. Thus, since the robot follows the position of the player, the child has to understand how to move around to make the robot roll over the figures.
Every time a figure is caught, another one appears in a different part of the playground. The game does not report a score. This is due to the willingness to avoid a sense of competition and incompetence, that some children might feel.
The only information visualized in the playground is the time, in fact, every match has a duration of one minute. Every match consists of four main phases: entry, start, play and ending. In the entry phase, the playground shows a flashing circle with footprints at the center.
The child has to place itself at the center of the circle and wait until it disappears. It follows the start phase where the playground is empty but the child can already try to control the robot by moving around. This is crucial to allow children to familiarize with the game functioning. Then, the figures start to appear in the playground and game begin. The child can take as many figures as he/she can until the time is up. At the ending, the game stops and a thanking screen appears in the playground.

5.6.2 The Experience

The tests with the platform were organized as part of a greater educational experience, in which children were introduced to the theme of coordinates, communication, and control through different activities. The tests were carried out involving school groups, in morning and afternoon sessions, for five days. They were conducted in a large room subdivided in two main areas. In the first area, the children were welcomed by two

Fig. 5.9 - A still-frame of the Phygital Game platform in use with the catching game.



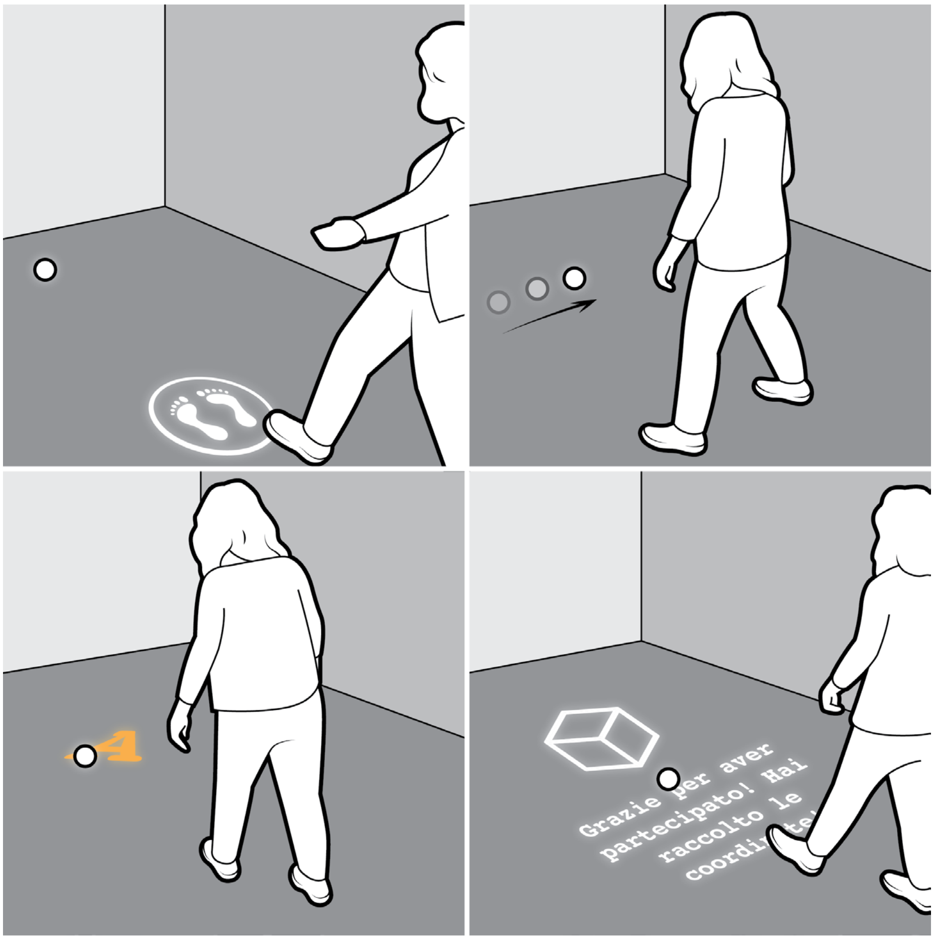


Fig. 5.10 - New version of the catching game co-designed with the experts of the educational center.

experts of the center and introduced by them to the first activities related to the coordinates, such as the Cartesian Cube, built on purpose.

These activities were carried out involving the whole school group. In parallel with these group activities, two children at the time were invited, by two people of the lab, conductors, to try two other experiences in the second area.

These consisted in two different setups for controlling the *Sphero*, a robotic ball. In the first setup, non-immersive (NIS), the ball was controlled through a mobile app for smartphone, while in the second setup, immersive (IS), the ball was controlled through body tracking. The immersive setup was also tested in two modalities: one with the robotic ball, and the other with a projected ball. This was meant to observe if the robotic ball was able to increase the attractiveness and the enjoyment of the immersive setup.

In addition to the conductors, in the second area, there were other four people entrusted of different activities: two observers, and two technicians, one for each setup. In particular, the observers, provided of observational forms, were seated at a margin of the test area, reporting children's behaviours and answers of the semi-structured interviews. Each observer was coordinated with a conductor.

5.6.3 Data collection

This experimental application was aimed at observing both if the developed solution was able to achieve the intended purpose, and if its features were appropriate for that. The initial purpose of promoting active behaviours in play was supplemented by the need for communicating contents through the game, a goal emerged from the co-design sessions with the experts of the educational center for children. The ability of the solution to meet these two purposes was estimated taking onto account different aspects, that are quantity of body movement, efficacy in supporting a week-long activity as a real application, and the

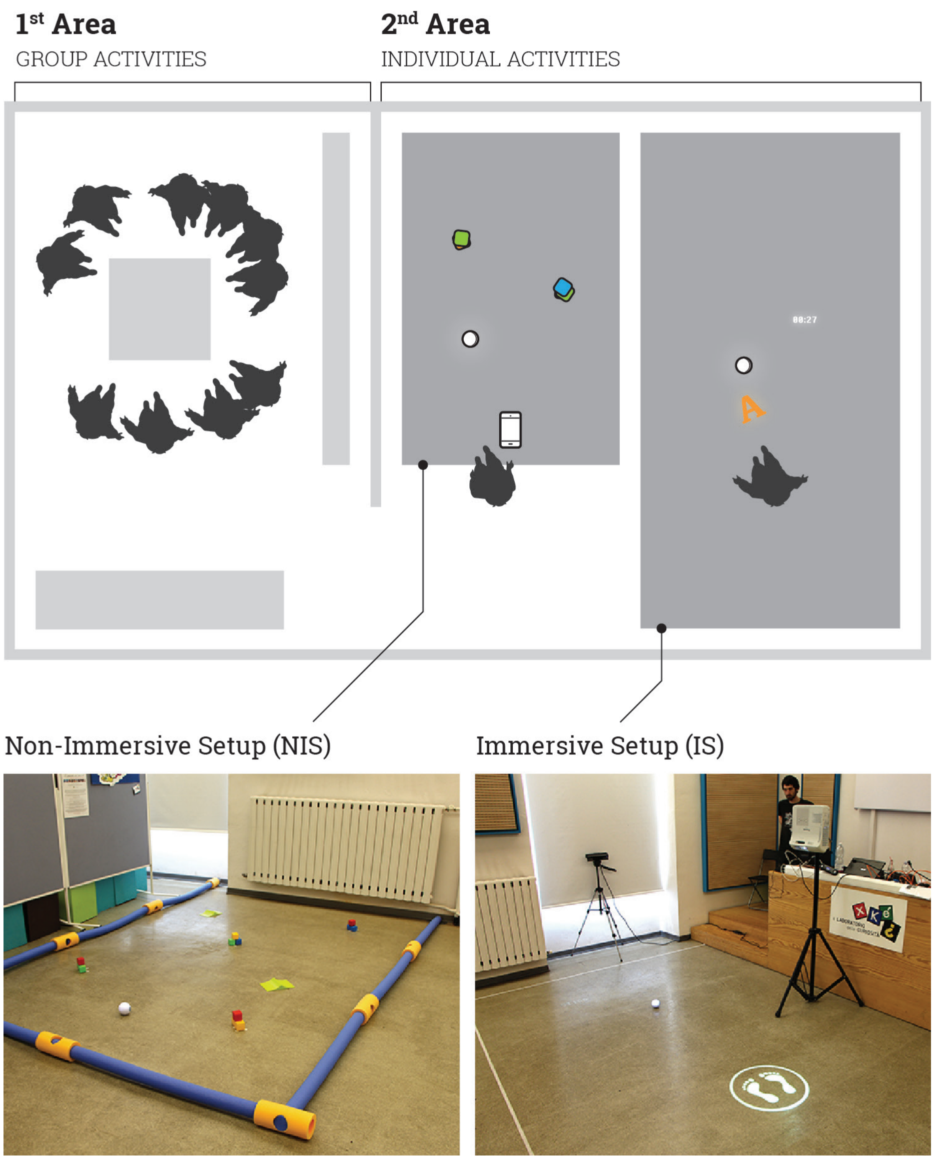


Fig. 5.11 - Schema of the test's setups at the educational center for children. On the bottom are showed the two setups managed by the research team.

persistence of interest toward the solution from the experts of the educational center.
Other more specific aspects were addressed for evaluating both the usability and the pleasurability of the solution, which should be two prerequisites of a fun experience (Vieira et al. 2017). Accordingly, at the level of the features, the platform was evaluated taking into account the following aspects: *likeability*, *learnability*, *enjoyment*, and *engagement*.
The data collection was carried out adopting two different strategies: direct observations and self-reported data from children. As it is common for wild studies, in fact, this real context posed a series of constraints, such as confidentiality issues (Ros et al 2011) and lower level of control on the study (Baxter et al 2016). Indeed, the fact of involving real school groups made impossible to have the parents consent for recording the experience.
In order to overcome this issues, *direct observations*, with the support of observational forms, were performed. These forms were developed referring to existing observational tools used in Behavioural, Developmental and Nutritional Sciences to observe children, especially in play and physical activities. In particular, the existing tools taken as reference for observing physical activity during play in real contexts were *SOFIT* (McKenzie et al 1991) and *SOCARP* (Ridgers et al 2010). These two tools, in fact, provide forms that observers can use to record children activities. In addition to the general

information about the observed, these forms ask to estimate aspects such as the level of activity, engagement, and enjoyment by giving a value in a five points scales. A series of self-reported data about the experience were, instead, asked to children. These were collected through a *semi-structured interview* carried out by the conductors, as an informal conversation. Children were asked to say how much they enjoyed playing; how difficult was to understand the functioning and playing; and, finally, they were invited to say what was the preferred setup and why. They were asked to give a value, from 1 to 5, about enjoyment and difficulty. In order to help children in visualizing the values, the conductors were provided with paper sheet on which was printed a 5 values bar chart. The forms edited for this study, hence, were composed by four main sections: child personal data; 5 points Likert scale questions about observed physical activity, engagement, enjoyment and concentration; semi-structured interview; and free comments areas.

Participants

The participant's sample is composed of 17 classes of third, fourth and fifth years of primary school. A total of 366 children aged between 6 and 10 years. However, the data analysed refer to a sample of 270 children, 135 of which experienced the game platform with the robot and the other 135 without the robot. The majority of children was male, 54%. The rest of the sample (96 forms) was excluded from the analysis for the incompleteness of the data.

5.6.4 Results

A first aspect addressed during the test was *enjoyment*. About that, the results of the semi-structured interviews revealed a general appreciation of the game platform.

Almost the totality of participants declared that enjoyed playing with the platform (table 5.4), and an average of about 80% of them were totally amused. In particular, children who experienced the platform with the robot resulted in a higher level of enjoyment.

These data, however, were not completely reaffirmed by the reports of the observations, which focused on facial expression of children for estimating the level of concentration and enjoyment during play.

In the forms, the level of enjoyment during play was associated with five main face expressions: bored, when the child never smiles and the face looks apathetic; not much amused, when the child does few hints of smiles; quite amused, when the child has a serene face; very amused, when the child smiles; and enthusiastic, when the child has a cheerful face and laugh. According to the observers (table 5.5), in fact, only less than 40% appeared enjoyed, while another 40% looked neutral and around 17% were not enjoying the activity.

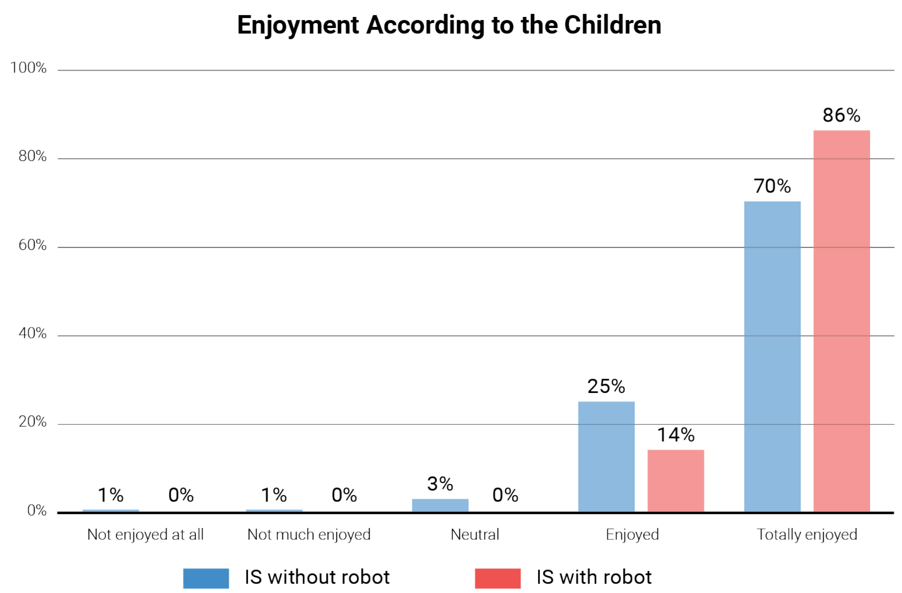


Table 5.4 - Enjoyment stated by children, about the Immersive Setup (IS), both with and without the robot

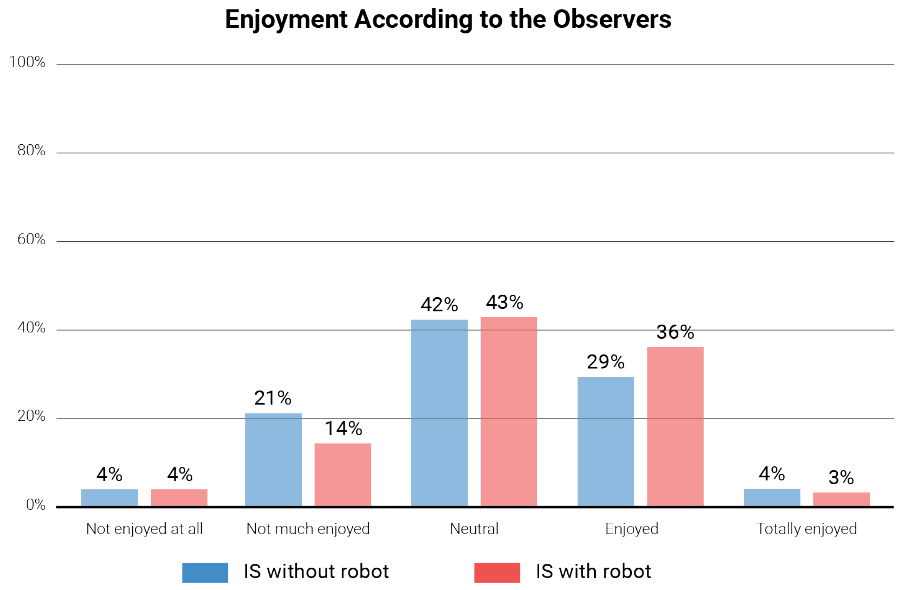


Table 5.5 - Enjoyment reported by the observers, about the Immersive Setup (IS), both with and without the robot

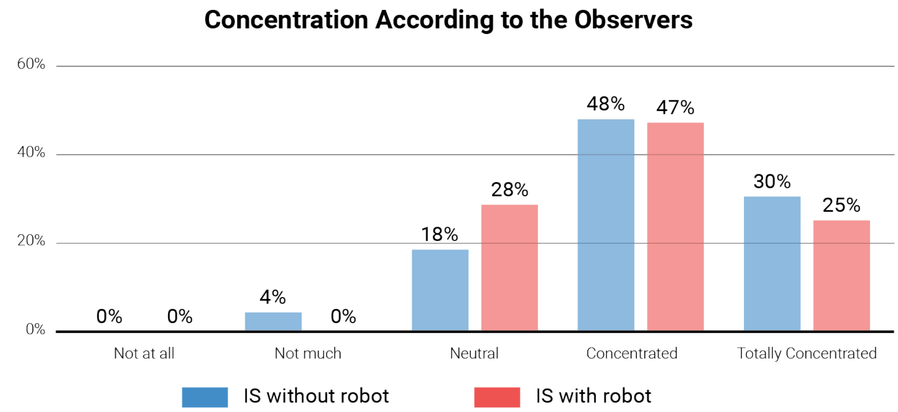


Table 5.6 - Concentration reported by the observers, about the Immersive Setup (IS), both with and without the robot

This discrepancy between the data points out that the experience was able to foster a positive valence, although without generating excitement, except in few cases.
However, by looking at the data regarding the concentration, this low level of the observed enjoyment may be motivated by the high level of attention required by the game. During play with the platform, in fact, children appeared mostly concentrated, and around 30% of them were totally concentrated.
In fact, by looking at the data regarding the children who appeared not much amused it is possible to notice that 70% of them was considered also totally concentrated and, another 20%, very concentrated (table 5.6). Therefore, it is possible to presume that a little smiling face is mostly determined by a high level of concentration and not necessarily to a low level of enjoyment. This somehow reaffirm the generally enthusiastic feedback given by children about the experience and reveal a high level of *engagement*.
The high level of concentration is also related to the game difficulty. By looking at the answers about the difficulty of the game given by the children, playing in the immersive setup resulted easier than playing with *Sphero* in the non-immersive setup.
In fact, almost 70% of children stated that controlling the ball with the body was little or not difficult at all.
Catching the projected figures in the immersive setup was also considered easy. Just 17% of participants, in fact, stated that it was difficult or very difficult, while striking the cubes in the non-immersive setup was considered difficult or very difficult by almost 30%.

Apart from the difficulties in controlling the robot and catching the figures/cubes, the initial phase of the game resulted challenging for children.
In terms of *learnability*, consisting of the initial difficulty in understanding the game logic, the two setups had analogous feedbacks.
Almost 40% did not find it difficult, while 30% said that it was quite difficult and another 30% stated that it was very difficult.
However, in 14 children's comments, some difficulties regarding the immersive setup *learnability* were explicitly pointed out. The main factors determining misunderstanding about the game were: tendency of "catching" the projected figures walking over them rather that controlling the immersive one was noticed and difficulty was pointed out as a preference factor by more than 10% of children. Some of them stated to prefer the immersive setup over the other because it was easier, and in some cases the ease was recalled to the intuitiveness of the solution. The other setup, instead, was preferred by some because was easier and by others because it was more difficult. These results look conflicting and it is not possible to support a hypothesis according to which the more the game is easy the more it is fun, or its contrary. However, these comments highlight the importance of the relationship between difficulty and game enjoyment, which will have to be addressed for future improvements.

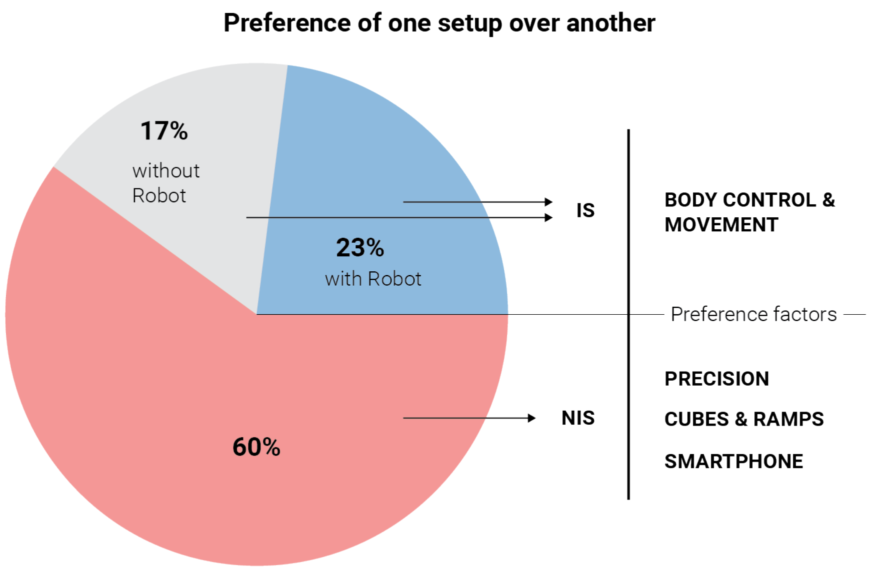


Table 5.7 - Preference of the two setups stated by children and some recurring motivations found in children's comments.

the robot to go over them; tilting the breast instead of moving around for controlling the ball; thinking that it is necessary to stay in the location indicated at the beginning of the game for the start; and inattention during the game explanation by the tutor. In some cases, in fact, the explanation was repeated two times. Finally, some children mentioned the precision of the game, especially about the non-immersive setup.
The game difficulty was also pointed out as a factor determining the preference of one setup over another, which was addressed as an indicator of *likeability*. By looking at the children's answers and comments, in fact, a significantly higher preference of the non-immersive setup (60%) over The preference of one setup over another, however, was strongly influenced by a series of other factors. The most influencing was probably the presence of the robot. The feedbacks were more positive with the robot and in the case of the immersive setup, children who expressed a maximum appreciation were 70% in the case of interaction with a projected ball and 86% when playing with the robotic ball.
Although the non-immersive setup was preferred only by 40% of participants, the percentage of preference of this setup was higher when experienced with the robot (+4%). Furthermore, in the 7% of children's comments the preference of the non-immersive setup was motivated by the presence of the robot. In these cases, they

experienced the immersive setup without the robot. The comments revealed also other recurring factors.
Regarding the preference of the non-immersive setup, many children highlighted positively the possibility to control the robot through the smartphone, a play modality that one kid defined more technological. Almost a fifth of participants enjoyed a lot the fact of striking the cubes and making the *Sphero* jump on the ramps.
Nevertheless, the comments highlighted also positive features that made the immersive setup preferable. In most of the cases, the preference of this was determined by the possibility of controlling the game through the body.
In fact, this feature was pointed out by the 35% of children and the 14% of them has positively remarked the fact that the platform requires them to move.

the contrary, a considerable correlation was found between the quantity of movement and the level of concentration, both reported by the observers.
By focusing on the data about the 78 children who appeared performing a minimum quantity of movement, the vast majority of them was also appearing very (41%) or totally concentrated (25%). And also the rest appeared quite concentrated.
This data reveal that the platform tested with the "coordinates" game was unable to foster a great amount of movement. This was probably due to the high level of concentration required by the game and some of the *learnability issues* mentioned earlier.
Nevertheless, lower level of arousal and higher concentration appear to be more suitable conditions for the playful learning activities carried out at the educational center. The activity carried out with the platform, in fact, was easily managed

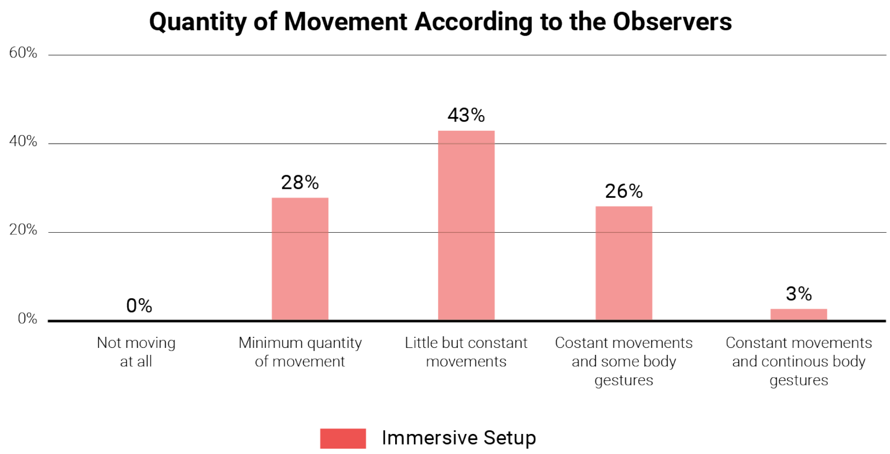


Table 5.8 - Quantity of movement reported by the observers, about the Immersive Setup (IS), with no distinction between with and without robot

This factor introduces the last aspect addressed in the observations, that is the movement during play. The data reported by the observers reveal that the platform and the game tested were not producing a great amount of movement in the players.
According to the observations, almost half of participants was doing constant but little movements, and the 28% of them were moving just a minimum. Some children showed more active and energetic behaviours, characterized by constant movement and body gestures (shaking harms, jumping), but these were only around 30%.
No significant differences were found between the data regarding the sample that played with the robot and the one that played without it. On

in parallel with the others, without affecting negatively or distracting children from the general topic. This represents a positive feedback in terms *compatibility* of the solution with the context and the existing practices.

5.6.5 Limitations

Despite the positive feedbacks received during the process and the insights produced to improve the developed solution and the related experiences, the evaluation of the platform resulted limited from one crucial point of view. This limitation consists in the lack of insights and knowledge regarding the ability of such kind of platform and games to foster

active behaviors and producing movement that might be considered as exercise.
The primary aim of the platform, in fact, was to promote physically active play. Nevertheless, the willingness of situating the platform in a real context, which introduced many constraints, and the fact of testing the platform only within the context of such application, led to step aside the main interest in favor of the opportunities offered by the collaboration with the educational center.
However, the assessment of the impact of specifically designed interactive systems on physical activities is a largely addressed issue. In the evaluation of *Playware* playground, for instance, Yannakakis et al. (2008) used a real-time recording of heart rate through a device placed on the children's chest, for assessing both enjoyment and level of activity during different games. Also in the study by Finkelstein et al. (2011) the measurement of heart rate was used for evaluating *Astrojumper*, a virtual reality game for autistic children exergaming. Heart rate measurement was also used in the study about *Wii Fit* and *EA Sports Active* by Perron et al. (2011). In this case, however, this measure was combined with the data from an accelerometer, and this data was then supplemented with self reported data by children about their perceived exertion, through a run/walk OMNI scale.
Methodologies like the ones mentioned in these few examples might have been used in lab testing of the platform for assessing the exercise level related to playing games with the Phygital Play platform. These, in fact, would have complemented the results and insights produced through the in wild study, achieving a more comprehensive evaluation.

5.6 Reflections and following work

The preliminary idea of the *Phygital Play* platform was situated in a real context through the collaboration with an educational center for children. Here, a catching game customized according to the theme of coordinates and remote communication of the posion in space by co-designing with the expert staff of the center. This was tested by 17 school groups, for a total of 366 children, during five days.
The *perceived usefulness* of the platform was firstly confirmed by the interest of the educational center toward using it in their activities, then it was reaffirmed by the renewed interest toward it after the experimental application. The platform, in fact, resulted compatible with the existing practices of the educational context and its customizability make it suitable for supporting different educational concepts.
The evaluation of the project purpose, including its perceived usefulness and compatibility, was not comprehensive. A more structured analysis of these aspects, through focus groups or interviews, would have been a great source for more qualitative data.
Furthermore, regarding the purpose of promoting active behaviours during play, more objective data should be produced. Knowing the displacement and the velocity of the children while playing would be useful from two points of view.
On one hand, it would allow having a control and validation system for the direct observations. On the other hand, having a quantitative data about the movement would allow to make comparisons with other existing physical activities and to understand how this can influence the perceived usefulness of the platform. To this end, a potential tool for recording motion quantitative data is represented by the depth-aware camera, already used for the position tracking of the player. On the contrary, the data about the specific usability aspects of the solution were richer. All the four key factors needed for the evaluation were addressed, namely *enjoyment*, *likeability, learnability,* and *engagement*. Nevertheless, the results revealed some limitations of the developed solution.
First of all, some usability issues rose, such as the elements disappearing from the playground, the non-easily intelligible functioning, and the high concentration required by the game.
These considerations are crucial for improving the usability of the developed games, and for the appropriate development of future games. In particular, the level of concentration that a game requires have to be taken into account, since it may influence the quantity of movement.
Secondly, even if most of the children appreciated playing with the *Phygital Play* platform, less than half of them preferred to play with this instead of playing with the robotic ball via the mobile app.

Some of children specifically stated to prefer to play with this because of the smartphone. Many of others, instead, highlighted that hitting the cubes was the reason for their preference. Accordingly, future phygital experiences should explore different design alternatives combining robots with existing physical elements, which can interact with projection too.
Beyond technical issues and usability evaluations, testing the platform in a real context with children allowed to get a broader vision of the implications that a situated project entail. In particular, a crucial role is played by people who manage the experience. The expertise of the centre's team was fundamental not only for the organization of the whole experience, the management of children, and their introduction to the themes. They built an engaging cultural discourse around the activities. The research team, instead, accompanying and introducing to the setups, was engaged in one to one interaction with children that required a continuous adaptation of the storytelling according to the peculiarities of each child.
Finally, this experimental application represented the beginning of an on-going collaboration, between the Xké? educational center for children, the department of Automation and Computer Science, and the UXD Polito research group.

Chapter 6

2nd design exploration: Shybo

A low-anthropomorphic robot for children playful learning.

Shybo is a low-anthropomorphic robot for playful learning activities with children. It was developed as part of a joint research that involved the UXD Polito research group, from Politecnico di Torino (Italy), and X-Studio, from Tsinghua University (China). The part of the project, carried out in Beijing (China) from September 2016 to April 2017, consisted of an investigation on the implications of designing for children's playful learning with robots, that resulted in the development of a robotic artefact and an experience for educational contexts.
The artefact and the related playful learning experiences were then subjected to iterations and the main concept was also reframed. The experimental application was, in fact, at the basis of a concept of innovative educational modules for schools, designed in collaboration with Annalisa Gallo, didactic manager of *10100 Percorsi*, and Lorenzo Romagnoli, interaction designer and creative technologist. This second phase of the project, carried out in Italy, led to the design and prototyping of a second version of the robot, that was then used as part of a pilot experience in a primary school.

6.1 The process

This project was developed by adopting a Research through Design approach, that combines actions aimed at involving potential users, situating the project in a real context, and actually designing and developing an artefact. An overview of the process that characterized the first phase of the project is presented in figure 6.1.

investigating the meanings that a project might assume for the people and the context for which it is intended, and for subsequently reframing the purpose of the project. In particular, in the first phase of the project, carried out in China, the peculiarities of the socio-cultural context were investigated through two exploratory actions: a questionnaire for parents and a hands-on workshop with children. Both the activities were carried out involving a small number of participants, due to the

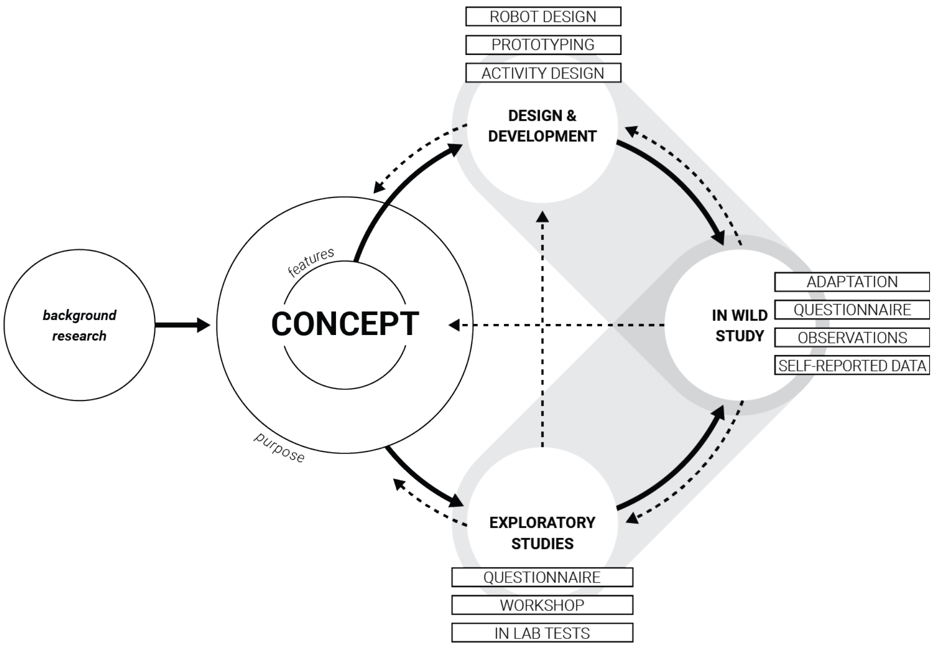


Fig. 6.1 - The process of the Shybo project, first phase carried out in China.

Unlike the first project, this was not influenced by the interests of the company, which was financing the research.

As a consequence, there wasn't a briefing at the beginning of the project and the process was guided only by the reflections about the edutainment robots scenario. Thus, in this case, a strategic role was played by the process of problem seeking and the identification of the project purpose.

Therefore, after a general concept was defined, based on the literature and the scenario analysis, the design and development actions started in parallel with the exploratory studies.

These two parallel types of actions were respectively focused on the two main levels of the project: the features and the purpose. On the one hand, making is aimed at defining and playing with the specific features that a solution might have. On the other hand, participatory design actions are intended for aim of getting inspirational data (Gaver et al. 1999) and building an empathic relationship (Kouprie and Visser 2009) for guiding the development of solutions based on the needs of the potential users. The results of these actions are intended for informing the actual development of the artefact and the possible interactions with that.

The design and development phase was, then, focused on the exploration of different design alternatives through the use of scenarios (Rosson and Carroll 2009), and on the investigation of specific aspects of robotic artefacts, namely morphology, non-verbal behaviours, and interaction schemas, through sketches, 3d modelling, and prototyping.

The high-fidelity and semi-functioning prototype was then situated in a hypothetical context of use. In particular, the artefact was adapted and supplemented with a series of materials for carrying out playful learning activities with

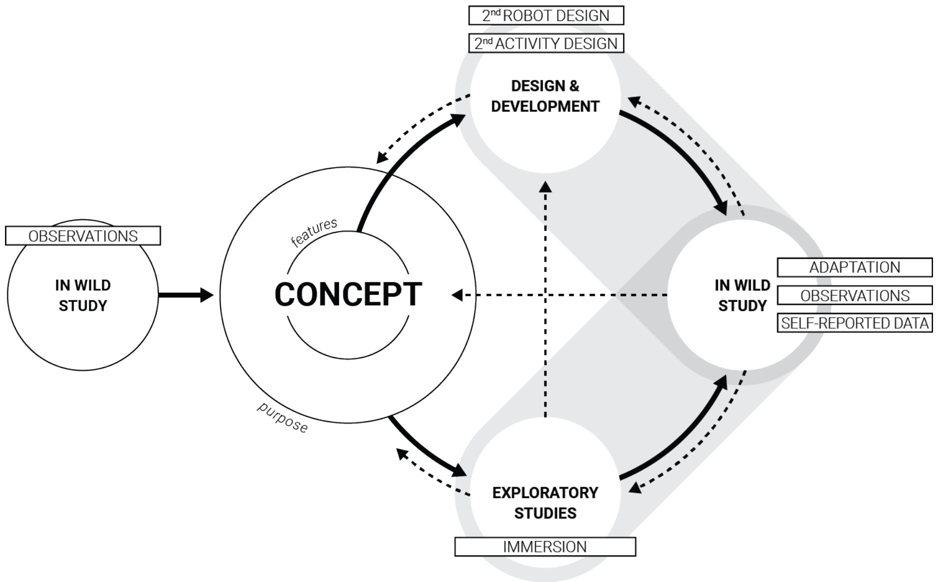


Fig. 6.2 - The process of the Shybo project, second phase carried out in Italy.

children, in educational contexts, such as schools or afterschool.
The resulting solution was, then, tested as a two hours activity carried out at the Yon Hu Qu Experimental Primary School, in Yuncheng, China. Subsequently, the results of the test were analysed and used to inform the development of a second prototype.
The second Shybo's prototype corresponds also to the second phase of the project, which is now evolving from a single experience with an artefact to innovative educational modules for schools. This part of the project, summarised in figure 6.2, is still on-going, and is carried out in collaboration with Annalisa Gallo, didactic manager of 10100 Percorsi, an organization that offers extracurricular courses to schools, and Lorenzo Romagnoli, interaction designer and creative technologist.
In particular, the collaboration with the educator is aimed at co-designing the learning experiences and defining the requirements for developing the second prototype. This collaboration is carried out as an immersive investigation (Donahue 2003) in the domain of education. On the other hand, the collaboration with the creative technologist is aimed at getting a deeper understanding of the technical opportunities available and at developing the second prototype. In the short term, this part of the project will result in another experimental application at a primary school.

6.2 The Clumsy Objects' Family concept

This project focuses on the possible role of a robot as an object-to-think-with for fostering reflection on both computational principles and identity concepts.
This theme is addressed through the idea of letting children play through a robot with the physical environment. Accordingly, a reflection on which features of the physical environment might be used for play was carried out referring to the work by Montessori (1912) about the materials employed in the Children's Houses, and to the work by Ackermann (2005) about animated toys, which share the fact of isolating a propriety for letting children learn and play. With the Montessori's materials, in fact, children can experience and master physical proprieties through dedicated objects. With animated toys, instead, children can play with behaviours determined by certain proprieties.
In the attempt of identifying the properties that might be used as starting point for experiences about physical phenomena, a reflection was carried out focusing on the child's room, as a context example. However, the main properties that characterise it can be considered valid for most of the children's physical environments. These can be subdivided into two main groups: properties that can be directly experienced through sight and touch, such

as colour, shapes, temperatures, and textures; and properties that cannot be perceived directly, rather by provoking reactions, such as sound, mechanical properties, and electrical conductivity.
In parallel to the identification of these properties, some desirable characteristics were defined referring to the literature and the scenario analysis. These can be summarised in five features:

reactive, the artefact is able to react to the perceived proprieties through legible actions;

tangible, the artefact, or its supplementary materials, can be touched, grabbed, or pushed;

familiar, the artefact refers to familiar kinds of play or familiar toy types;

smart, the artefact shows some level of intelligence for communicating its states during the interaction;

screenless, the artefact does not need additional devices, such as tablets or smartphones, for working.

and series of possible combinations between the proprieties that can be directly perceived in the environment (colour, shapes, temperatures, and textures). It consists of a set of robots called *The Clumsy Objects' Family*. This name was used to summarize the characteristics of the concept: the family stands for the fact that the solution is composed by three different elements, the term "objects" is used to point out the aim of animating familiar elements, and the adjective clumsy is used to introduce the ideas of personality and behaviours that should characterize the artefacts.
The robots of the set are able to sense and react to different qualities of the physical environment through non-verbal behaviours. Each of them is able to perceive a different propriety and to react through different features. The first robot, the joyful one, is able to perceive sounds and to react by lighting up in different colours. The timorous one, instead, is sensitive to temperature and reacts by changing the texture of its body. The third one, the audacious one, can read textures and reacts by producing sounds. These combinations were selected through a process of reflection that took

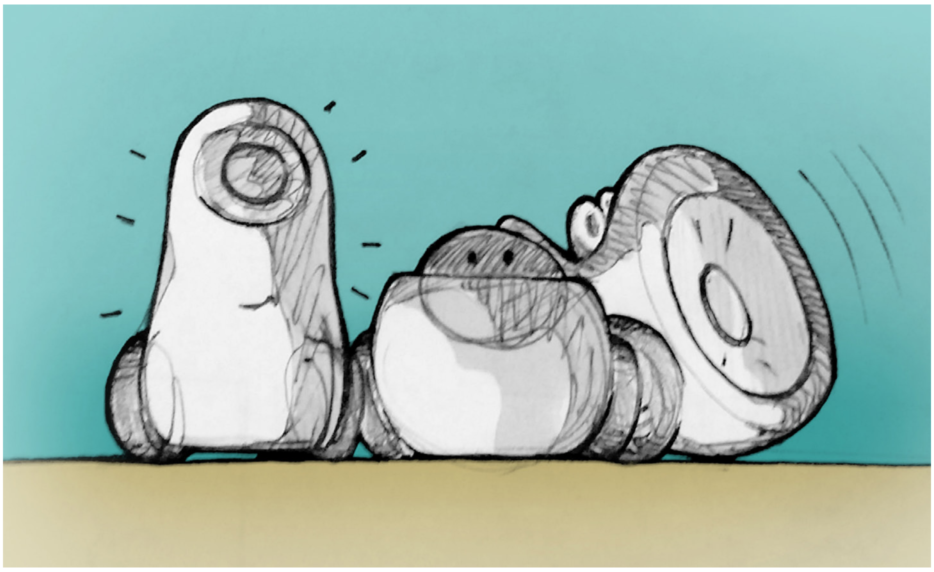


Fig. 6.3 - The Clumsy Objects' Family. Concept of the project.

These features were used to guide the definition of the design concept, taking also into account a set of variables, namely the modalities related to the number of players, the possibility of being a single artefact or a set, and the movement modalities (autonomous or teleoperated). A design concept was then defined by taking into account these features into account all the possible combinations and pointed out the ones that are easily suitable for supporting thinking processes about a physical phenomenon. Among the possible combinations, in fact, the are some who are not very suitable for introducing physical phenomenon because of a lack of relation between the proprieties, such as a change in temperature according to a perceived sound, or a too high level of complexity, such as a change of colour according to a texture. The idea is that children, by observing the changes in the robot's behaviours can embrace a process of inquiry for understanding how it works and how certain behaviours can be controlled and altered.

6.3 Exploratory studies

The exploratory study was carried out involving children and parents for answering the preliminary research questions about about play and education, how are changing children's habits, and to get inspirational data for guiding the robot design process.
On the one hand, parents can provide detailed information about their child habits and daily activities, and moreover, they can provide opinions and suggestions about toys and activities for children.

Fig. 6.4 - Exploratory study materials. The big bags contain all the materials for the children's workshop, subdivided for the three activities. The small bags on top contain the questionnaire and the forms for parents.

On the other hand, conducting activities with children allows to observe how they approach play activities, how they self express and how they might interpret specific elements of play, such as sensory associations which are at the basis of the project concept. In particular, the activities with children were carried out by providing them a set of *cultural probes* (Gaver et al., 1999), based on existing activities about senses and storytelling. Parents and children received a big paper folder at their arrival. The bags were containing the materials prepared for the study: a set of forms for parents, and a toolkit for children. At the end of the activities, children were allowed to keep the toolkit materials as compensation, while parents received a monetary compensation. In fact, as reported by several studies, e.g. Musthag et al. (2011), a monetary compensation can foster compliance, retention and good quality of data.

Participants

These exploratory actions were carried out by involving a group of 9 Chinese children and one parent for each child. The participants already knew each other, since the children attend the same school class, in Beijing. The group was composed by 4 girls and 5 boys, aged between 7 and 8 years. All the children, except one, were single child. The parents who filled the forms and questionnaire, 4 mothers and 5 fathers, were aged between 32 and 46 years.

6.3.1 Forms and questionnaire for parents

The set of forms was composed by a *consent and recording release form*, a *questionnaire*, a *child one-day agenda form*, a *child one-week agenda form*, and a form were parents were invited to describe briefly their children. The questionnaire was aimed to get a better understanding of Chinese children's play and spare time habits. To this end, parents were asked to answer 34 questions regarding general

personal info, time dedicated to play by their children, play typologies, recreational activities of children with parents, and open questions about parent's opinion regarding toys, technology and children's education.
The *one-day agenda* and the *one-week agenda* consisted of forms were parents were asked to mark down the daily and weekly activities of their children, from school to sports, and spare time. These two forms were aimed to get information about how busy Chinese children are and how much of their time is dedicated to educational activities and how much to play.

Results

The questionnaire was meant to get a better understanding of the current scenario of children play and their daily habits. Accordingly, the data collected from the parent's answers refer to four main aspects: children daily life, children play habits, parents engagement in children's spare time, and expectations and preferences of parents for children's toys and play.
A first significant finding is that the children in China dedicate many hours of their days to educational activities, including both schools and extracurricular courses. During the week, in fact, they spend at least 10 hours a day for these activities. In the weekend they have more free time and they attend on average 12 hours on courses, in two days. However, there are cases in which children are as much busy as during the week.
Regarding the rest of their time, less than 2 hours per day is dedicated to play and they usually do free play or educative games on smartphone. Rarely they play with role playing games (dolls, cars, etc) or traditional games (board games, chess, playing cards). Moreover, they usually play alone, since almost all of them is a single child and parents rarely have time to play together. Parents, in fact, spend between 2 and 4 hours per day with their children, but this time is usually dedicated to normal daily life activities, such as cooking and eating together. Thus, most of daily life of these children is dedicated to educational activities. Nevertheless, among the extracurricular courses they attend almost every day interesting courses like musical instrument classes, art classes and robot programming classes. These are particularly important both for the subjects of the classes and for the interaction style that proposes. In fact, these classes engage children playfully and promoting collaboration, imagination, problem solving and creativity. Especially programming classes with LEGO are specifically designed to support active learning through hands-on activities.
The fact that these children regularly attend these courses affects strongly the parent's perception and expectations about toys. In the first open answer question, for instance, parents were asked to mention which characteristics should have a good toy for children. They answered this question by naming characteristics like hand-on skills, simplicity, modularity, limitlessness, interactivity, promotion of creativity, and promotion of science concepts that can all be traced also to the characteristics of robot programming classes. Even more explicit was the answer to a following

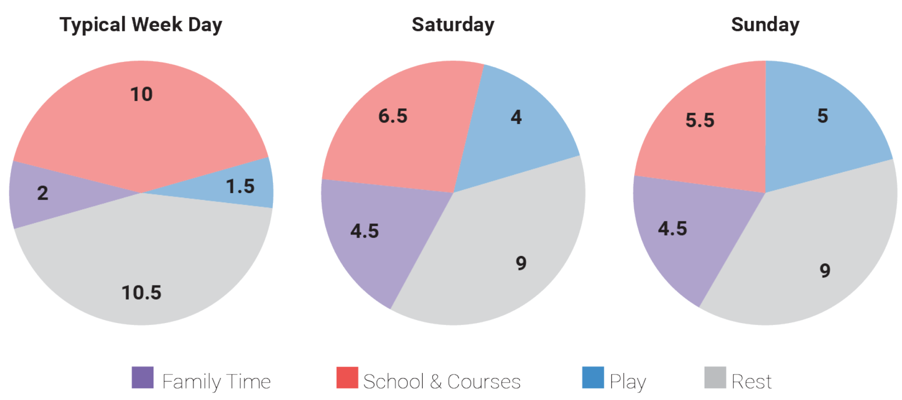


Fig. 6.5 - Children's daily habits regarding family time, school & courses, play, and rest.

question about how technology should be used for children's toys. In this case they mentioned that toys should be interactive, intelligent and able to help children to understand concepts of space, math, physics, chemistry and logic.

6.3.2 Hands-on workshop with children

The activities with children were organized as a workshop, for which a set of materials were prepared. This toolkit was composed by three smaller paper bags, each of which contained the materials for the activities of the study.
The three activities consisted of: acting and guessing emotions; drawing soundscapes; associating sounds, objects and colors. Accordingly, in the first bag was placed a small white board, a marker, and two emotions cards. The second bag contained five white sheets of paper and a pack of colored markers. In the last bag was placed a colored board and a set of 15 objects cards. The expected outcome of this approach was getting inspirational data (Gaver et al. 1999) rather than specific knowledge about given assumptions. To do so, a playful atmosphere was created by giving to children the toolkit as a sort of gift. At the end of the activities, in fact, they were allowed to take it home.
Referring to related works, the three activities were organized as sort of games paying attention to children's peculiarities. In fact, several studies show how *cultural probes* were in some cases redesigned as games (Bernhaupt et al. 2007), in other cases adapted specifically for children (Gielen 2013). The adaptation of cultural probes as games can increase engagement of participants, as well as the amount of material produced (Musthag et al. 2011).
The adaptation in terms of participant's peculiarities, namely children, is instead necessary for the effectiveness of the study. In particular, addressing the suggestion of Wyeth & Diercke (2006), the number of activities was limited to three for avoiding low completion rate and loss of engagement. The level of abstraction required by the activities needed also to be addressed. In fact, as reported by Gielen (2013), children's language skills and their ability to deal with abstract concepts is still under development.
For this reason, the success of a study can be greatly influenced by the guiding role that researchers may assume, by the presence of figurative alternatives to verbalizations, and by promoting direct experience rather than recalling memories and latent knowledge. Thus, the materials produced for the study was designed taking into account these considerations. Every playful activity was supported by materials for creating direct experiences, that were introduced by one researcher and supplemented by illustrations of the activities, showed on a screen.

1st Activity

The first activity consisted on acting and guessing emotions. Every child had two cards, each with the name of one emotion. One at the time, they were asked to perform gestures and facial expressions to describe those emotions. At the same time, the other children were asked to observe and guess which emotion was performed, and to write it down on the white board. The cards contained 18 different emotions, from simple to perform like happy, scared or angry, to more complex emotions, such as embarrassed and hurt. The children who were guessing were allowed to discuss.

2nd Activity

In the second activity, children were asked to listen to five different soundtracks, one at the time, and to draw the scenario that these evoked to them. The soundtracks described different contexts and activities: a school bell, a city traffic, some cooking sounds in kitchen, nature with birds and water, and a luna park. After drawing all the scenarios, children were invited to stand up and describe their drawings. Drawing, in fact, is widely used in studies with children for bringing out ideas, such as in the work by Gielen (2013), were it was used as brainstorming tool, or in the work by Wyeth & Diercke (2006), were it was used as a way to describe project hypothesis.

3rd Activity

The third activity consisted on associating sounds, objects and colors. The team had a set of real objects hidden in a wooden box. The sounds were produced by "playing" the objects in different modalities, such as beating, squeezing or shaking. Every child had a set of cards were all the objects

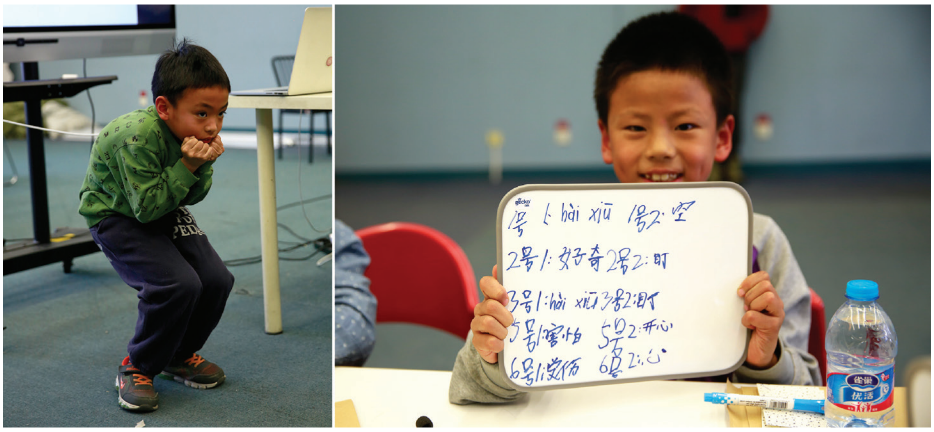


Fig. 6.6 - First activity. On the left, a kid is acting an emotion. On the right, a kid shows his board where he wrote the name of the emotions recognized during the activity.

Fig. 6.7 - Second activity. On the left, a kid is drawing a scene that he imagined listening a soundtrack. On the right, a girl is telling her interpretations of the soundtracks by describing her drawings.

Fig. 6.8 - Third activity. On the left, a set of objects, hidden in a wooden box, is used to make sounds. On the right, children discuss about which object is being played.

were represented. With these, they were asked to recognize which object was played every time and then to associate its sound to a color. This association was made by placing each object card in one of the colored areas of the board that they received with the object cards. Also in this case, the children were allowed to discuss together.

Results

Activity 1

In the first activity one child at the time was asked to stand up and act to show the emotions written in the cards while the others had to guess the emotion. The children were firstly embarrassed to act and some of them were too shy to do it. Despite this, observing them allowed to understand that

they were enjoying the activities, but they were also afraid of making mistakes. In fact, after that everyone performed, some of them wanted to perform again and one explained that he wanted to do it because he saw that the other children wrote the wrong word when he was performing. Another interesting aspect is that they performed the emotions as static poses, rather than gestures and movements.
In the end, this activity, that was also chosen as ice-breaking, appeared to be the most challenging. Children found difficulties at different levels: incomprehension of the word wrote on the cards, not knowing how to act an emotion, and difficulties in recognizing the emotion acted by the others. Simple emotions like happiness, anger and fear resulted to be easy to perform as well as to resulted complex and the child did not share the word, the children gave more creative answers.
In particular, a boy, who didn't know the correct word for some of the emotions, adopted a descriptive approach.
Instead of writing another emotion, as a tentative, he used small descriptions of the expressions of the performing child, such as "What happened?" for worried, "frowning" for embarrassed, and "cannot bear it" for scared.

Activity 2
In this activity children were free to choose the colours to use for drawing, and they were not asked to give a reason for that. However, some of them spontaneously gave a reason for their choice and observing their drawing it was possible to identify

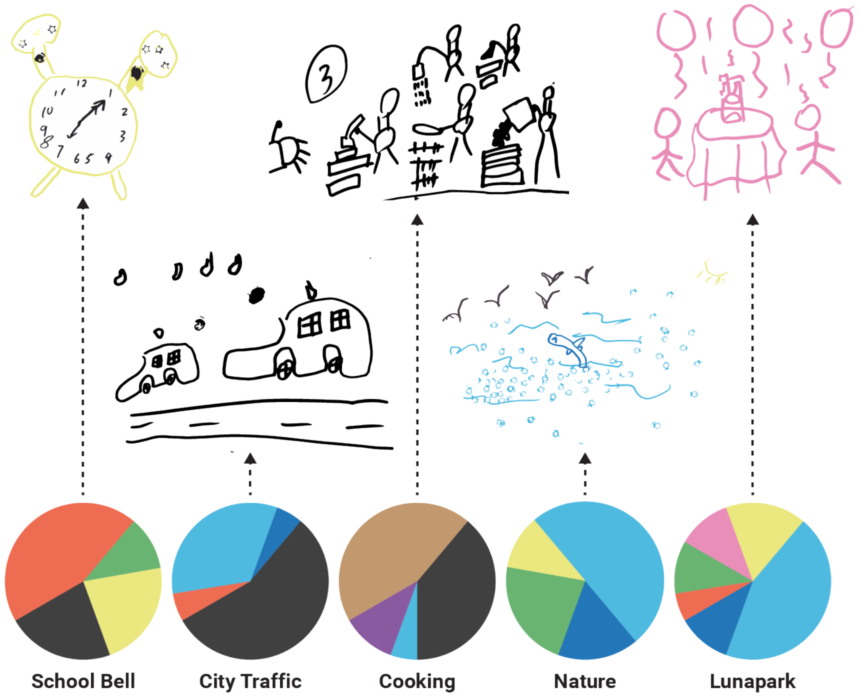


Fig. 6.9 - Some aspects emerged from the 2nd activity. For each soundtrack are reported the colors to which it was associated and an example of drawing.

understand, while others were more difficult, such as concern, nervousness and embarrassment.
Despite the observed difficulties, most of children wrote the correct words on the white boards. This is not due to the fact that children were actually understanding all the performances, they were rather discussing all together, and in some cases they told the others what was written in their cards. However, in those cases in which an emotion similarities.
For instance, the drawing for the second soundtrack, urban traffic, were mainly black with parts of light blue due to the presence of rain, explained by some children. One child, while describing his drawing, said that the choice of black was because "*traffic has no color, so I used black because it includes all colors*". This statement was very interesting as it introduces two incongruities: on the one hand, he

said traffic has no colours and then he chose "*all colours*" to describe it, on the other hand his belief that black includes all colour is actually incorrect, from the physical point of view.
Also in the case of the third soundtrack, children used mainly dark colours: black, brown, and purple. This was probably due to the negative feeling that the soundtrack evoked to them. In fact, instead of perceiving someone cooking in the kitchen, some of them imagined a factory where workers were making things fall down. Another child imagined someone hitting a nail with a hammer and even a kid who recognized a pot described it negatively, saying that there was "*some dirty things in a pot*".
The fourth soundtrack, instead, was easy to understand for all of them. They all recognized the natural setting with birds and, accordingly, they all used nature-related colours, such as light blue, blue, green and yellow.
The last and the first soundtracks are more various in terms of colors used. However, in both cases there is presence of red associated with alert. In particular, one child motivated his use of red in the luna park soundtrack because he imagined that there was fire and scared people.
A crucial aspect emerged from this activity: children go beyond what they hear. They spontaneously imagined situations with multiple subjects/ objects and events. As an example, the waterfront soundtrack was easy to understand because of the clear sounds of birds and water. However, all of them added some other elements that actually have no sound that can be recognized in the soundtrack, like dolphins, fishes and a tree. The children's imagination was even more encouraged by the ambiguous soundtracks, namely the third (cooking) and the fifth (luna park).
A last interesting aspect, emerged from this activity, is that most of children were enthusiastic and impatient to describe their drawing. However, two girls (5 and 7 in figure 2) didn't want to do it. They were the last two children left, since the speaking order was random and children were asking by themselves to stand up and tell their story. While others were speaking, they were carefully listening, but when their turn came, they appeared too shy to do it. However, looking at their drawings, it is possible to observe that both described at least 2 soundtracks differently from the rest of the group. In particular, one of the two girls drew a boat under the rain instead of urban traffic, and a party instead of the luna park. Thus, it is possible to hypothesize that, after listening all the other descriptions, she felt like her drawings were wrong. However, in this activity the point was not to guess and draw the correct thing, but rather to express impressions and situations evoked by the soundtrack. Her interpretations were probably more focused on the impressions rather than on understanding the exact elements of the soundtrack. For instance, she perceived the luna park sound-track as a cheerful situation and described it by drawing a party. If she had described her drawing, she would have probably introduced a different point of view, enriching the whole experience.

Activity 3
In the third activity, children were specifically asked to think about the association of objects to sounds, of sounds to colours, and to give a motivation for their choices. During most of the activity, all the children were discussing together to which object belonged the various sounds, giving motivations and examples to explain to each others. For instance, to motivate the association of a sound to a plastic bottle, two children replicated that sound with their plastic bottles. In more than one case they did not agree on the association of sounds to objects, as in the case of the book: a girl was convinced that it was a hair drier and she said that the others were wrong, so, all of them wanted to listen again the sound. Many sounds, instead, were very clear to everybody.
Regarding the association of the sounds to the colours, instead, many differences were noticed. First of all, there were objects, such as the plastic bag, that for all of them cannot be associated with a specific sound. However, they all choose light colours, like light blue, orange and yellow, to describe these objects (plastic bag, plastic bottle and glass bottle). Metal objects, such as keys, pot and cutlery, also resulted to be not easy to associate to a specific colour. Differently from plastic and glass objects, these do not even share common characteristics like light colours. In fact, in these were associated to at least four colours each, from light to dark. However, referring to the cutlery, a boy motivated his association to yellow because, he said, the sound is "*more pure*".
Some interesting similarities, instead, can be

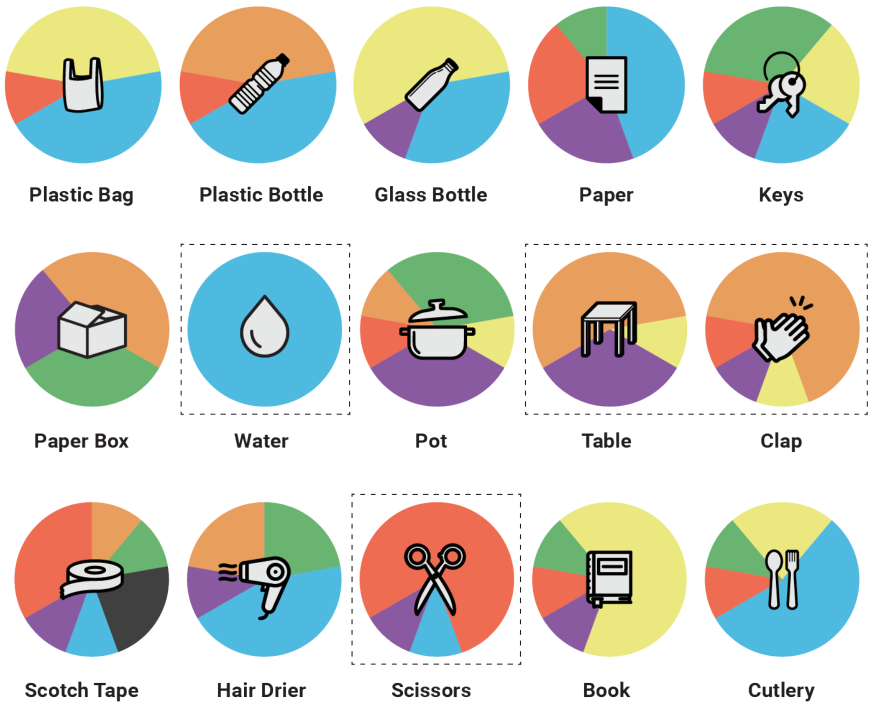


Fig. 6.10 - Associations of sounds and colors emerged in the 3rd activity.

identified in water, scissors, and paper box and clap. Water was associated by everyone to the light blue color. This is probably due to the archetypal representation of water, familiar to everyone. Scissors, instead, were associated by most of children to red. Differently from water, this object is not usually represented with a specific colour, however, it probably evokes concepts like anger and alert, that are culturally represented with red. Similarly, some children associated also the scotch tape, the paper, the keys and the pot with red, with the motivation that the sound of these objects is strong, noisy, and, according to one "*red is for noisy sounds because it is extreme*".

Scissors and water represents also two opposite approaches in the colour-sound association adopted by children during this activity. Some of them, in fact, chose the colors on the basis of the colors that the material of an object usually has. Others, instead, associated sound characteristics, such as loudness, to colors. In this regard, in fact, the table and the clap are interesting. These were mostly represented with purple and orange. Maybe orange was largely used because it was the one, among the colors present on the board, more similar to brown and skin color. However, some chose purple, which is completely in contrast with the color of the materials, but was explained by a girl with the following statement: "*the table is normal, so it is purple because purple is for normal things*". Then, she explained that her choice of colours was driven by a self determined "rule" in which red is for strong sounds, purple is for normal sounds, and light blue and green are for pure and light sounds. She actually didn't mention yellow, even if she used it. However, it is interesting the process of categorization and self imposed rules that she adopted.

Overall, the activity resulted engaging and enjoyable for the children who were constantly discussing cheerfully and changing their choices of the colours on the basis of the discussion. At the end, they were also very curious of looking behind the box and making sounds with the real objects.

6.4 Requirements

The first exploratory phase of the project, aimed at investigating the habits of Chinese children and observing how they approach certain activities, was crucial for defining a series of requirements that concern, mainly, the purpose of the project proposal.

Through the questionnaire, in fact, it was possible to notice how children's daily life is tightly scheduled, resulting in a dominance of educational activities and limited time dedicated to playing. The unbalance towards education rather than play was also noticed in the parent's opinions about the characteristics that a good toy should have. In most of the cases, it has to have a clear educational purpose. Another peculiar aspect identified through the questionnaire is that children, especially during the week, have small chance to play socially, with adults or peers. According to these findings, three requirements were identified: *fitting into existing habits, making clear the learning potential of the proposed solution*, and *promoting social engagement*.

The observation of the hands-on workshop, instead, allowed observing how children spontaneously engage these kinds of activities creatively and critically. Regarding the soundtracks, for instance, they automatically tended to make complex interpretations of each track creating stories and adding interesting details.
By relating to the activity about sound-colour associations, it was possible to notice how they were spontaneously creating their own rules of approaching the activity and explaining their decisions. Thus, these observations allowed defining three other requirements also related to the project's purpose. Rather than designing the most efficient social robot, the challenge became designing for *giving control to children*, by *considering the robot as part of a broader storytelling* that can be developed though *open and customizable experiences*.

These six requirements were then supplemented with other concerning the specific aspects of robot's design, emerging mostly from the literature review. The design of robots usually addresses three main aspects, namely morphology, nonverbal behaviours and interaction schemes (Luria et al. 2016). Accordingly, the robot's design requirements were defined referring to these three aspects.

Regarding nonverbal behaviours, the robot has to *communicate different statuses through movement*, and it has to *show explicit input-output relations*. The first is because the sense of animacy and causality spontaneously emerge with the visual processing of movement (Hoffman and Ju 2014). The second, instead, refers to the work of Ackermann (2005), who explains how toys that are sensitive to some features of the environment can be controlled and affected by children's actions.

About morphology, the robot has to show an *iconic appearance* and provide some *physical affordances*. The need for an iconic appearance is motivated by the willingness of providing lifelike features that can be attractive and raise a sense of familiarity (Blow et al. 2006) while avoiding the risks of surface mimicry (Marti 2014) that can lead to uncanny feelings (Mori 1970). Physical affordances (Hartson 2003), instead, are needed for inviting and facilitating user's interaction.

Finally, also regarding the interaction schemes, two requirements were identified. On the one hand, the use of the *robot as a mediator of the interaction* engages and motivates children to interact with the physical environment. On the other hand, the interaction has to *give control to children*, at some levels. Although it is related to the requirement emerged from the exploratory study, this somehow differs since it refers to the idea, by Ackermann (2005), of toys that feel and that can be controlled by children. In this case, thus, the act of giving control determines a feature of the robot.

6.5 Design and development

In the attempt of meeting the requirements emerged from the preliminary research and the exploratory studies, a trainable sound-reactive robot, called Shybo, was developed. The design process was characterised by sketching, prototyping and documentation of the various ideas. In particular, a series of five low and high fidelity prototypes was developed for investigating different aspects of the robot, such as nonverbal behaviours, interaction with users and morphology.

Sketching

Sketching was practiced as a tool to support an individual thinking process and to explore possible design ideas, useful for future developments.

The sketches produced in this work consists of thinking and storing sketches. Regarding the communication of design ideas, fast prototyping techniques were preferred over talking and prescriptive sketches. With regards to the requirements mentioned earlier, sketching was used as a preliminary activity to address all the three categories, and as a way to define possible strategies to answer the requirements, that were subsequently explored through prototypes. A reflection on the preliminary idea of a robotic toy's set highlighted the need for designing the robots with a personality and for defining simple and legible functioning principles. In fact, reflecting on the possible combinations of senses and reactions that could have been embedded on each robot of the set, allowed to define meaningful combinations (such as colour-sound, temperature-texture, and texture-sound). However, the need for prototyping and testing at least one of the characters, in a limited time span, led to the choice of only one combination: sound and colour. Given this functioning, further

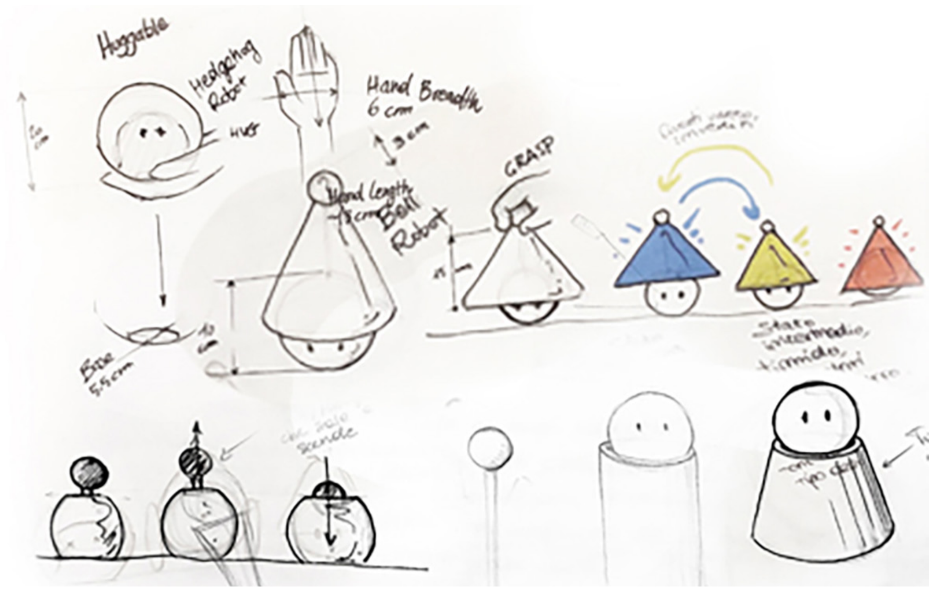


Fig. 6.11 - Sketches of the concept and preliminary studies of the robots' behaviours.

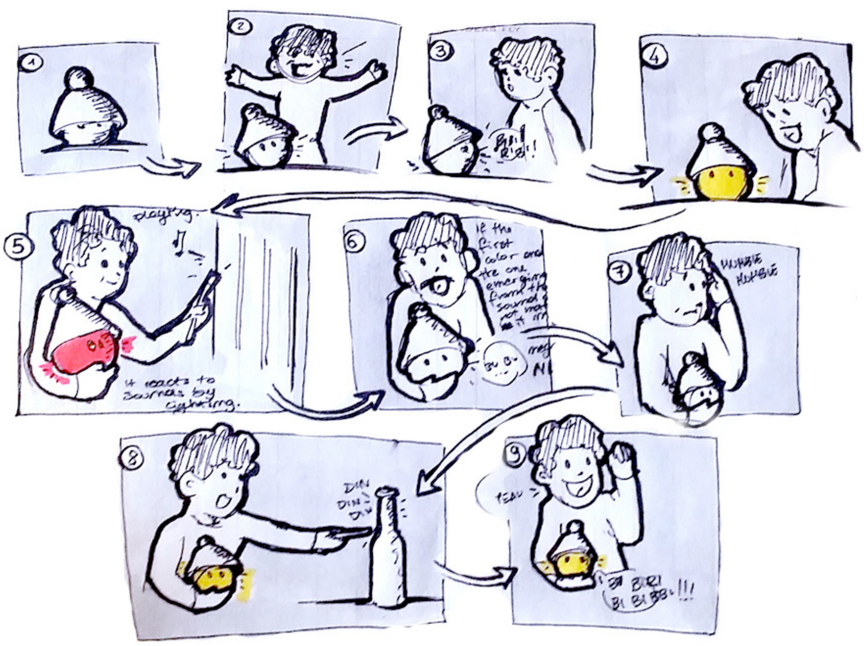


Fig. 6.12 - A storyboard illustrating a possible interaction scenario.

sketches were made for thinking about alternative morphologies, non-verbal behaviours, and possible interaction schemas.

Prototyping

The prototyping phase of the project consisted of a series of different prototypes. Each of these was developed with a different technique, chosen according to its purpose. Hence, a variety of paper models and physical computing platforms were drawn up to explore morphology, non-verbal behaviours and a possible interaction schema. another morphological aspect, related to the need for providing physical affordances. Given the intent of designing a robot that invites children to the interaction, a rounded shape was identified as a way to let them grab it and hold in their hands. This second prototype, hence, represented a way to investigate the formal relationship between the shapes of the hat and a rounded body, and on how to attach the two elements physically.

The paper prototypes were followed by interactive prototypes. A first low-functioning and low-fidelity interactive prototype was characterized by the aim of developing and play with a preliminary interface

Fig. 6.13 - First paper prototype

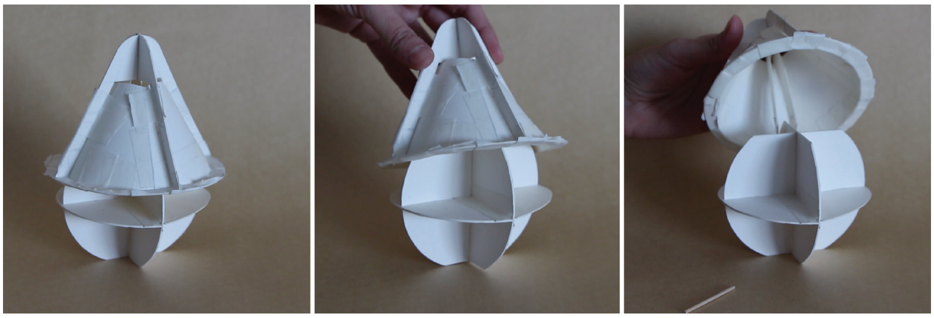


Fig. 6.14 - Second paper prototype

The first two paper prototypes were aimed at investigating morphological aspects of the artefact. In particular, both were focused on one element: the hat.

The movement of the hat, in fact, is used to obtain three different states of the robot. According to its position, the robot might look active, calm or scared. Thus, the two paper prototypes were developed for observing the efficacy of hat's movement for obtaining the statuses. Furthermore, the purpose of the first prototype was also to reflect on the preliminary aspects of character's design, defined by few minimalistic elements, answering the requirement of iconic appearance.

The second paper prototype focused also on for the training mode of the robot. Given the fact that the character design was not the crucial aspect of this stage, the prototype had a squared shape and was made of foam. In this case, a key role was played by the hardware components: a button, a potentiometer, a microphone, an LED ring, and a touch conductive surface. These elements, connected to an Arduino board, enable to record a sound, select a colour and save the colour-sound association.

Morphological aspects were also addressed in this prototype. However, differently from the previous two, the intent in this case was to explore a way to provide physical affordances for facilitating the interaction in the training mode. On the other

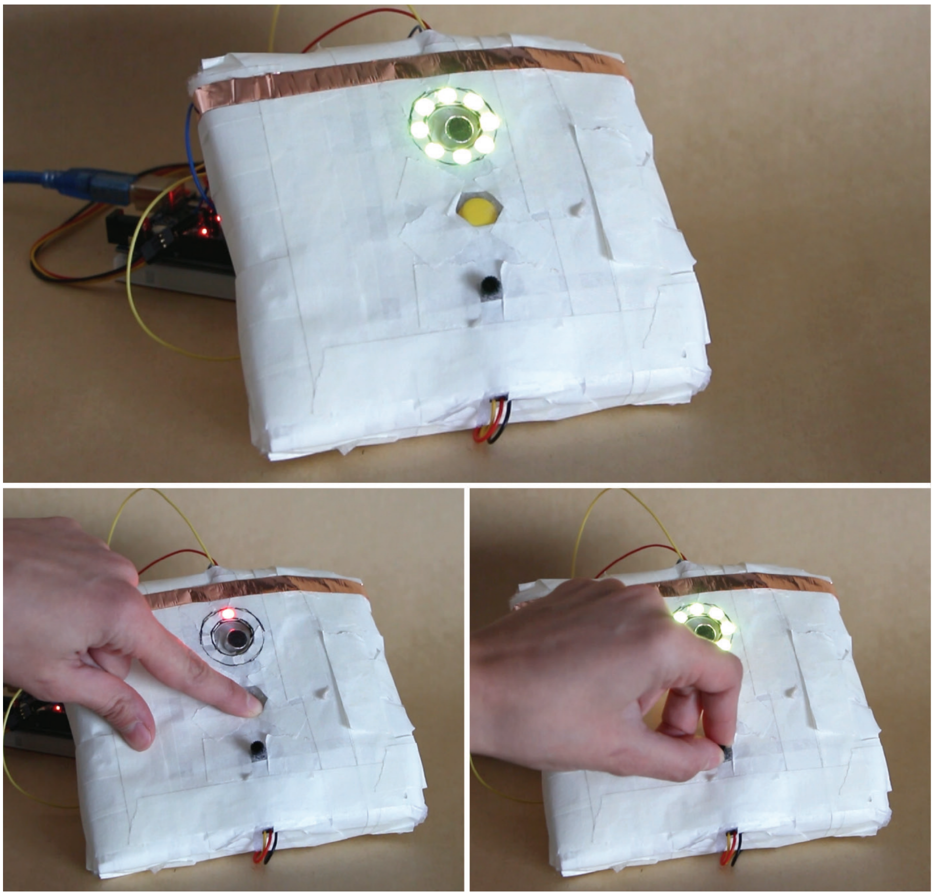


Fig. 6.15 -Low-fidelity and low-functioning interactive prototype.

hand, the interaction with this prototype allowed an issue to be identified. The training configuration and the required sequence of actions that were initially hypothesized were too complex. Thanks to this observation, the sequence was subsequently simplified and reduced in the number of actions and elements required. This led to the current arrangement of the elements, which has the button as the mouth, the potentiometer as the nose and the LED ring and microphone as the eye.

This prototype was followed by a low-fidelity semi-functioning prototype aimed at improving the training interface and developing the robot's behaviours. Given the focus on the functioning rather than morphology, the hardware components were roughly connected to a breadboard, without any sort of cover. The movement of the hat was simulated by sticking the paper hat from the first paper prototype on a servo motor.

At this stage, the two prototypes were mostly focused on the development of the non-verbal behaviours and the interaction schema. The morphological and aesthetical aspects of the artefacts were investigated through 3D models. The 3D modelling, made with Rhino, a CAD software, was fundamental for combining morphological aspects with constraints given by the hardware employed. By modelling various slightly different alternatives, it was possible to identify the simplest and efficient morphology for the robot, that would meet both technical and expressive needs. Furthermore, the 3D model was also animated using Blender, an open-source software for 3D computer graphic, to simulate the movement and the light behaviour.

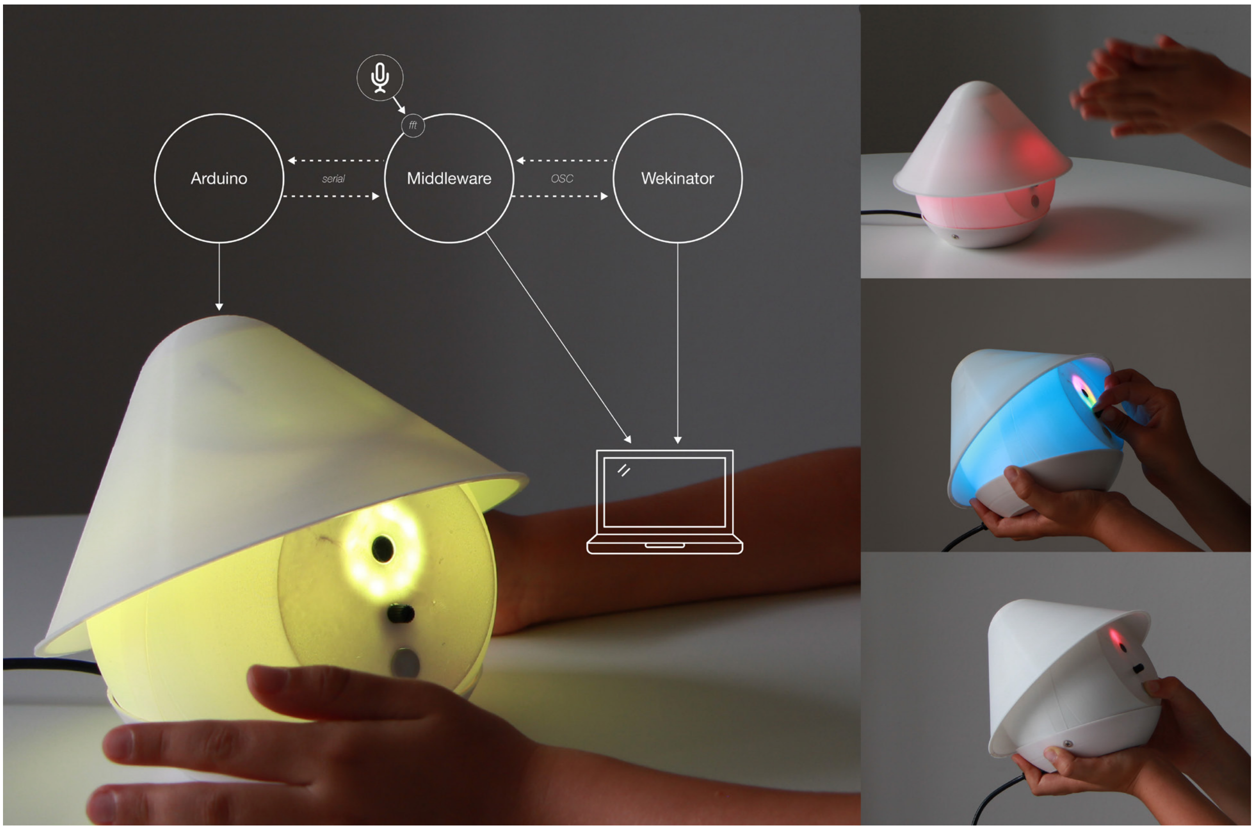
A high-fidelity and semi-functioning prototype was, then, developed by 3D printing those 3D models exported in STL (Stereo Lithography) format. The printing was entrusted to a professional 3D printing service, which allowed to save time and

Fig. 6.16 - High-fidelity and semi-functioning prototype of Shybo. On the right, some still-frames of the functioning.

to achieve a high quality of finishing.
The pieces were printed in PLA (150µm, white).
In this fifth prototype, the morphology and the main functioning were mostly defined, and the purpose was to play and test these two aspects. Nevertheless, the efficacy of the robot's behaviours was strongly affected by the details of its actions. For these reasons, this prototyping stage paid great attention to the details of the robot's non-verbal behaviours, namely the hat's movement and the light animations, which answer to the requirement of having explicit input-output relations. In particular, the animations of the eye of the robot were designed to communicate the functioning in the training mode, while in the play mode the body lighting was improved by paying particular attention to the fade and the transitions between the various colours.

6.5.1 Shybo: high fidelity and semi functioning prototype

The making process, described in detail in Lupetti (2017) resulted in an artefact called *Shybo*: a small low-anthropomorphic robot that perceives sounds and reacts by lighting up in different colours and through a minimal nonverbal behaviour, namely the movement of the hat. Shybo is designed to be used as a character for stories, aimed at letting children construct knowledge that can be related to academic contents or more abstract concepts such as identity and emotional intelligence. It is intended to be part of broader learning experiences, which can be carried out in class with groups, fitting into existing habits and answering to the requirement of promoting social engagement.
To do so, it is designed to be accompanied by a set of elements that can change and be defined according to the context and the educational interest of the situation, also answering to the need for open and customizable experiences.
Given the interest in giving control to children, for expressing their visions and interpretations of experiences, the robot has no pre-set colour–sound combinations and children have to train it to play.
The training consists of simple actions: switching modality, selecting a colour, and recording sounds. At the bottom surface of the robot is located a switch that changes the status of the robot from play to train. In this state, the child can select a



colour by turning the nose of the robot.
Once a colour is chosen, the child can associate a sound to that by pushing the robot's mouth. When the mouth is pushed a small red light indicates that the robot is recording. Once it is released, Shybo automatically saves the association of that sound to the selected colour category. In this way, children can potentially choose to make sound with any kind of object and they can record multiple sounds on the same colour category, paying attention to the similarities of the various sounds.
Shybo is designed as a low-anthropomorphic robot, consisting of a round-shaped head and a hat. Addressing the requirement of an iconic appearance, its face is obtained using electronic components, such as a potentiometer (nose), a button (mouth) and a LED ring (eye). The components also represent an intuitive training interface of the robot, answering to the need for giving control to children. The shape and the face-interface answer to the need for providing physical affordances to children. The rounded body, in fact, invites to the physical contact and let children hold the robot in their hands. The "nude" electronics components, instead, provide hints of the use.
By perceiving sounds and reacting through light and colour, the robot presents an explicit input-output relation that easily allows children to see the effects of their actions. In this way, the robot can be used as a mediator if the interaction that can take place between children and elements of the physical environment, such as musical instruments or daily life objects used to make sounds. The robot's reactivity and status are also manifested through the movement of the hat, which can be at an intermediate position when Shybo is switched off, totally open when it is active, and closed and shaky when it is scared.

6.6 A playful learning activity with Shybo

Although lab experiments allow a greater level of control, wild studies are preferable in those projects in which the interest is in getting results about the effective applicability of the proposed solution (Baxter et al., 2016). For this reason, the play test with children was run at Yon Hu Qu Experimental Primary School, in Yuncheng, China. The activity was carried out in the conference room of the school, where a set of tables and other materials were arranged. The materials consisted of twelve musical instruments, five paper colour-cards, four boards of colours, a game board, a set of game cards, four pawns, an hourglass, a laptop and the robot.
The evaluation of Shybo and its intended use was carried out as a playful learning experience, with a duration of two hours, subdivided into four main phases.
In the first step, children were invited to play musical instruments, create groups of similar sounds and choose a colour for the group.
In the second phase, the robot was introduced to children and every child, group by group, was invited to train it by making sounds.
In the third step, a researcher, who was leading the experience, introduced children to simple principles of colour theory and then introduced the elements of the game and the rules.
Finally, children, divided into teams, played the board game. The procedure's subsection provides a detailed list of actions that characterised the activity.
The setup was organized as follows. At the centre of the dedicated area was located a group of six small school's tables, used to create a big table for group activity. In front of this was placed a long table, used to arrange the musical instruments, before and during the activity.
On the right side of the central table was located another table were the elements of the game were kept until their use. On the left side, instead, a lectern was placed. This was used to support a laptop connected to Shybo, taking advantage of the height to prevent children from being distracted from the running software. The robot was also placed on the lectern at the beginning of the activity, hidden from children.

Fig. 6.17 - Children interacting with Shybo during the activity at the primary school in Yuncheng, China.

6.6.1 Supplementary materials

As mentioned above, Shybo is designed to be used as a character for stories and it is intended to be part of broader learning experiences, which can be carried out in class with groups, fitting into existing habits and answering to the requirement of promoting social engagement. For this reason, it is designed to be accompanied by a set of elements that can change and be defined according to the context and the educational interest of the situation.
The first experimental experience with Shybo, documented in Lupetti et al. (2017), was meant to explore with children some primary concepts of colour theory and discuss together the qualities of sounds, and how sounds and colours can be associated. These aspects were, then, intended to be used through a game with Shybo, that would require children to remember colour–sound combinations and coordinate in groups for playing. Accordingly, a set of game elements was designed and developed.
The set includes twelve musical instruments, five coloured paper cards, four boards of colours, a board game, a set of game cards, four pawns, and an hourglass. The musical instruments, consisting of both existing and custom made instruments, were firstly used to let every child play, find similarities among sounds, train Shybo and, then, to play the game for obtaining certain colours on Shybo.
For better understanding the role of each game element, the list of game rules is listed below:

1. divide the players into groups of 3, so to have 4 groups;

2. each group plays in turns. One turn lasts 1 min, showed by the hourglass;

3. during every turn, each member of the group has to do a different thing. One child reads the card, one takes the object, and the last child moves the pawn on the board. Every turn the children can exchange the role;

4. every card has a coloured circle or a description of colour. The teams have to obtain those colours on the robot by making sounds. The sounds were previously associated with colours by children;

5. in one turn each group can do as many cards as it can. Every card done allows moving one step forward on the board;

6. if the robot gets scared by the sounds, the team loses the turn, unless the card requires the red colour;

7. the team that arrives first at the end of the board wins.

Fig. 6.18 -Children playing a board game with Shybo during the activity at the primary school in Yungcheng, China.

6.6.2 Evaluation methods

The evaluation of the experimental application at the school, reported in Lupetti et al. (2017), has encompassed two main actions: a questionnaire for parents and the actual playtest with children. During the playtest with the kids, different methods were used to collect data. On the one hand, the whole experience was video recorded for subsequent observation and transcription of the verbal interaction. On the other hand, children were invited to self-report data about the experience through three tools: an after experience questionnaire, inspired by the Godspeed questionnaires (Bartneck et al., 2009), an Again and Again table (Read and McFarlane 2006) and a Difficultometer, an adaptation of the Funometer (Read and McFarlane, 2006).
The playtest was firstly aimed at observing both usability and user experience aspects. Play related experiences, especially pure entertainment applications, in fact, require not only to evaluate the key factors that affect the playability of the proposed solution but also to understand the emotional experience of users (Mandryk et al., 2006).
The questionnaire, instead, was meant to investigate factors of social acceptance and societal impact that, in human-robot interaction studies, assume a crucial role in acceptance. Robots, in fact, represent a more complex challenge regarding evaluation compared to computer based applications. For instance, expectations and resistances toward robots are significantly affected by the fact that people's mental model of these artefacts is more anthropomorphic than the one of other systems (Kiesler and Hinds, 2004). Furthermore, various sociocultural and perceptual factors, such as education, life and work conditions, attitude toward technology, and forms of attachments can determine the way people approach and behave with robots (Weiss et al., 2009).
Accordingly, the evaluation of the project presented in this article was carried out with the attempt of providing useful insights regarding both the general purpose and the specific aspects of the project. With regards to the purpose, on the one hand, the study was aimed at getting insights about the perceived usefulness, which is crucial for product acceptance (Davis, 1989) of the solution. On the other hand, the goal was understanding the compatibility with the context and the existing practices, which determine the way potential users give meanings to the proposed solution in relation to their values and beliefs (Rogers, 1995).
Regarding the robot, three main factors were observed, namely likeability, learnability, and perceived animacy. Robot's likeability is addressed since it has been reported that this factor can significantly affect the users' way and willingness to interact with a robot, for instance reducing or increasing the distance during the interaction (Mumm and Mutlu, 2011). Learnability, namely how easy is the system to be learned for novice users (Mumm and Mutlu, 2011) is particularly important for this project, and it is mainly related to the training mode of the robot. This aspect, in fact, may invalidate the overall experience, by moving the focus from sound-colour associations to how to train the robot.
Perceived animacy, instead, is crucial for understanding the efficacy of the interaction that relies on the user's ability to attribute individual mental states based on certain forms and movements (Castro-González et al., 2016). The solution presented in this project, in fact, relies on the children's ability to perceive the robot's status, active or scared, according to its light and hat movement.
Finally, the overall experience was evaluated referring to two most important aspects: enjoyment and engagement. According to Xie et al. (2008), in fact, these two are integral, and prerequisite aspect's of children's playful learning experiences. Still referring to the authors, this work address enjoyment as children's intrinsic motivation, in which people engage the learning activity for their own sake, rather than for receiving some external reward or avoid some external punishment (Malone and Lepper, 1987). Furthermore, Xie et al. (2008) refer to Salomon and Globerson (1989) who provide a useful conceptualisation of engagement within the context of learning experiences, as a mindful activity that requires cognitive effort and deep processing of new information.

Participants

Engaging a representative sample of the population in the study is of primary importance to get

ecological validity and make better generalisations of the real world for which the solution is intended. Moreover, in the case of this project, this good practice acquires even more importance. Children respond more readily and strongly than adults to social robots and even a minimal robot movement, such as gaze movement, can affect the perception of animacy and likeability.
Referring to these considerations, the evaluation stage was carried out involving twelve Chinese children (N = 12) aged 6–9 years old (age: M = 7.08, SD = 0.95). They were half females and half males (F = 6; M = 6). They all attend extracurricular courses, on average, twice a week (M = 1.9, SD = 1.3). Parallel to play-testing with children, one parent for each child was asked to answer a questionnaire. The parents involved (N = 12), aged between 28 and 41 years old (M = 33.25, SD = 3.86), were eleven females and 1 male (F = 11; M = 1). Regarding education, six of them have a university degree, four a high school diploma, and two attended only the middle school. In addition, their current employment is diverse: seven are teachers, two are farmers, one is a legal assistant, and one is an accountant.

6.6.3 Results

Questionnaire

The questionnaire submitted to the parents revealed a general agreement toward the proposed solution, despite in few cases the answers were entirely positive. Especially regarding the general aspects of the project, table 6.1, received very few negative answers. Relating to the purpose of the project (Q1), namely promoting children reasoning and motivation, half of the parents (6) said that it is relevant and two that it is very relevant. Only one parent affirmed that it is not at all relevant. About the appropriateness of using a robot for such a purpose, parents were even more positive: ten out of twelve were positive (8 yes; 2 absolutely yes), while only one was extremely negative. The third question (Q3), gave, also, a very similar result: nine out of 12 parents find interesting the trainability of the robot (8 yes, 1 absolutely yes), while two said that is maybe interesting and one said not so much. Regarding other more specific aspects of the project, in figure 4, the agreement decreased slightly. Parents gave very positive feedback to the question about the likeability of the solution, namely if their children would like Shybo and to play with it (Q4). In fact, ten out of twelve were positive, and none

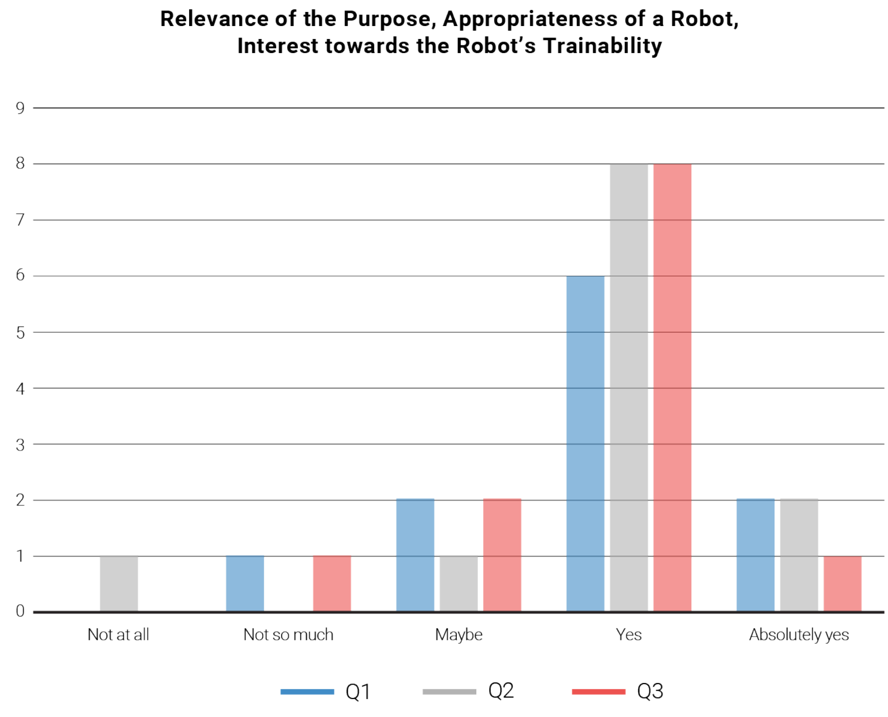


Table. 6.1 - Parents' answers to the first three questions about the robot's purpose, appropriateness, and interest toward the robot's trainability.

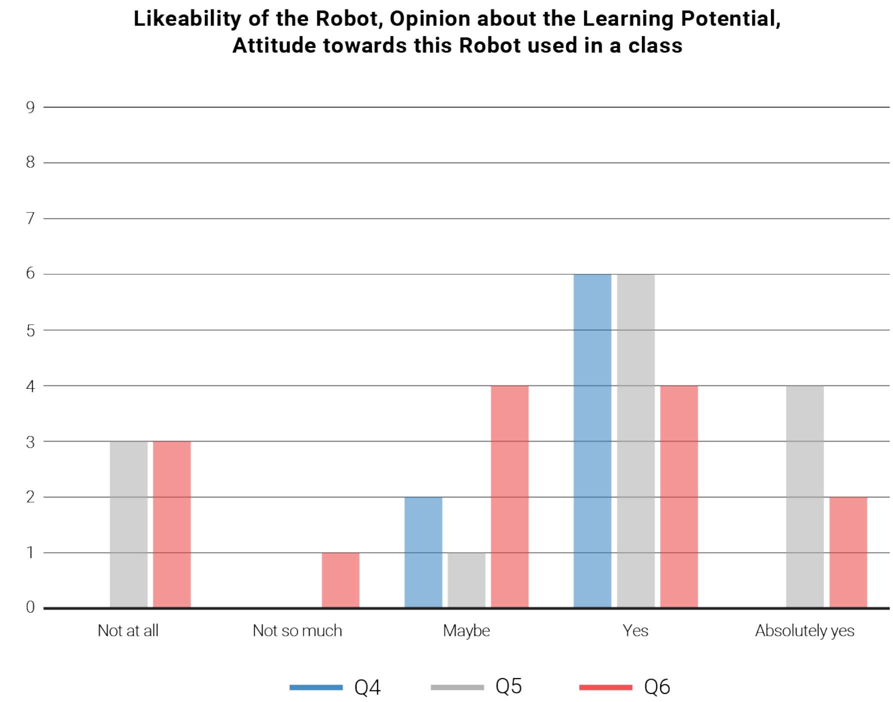


Table. 6.2 -Parents' answers to the following three questions about the robot's likeability, learning potential, and suitability for school activities.

was negative. Conversely, when parents were asked to say if, in their opinion, children may learn from observing the robot's reactions in terms of color-sound associations (Q5), three answers were totally negative.
However, the majority of parents (6 yes; 2 absolutely yes) believe that there is a learning potential. Parents, instead, were quite doubtful when asked to say if they would allow their children to attend a class that employ this robot in a game with rules for the purpose described above. In this case, the positive answers were just four (4 yes). Four other parents stated that maybe they would allow that, while four gave a negative answer (1 not so much; 3 not at all).

Parents were, then, asked to evaluate the robot on a semantic-differential scale. The descriptors of these questions, were intended to assess, on the one hand, the likeability of the robot and, on the other hand, its suitability for children. As shown in table 3, both likeability and suitability aspects gained overall positive feedbacks, the mean (M) values higher than 4.4 for each descriptor. In particular, the mean about the appropriateness of the robot's appearance for children is equal to the total: every parent considers it appropriate. Another aspect that can be observed is that, although the M of three aspects, namely appeal, beauty and safety, are equal, their standard deviation (SD) reveal greater differences in the evaluation of beauty. One

Parent	Comment
1	This game can improve children's observation and reaction ability
2	I really agree that kids can study something at play and all of kids would like to play with Shybo
4	Really like those type of games (game with rules)
5	Its really good for introvert children
7	I hope there are more chance for kids to attend this activity
9	Half of the results with the double of effort, and students should study basic classroom knowledge
11	Good toys and Shybo need to keep on improving and add the anti-interference ability, if not it is just suitable for home play

Table 6.3 -Parents' notes reported in the free comments section at the end of the questionnaire.

parent, in fact, rated Shybo as almost awful (on the scale from 1= awful and 5 = nice, he rated it 2).
These results suggest that the robot's appearance is both likeable as well as suitable for children. The open answers at the end of the questionnaire provide, also, a further chance for understanding the parent's attitude towards Shybo and the proposed activity. Although not all parents (7 out of 12) answered to this question, which was optional, most of the comments were positive.
The first five comments, listed in table 6.3, manifest the parent's positive attitude towards Shybo and the proposed experience, and some of them highlight that it can be beneficial for children. Parent 9, instead, points out that in his opinion, the project requires a double effort compared to traditional activities while produces the half of the benefits. He also states that children have to study basic subjects. The last comment from parent 11, instead, seems to be a warning. She points out that a good toy, in this case, Shybo, has to be provided with an anti-interference ability (presumably for noise issues) and needs to keep on improving over time.

Children's activity

Regarding the data self-reported by children in the questionnaire, the results appeared not reliable and were excluded from the evaluation. In fact, although figures supported the semantic differential scales, the aspects under evaluation were too abstract for children of this age. All the answers resulted in the same, oriented on the right axis of the scales.
Also the other tools, namely the Again and Again table and the Difficultometer did not provide very differentiated results. In the first case, in fact, all children said that they would do every phase of the activity again, except one who stated that "maybe" would do the colour-sound association part again.
The first phase was considered very easy by almost every child, the SD, in fact, is also small. In the other phases of the activity, instead, the average difficulty increased constantly, together with the SD. Although according to the M the activities resulted overall easy, some children reported difficulties especially in the last two parts. Training the robot, in fact, was considered difficult by two children and very difficult by one, while all the rest considered it easy. Even more difficult resulted playing the game for some (3 very difficult, 1 difficult).
The observations, instead, were more productive. The whole activity with children, in fact, was video-recorded using an action camera, mounted on a tripod. The video was automatically saved in four parts, lasting twenty-two minutes each, for a total of eighty-eight minutes (1,5 h). The videos do not include the preliminary part in which children were welcomed in the room and the final part in which they filled in the questionnaire and the other forms.
The video recordings were edited and subdivided according to the procedure listed in table 6.4 and subsequently coded using *Boris* (Friard and Gamba, 2016), a free and open-source software for video-coding and live observations.
Some of the steps of the activity (1, 2, 3, 5, 11, 14, 15) were excluded from the coding action, after a brief observation. In fact, these parts can be described as transition and propaedeutic steps. Thus, the observation addressed the most salient parts of the activity. The observation was integrated with the transcription and translation of children's comments.
By observing the recordings, a set of fourteen recurring and relevant behaviours were identified and used for the video coding. Due to the difficulties of observing a group interaction in such a context (e.g. some children cover the others, some parts are too far from the camera, etc...), some of the reported behaviours refer to the overall group's behaviours. Others, instead, were pointed out when at least one child showed a certain behaviour. These behaviours differ also in terms of event type and valence. Some events, such as smiling or verbal interaction, that are prolonged in time, were coded as a state event, indicating a start and stop time. Conversely, others behaviours, characterised by a limited length, such as jumping, were coded as point event. The behaviours were also divided in positive and negative, according to the activity's valence they manifest.
The output of the video coding, consisting of ten plot graphs and time budget excel files, allowed to notice the overall feel of the experience, as well as some differences among the various phases. By looking at table 6.5 it is possible to observe the general trend of the four main group behaviours: smiling, focused, concentrated, and silence. Children resulted overall engaged by

Step	Video Sequence	Description
1	00:00 / 00:01 (video 1)	Children are welcomed in the conference room of the school
2	00:01 / 00:35 (video 1)	Each child is invited to take one musical instrument from the front table
3	00:35 / 01:55 (video 1)	One child at the time is invited to play his/her musical instrument while the other listen
4	01:55 / 06:01 (video 1)	Children are invited to find sounds similar to the one of their instrument and to make groups of two or three children
5	06:01 / 08:18 (video 1)	Each groups play again the instruments and select a color, picking a colored paper card
6	08:18 / 11:30 (video 1)	The tutor shows a short video that illustrates the functioning of Shybo
7	11:30 / 15:20 (video 1)	The tutor introduces Shybo to children
8	15:20 / 21:55 (video 1)	The tutor demonstrates live how to train Shybo
9	00:00 / 13:00 (video 2)	Each group, one by one, is invited to train Shybo by recording sounds and associating them with colors. During this action one child manage Shybo while another plays an instrument
10	13:00 / 18:58 (video 2)	After each group trained Shybo, the tutor switch Shybo in play mode and ask to children to play again the instrument. If the robot lights up in the colors associated during the training, it is working
11	18:58 / 21:56 (video 2)	Children are invited to leave the instruments on the front table, where they found them
12	00:00 / 04:17 (video 3)	The tutor introduces to children a small paper board of colors and explain what are primary, secondary and complementary colors. Then she asks questions to verify that children are understanding
13	04:17 / 05:51 (video 3)	The tutor introduces a board game that can be played with Shybo. She also explains the rules of the game, especially regarding the game cards and how to move ahead on the table
14	05:51 / 13:48 (video 3)	Children are divided in four groups and each group receive a pawn
15	13:48 / 16:31 (video 3)	The game is set up on the table
16	16:31 / 21:59 (video 3)	The game starts
17	00:00 / 20:10 (video 4)	The game go on
18	20:10 / 21:57 (video 4)	A group arrive to the last box of the board game, the game end

Table 6.4 - Procedure of the activity subdivided in 18^{th} steps.

the playtest. The level of focus on the activity, in fact, was over 90% for almost all phases, while just in phase 12 the focus decreased sensibly. This decline of attention was reaffirmed by the solo and small groups behaviours, illustrated in table 6.6. However, by cross-checking with the video, the distracting element in this phase was represented by the robot. In fact, after the tutor has introduced Shybo to children, this was left on the central table, while the activity moved to the right table focusing on the introduction of some concepts about colour theory. Moreover, the introduction of Shybo in phase 7 had an immediate effect. Children, who were very concentrated during the video about Shybo, when the robot was physically presented to them lost their serious and concentrated expression and started laughing frequently.
Table 6.7 shows, in fact, a peak in the laughing frequency which has grown from 0.5 events/minute in phase 6 to 2.25 events/minute in phase 7.
Less regular was also the level of smiling behaviour. During the first three phases, in fact, children appeared very smiling, while in phase 8, 9, and 10 this behaviour has fallen dramatically, to rise again in phase 12. However, the declining trend of smiling was compensated by the rising trend of concentration, which greatly varied among the phases. This inversion of the two trends manifests the nature of the activities carried out in those parts. In these phases, in fact, the tutor explained

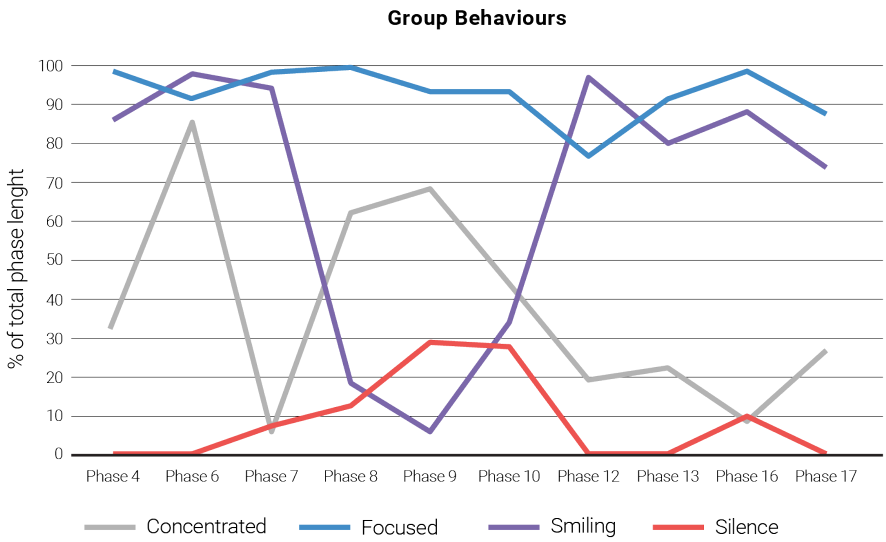


Table 6.5 -Overall group's behaviours.

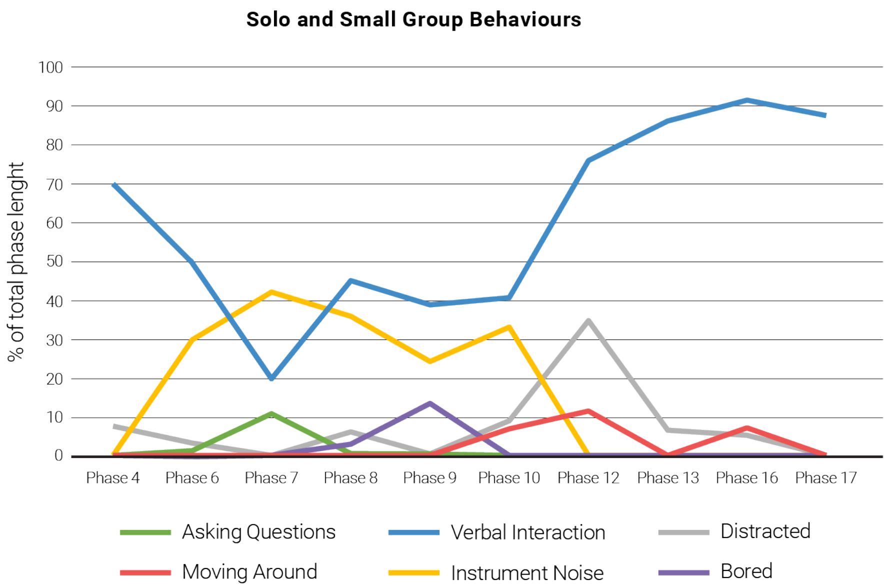


Table 6.6 - Trend of behaviours manifested by at least one or more children.

to children how to train Shybo, and let them do it. Furthermore, especially in phase 9 and 10, another behaviour rose together with the concentration: silence. Children were making silence and appeared serious because they were paying attention to the tutor's explanations and because of the robot's sensitivity to sound. Both silence and concentration decreased considerably in the following phases, after the training of the robot was concluded and children became familiar with its functioning and the game. This is also noticeable by looking at the trends in table 6.6, where in phase 7 the general verbal interaction decreased considerably while some children started to ask questions about the robot. Nevertheless, the fall of smiling in phase 8 and 9 is not only traceable to the normal robot's training activity. Looking at table 6.5, in fact, it becomes evident that, in these two phases, some problems emerged. On the one hand, one of the two tutors didn't connect properly Shybo to the software that was running on the laptop to perform the training. As a result, children started to get distracted and to appear bored. On the other hand, especially phase 9 in which children trained

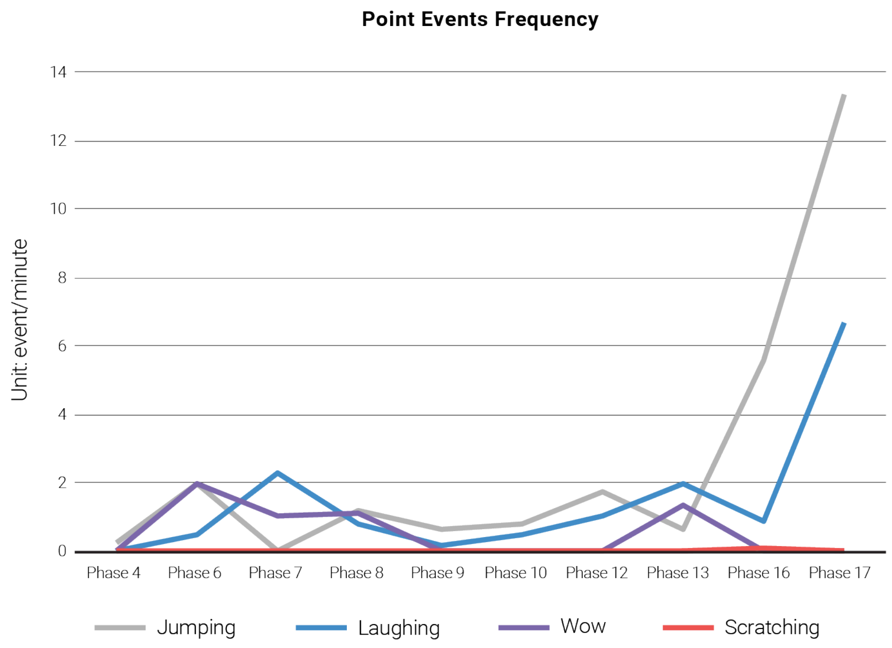


Table 6.7 - The table shows the frequency of the four point events in a minute range

Shybo, the activity involved children at turns and required them to be quiet, resulting in a decrease of excitement and a rose of boredom.

The level of verbal interaction, as shown in table 6.6, experienced a fall in the central part of the activity, in which children were mostly asked to observe and listen to the tutor explanations, and rose again from phase 12 to the end. On the contrary, the level of instrument noise, namely children playing the musical instruments when the activity did not require it, presents an opposite trend. This, in fact, increased significantly from phase 6 to 10, and ended in phase 12, since in this phase children had to leave the instruments on the table and in the following phases they were used for the game. Especially in phase 8 and 9, while the tutor was demonstrating how to train Shybo, children were often playing the instruments to see its reactions.

The final phases of the experience, from 12 to the end, were characterized by a very joyful atmosphere. As a matter of fact, although figure 5 shows a slight decrease in the focus towards the activity and in smiling, Table 6.7 presents an increase in laughing and a dramatic rise of jumping behaviours. From the beginning of the activity, in fact, children were sometimes jumping, manifesting excitement and joyful impatience. However, when the final game started, in phase 16, the frequency of this behaviour grew by 600%, moving from an average of 0.9 events/minute to 5.61 events/minute. The final phase (17) also reached a peak regarding the excitements, since it represented the end of the game and the victory of one team.

Despite the general excitement and the joyful atmosphere, by looking at the table 6.5 it is possible to notice some behaviours that might result in a negative valence of the experience. As already mentioned, the training phase and the error in the setup, in phase 8 and 9, resulted in a rise of boredom. From these phases also the level of distraction increased slightly. In fact, although in phase 12 this was due to the robot, in these phases some children started to move around the room, not very far but anyhow distracted from the activity. This was mostly happening when children had to wait for their group's turn to play. Other children, however, approached these waiting phases by collaborating with the other teams to find the right instruments, or just watched and incited the game staying around the table.

Another important point event illustrated in table 6.7 is “wow”. This represents the actual occurrence of children expressing a positive surprise by saying “wooooow”. This mostly happened in the phases in which new elements were introduced, that are the robot and the game elements. Especially regarding the robot, children expressed curiosity by also

asking questions.
The comments of children that were transcribed and translated, highlighted some children's expectations toward the robot. In fact, a girl asked why Shybo, as a robot, can't talk and has no legs. Another girl answered her that Shybo can't talk at the beginning. Some children say that they would like Shybo to be able to reproduce the sounds they play with the instruments or their voices. Another interesting comment is about Shybo getting scared. Rather than thinking that it is getting scared, some of them thinks that it gets angry. In fact, during phase 12, in which children were constantly getting distracted and making noise to see the robot's reactions, a boy was playing aggressively by walking fast toward the robot with a fist pointed at it. With this behaviour he was simulating a sort of fight in which he was acting aggressively to make Shybo calm rather than angry.
Finally, table 6.7 shows a point event that occurred only in one phase, namely when children started to play the game. A boy, who was entrusted of finding the right instruments to play, started to scratch his head manifesting a difficulty and making evident that he didn't remember which object was associated with which colour. In fact, at the beginning of phase 16 also some other children commented that playing the game was challenging and that they forgot the colour-sound associations. A last difficulty observed in the game regarded the game cards. Some of the cards were more difficult than others because these asked children to reflect on primary, secondary and complementary colours, rather than showing the colours directly. After some children did this kind of cards, the tutors decided to remove them from the game, because of the difficulty and the time required to children to play with these.

6.7 From a test to didactic modules for schools

The test carried out in Yungcheng, China, documented in Lupetti et al. (2017), allowed to get feedback on the overall validity of the project, on the robot and the playful learning experience. Regarding the project, parents confirmed the relevance of the purpose, that is promoting children's reasoning through play, as well as the learning potential and appropriateness of robots, among which Shybo, to support this purpose. Regarding the compatibility, instead, the questionnaire revealed some resistances of parents towards letting children attend a class that employs a robot like Shybo. This is probably motivated by the fact that very often there is a fear of adversely affecting the education of children. A comment from a parent, in fact, explicitly mentioned that children have to focus on traditional subjects.
About the robot, instead, both parents and children seemed positive. In particular, parents' results showed a high appreciation of the robot's appearance and also affirmed that children would like it too. The observation of the activity, in fact, revealed how children were positively impressed and enjoyed by the robot. They were constantly looking at the robot, making noise to cause a reaction from it, and some children were also touching it when the group was distracted. Some of these behaviours revealed also that children perceived the robot as animated, in fact, they were acting towards the robot as if it was alive and able to react socially.
The observation revealed also that both training and playing with the robot was easy to earn for children, giving a positive feedback in terms of learnability. This was also reaffirmed by the fact that, at the end of the activity, children independently explained to their parents how the robot works by showing them and playing together. Nevertheless, some comments of children highlighted a mismatch between children's expectations towards the robot's abilities and the actual abilities of Shybo.
The observations allowed also to notice a general positive valence of the experience. Regarding the enjoyment, this was revealed by a general smiling atmosphere and the constant increase of the laughing and jumping frequency that characterized the whole experience. The enjoyment of the experience was also confirmed by the *Again and Again* table, in which children stated that they would like to attend all the phases of the experience again. Furthermore, children appeared highly focused for the entire duration of the experience and, in many phases, they also appeared very concentrated, maintaining silence if necessary. This resulted in a high level of engagement. In spite of this, some issues emerged also regarding the engagement. In fact, on one hand, when the activity required

interaction in turns, and the groups had to wait, some children started to be distracted and to move around. On the other hand, during the explanation of the colour theory's principles children were distracted by the robot.
To sum up, the questionnaire and the playtest's observations highlighted four main issues, regarding both the robot and the organization and communication of the experience. Regarding the robot, children have expectations towards the robot's abilities that the current prototype doesn't meet. About the experience, instead, the first issue is that parents may not be in favour of letting children attend a class that implies such experience. With respect to the experience's activity flow, an issue is represented by the activities in turn, which may lead children to boredom and distraction. In addition, the robot may represent a very distracting element if not integrated in the activity.
Thus, in order to address these issues, the following part of the project consisted of a robot redesign according to children's comments, and of a partnership with an educational institution for addressing the issues of compatibility through the direct involvement of an educator in the design process. The actual development of the new robot was also carried out by involving a creative technologist in the project.

6.7.1 Partnership

The second main phase of the project was carried out in Italy in collaboration with Annalisa Gallo, didactic manager of *10100 Percorsi*, an organization that offer extracurricular courses to schools, and Lorenzo Romagnoli, interaction designer and creative technologist.
This collaboration was established for answering to a need emerged from the experience carried out in China. In particular, the collaboration with the educator was aimed at co-designing the learning experiences and defining the requirements for developing the second prototype. Through this collaboration the design process was carried out as an immersive investigation (Donahue, 2003) in the domain of education.
This collaboration offered the opportunity of creating a dialogue between a research focused on the use of technology for children and existing activities that usually do not imply any use of technology. As in the case of many educational organizations, in fact, *10100 Percorsi* does not organize courses related to technology, rather history, archaeology, geography, multiculturalism, creativity, and cultural heritage. Thus, through the co-design of the experience and the co-definition of the educational objectives, it was possible to investigate ways of supporting, through a robot, activities that combine themes of various disciplines.
On the other hand, the collaboration with the creative technologist was aimed at getting a deeper understanding of the technical opportunities available and at developing a second prototype. Furthermore, the design and development process, at this stage, was guided by the precise intent of developing a versatile artefact that would be able to support a range of possible experiences, rather than a unique kind of activity.

6.7.2 The Open AniMates concept

The "*Open AniMates*" concept represents the result of this collaboration.
It consists of a didactic project that involves children and teachers in playful learning experiences with small robots, developed taking advantage of the combination of open-source technologies and traditional materials.
The robots, protagonists of stories and activities connected with the school curricula, support the creation of educational models based on multidisciplinary experiences, enhancing students' engagement. Shybo is intended as the first of the series. By interacting with it, in fact, children can explore concepts related to art, music, informatics, geography and local knowledge.
These playful learning activities with small robots present some key characteristics:

- *Computational thinking as a tool:* through these playful learning activities, children can develop computational thinking skills that can be used for enhancing their understanding of curricular contents and for introducing extra-curricular knowledge;

- *Problem-solving and lateral thinking:* with Open AniMates, knowledge and contents are not transmitted, rather creatively constructed among peers and educators. Using little challenges as incipit for the activities. As a consequence, by interacting with the robots, children can develop problem solving skills and lateral thinking;

- *Children as protagonist:* with Open AniMates the educative process is subverted. The child is engaged in a creative and critical way, asked to interpret and determine the dynamics of the experience. Furthermore, some robots need to be educated by children for functioning;

- *A robot, multiple activities:* the small robots become actors of stories and adventures that allow to create unique and multidisciplinary didactic modules, which can differ according to age, adapting to different needs of the didactic program. Teachers can play a strategic role in the co-creation of the modules;

- *Unique but open solutions:* the activities are developed employing traditional materials combined with open-source hardware and software, designing unique but also replicable solutions. The developed activities and robots, in fact, are documented and shared with open-source licenses, following an Open Education philosophy.

6.7.3 Co-design

Two types of co-design actions were carried out. On the one hand, the activity was defined in collaboration with the educator. On the other hand, a new version of the robot was developed with the creative technologist, taking into account the requirements emerging from the co-design of the activity.
The activity was, first of all, designed to be connected with the school curricula. To do so, a story was developed as a strategy for both introducing the robot to children and providing a *fil rouge* for building consistent activities. Also regarding the activities, a series of supplementary materials were co-designed, such as a toolkit for analysing the robot with children, a set of musical instruments, a board game, and a set of printed cards containing a series of pictures and a map.
Regarding the robot, instead, the co-design activity was focused on increasing the robot's sensory capabilities, the set of responses, and his motor abilities. In the first Shybo prototype, in fact, the movement was limited to an expressive movement of the hat. A functional movement was then added, consisting of a directional movement on wheels.

A story with Shybo

A crucial aspect of conducting activities with children consists of introducing the robot in an engaging, credible and meaningful way. To do so, a story was written together with the educator, through a shared editable document.
According to the story:

"*a little robot was found by Annalisa [the educator] in a late afternoon, close to a school garden. Annalisa started to look at the robot, but it appeared inanimate. None of her attempts to arouse reactions were successful. The robot, in fact, did not show any kind of reaction. Because of that, at first, she wasn't even sure if it was a robot or just a toy.*
To find out more about it, Annalisa asked for the help of two robot experts: Maria Luce and Lorenzo [the primary investigator and the creative technologist]. They arranged a meeting for the day after, at the school, because the robot was found close to it, and since the meeting was going to took place at the school, Annalisa asked to children to help analysing the robot. The aim of this analysis is to find out how the robot works, where it came from, and to bring it home."

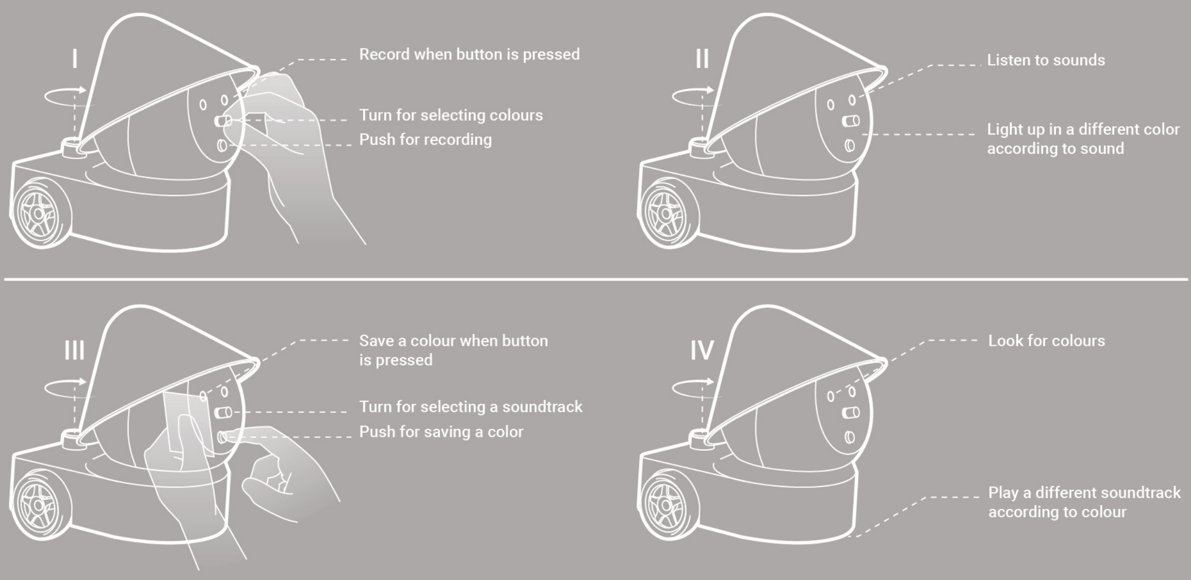
The intention is to let children reflect and elaborate hypotheses, for enabling them to understand, little by little, that Shybo is an "explorer robot". According to the storytelling, the characteristic of this category of robot is that they explore unknown places and during the journey they save memories of relevant things that they see. The memories are stored in the form of pictures associated to colours.

Shybo V. 2

As in the first robot, the second version of Shybo, showed in figure 6.19, is able to perceive sounds and to react by lighting up in different colours

Fig. 6.19 - The second version of Shybo robot.

FUNCTIONING MODALITIES



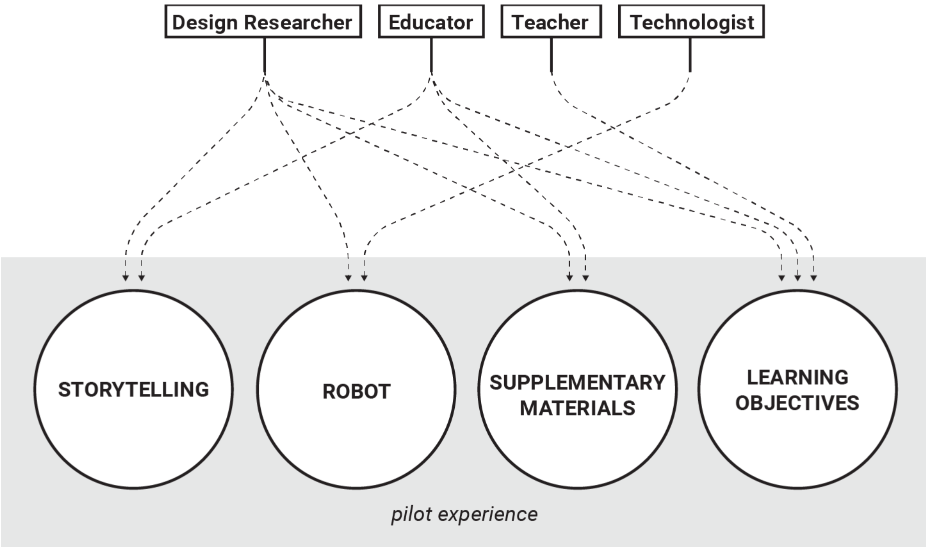


Fig. 6.20 - The contribution of the main actors involved in the design of the pilot experience of the Open AniMates project.

and by moving the hat if the sounds are too loud. Nevertheless, it is also able to do the opposite: it can perceive colours and react by emitting sounds. The sounds consist of audio tracks saved on the robot's memory that can be associated, potentially by both children and educators, to specific colours through a training process.

In the first story, the audio tracks corresponded to memories of places that the robot visited before arriving in front of the school. Thus, the soundtracks were previously selected and uploaded, then associated to colours before the activity with children.

The training modalities can be activated by turning the yellow switch on the robot back.

The robot functioning modalities, in fact, are four: training sounds on colour categories (I), listening to sounds and reacting through colours (II), training colours through sounds categories (III), and looking for colours and reacting through sounds (IV).

In the first training mode (I), the robot allows to select one out of five colours (purple, blue, green, yellow, and orange) by turning the nose, that consists of a potentiometer. Then, the selected colour can be associated with a sound by pushing the button and playing an instrument in front of the robot. In many cases, children should collaborate for doing this training, because some instruments require both hands for playing.

Then, these sound-colour associations can be saved by simply turning the yellow switch, on the robot back, into the close modality (II).

Similarly, the second training mode (III) allows to select a soundtrack by turning the nose. When a soundtrack is selected it is played so that the user can listen to what is selecting. Then, the selected soundtrack is associated to a colour by placing in front of his left eye a coloured thing, that can be also a simple coloured paper. Also in this case, the associations are saved by simply turning the switch on a close modality (II or IV).

Also the motor abilities were increased. In fact, the expressive movement of the hat was supplemented with the ability of moving around, through a directional movement on wheels. This ability was added for two reasons. On the one hand, the willingness of developing a flexible robot that can be easily adapted to different kind of activities revealed the need for making it "mobile".

In this way, it can potentially be used for common activities of robot programming. On the other hand, in the story defined with the educator, the robot is described as an explorer, that during his journey got lost. Thus, the ability of moving around was a characteristic aspect of the character.

In particular, during the pilot experience, the robot movements consisted of the expressive movement of the hat when the sounds were too loud, and on minimal movements of the hat and on minimal autonomous movements that the robot performed about every ten minutes, for giving a sense of animacy.

The size of the robot was also increased with the aim of making it more suitable for activities with groups of children.

Fig. 6.21 - Day 1, group analysis of the robot with the support of forms.

Fig. 6.22 - Day 1, a child is looking for hidden parts of the robot with a magnifying glass.

Fig. 6.23 - Day 2, children are training the robot with analogous sounds using musical instruments.

Regarding the morphology and the aesthetics, the robot was developed keeping the minimalistic style of the first Shybo. A small change was introduced regarding the elements functional for interacting with the robot. These, in fact, were highlighted through the use of yellow.

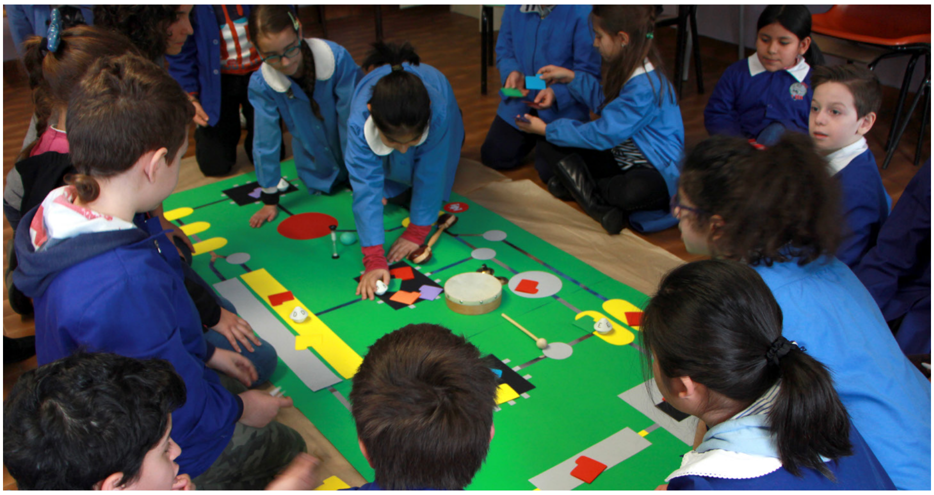


Fig. 6.24 - Day 2, children are playing a board game that allow to reorganize the memory of the robot.

6.7.4 pilot experience at school

A pilot experience was then designed on the basis of the aforementioned story. This experience consisted of three meetings at the school, lasted about three hours. Each meeting was characterised by different activities, supported by different sets of materials.
The pilot experience was carried out in the primary school Cesare Battisti (Istituto Comprensivo Corso Racconigi), in Turin, Italy, and it involved twenty children of a fourth grade class. The activity was adapted to create connections with the curricula. To do so, a school teacher contributed to the definition of the learning objectives.

Day 1

The first meeting consisted of the introduction of the robot to the class, through the pretense of the story. In this occasion children were asked to analyse together the robot for understanding its abilities. To do so, a set of materials were provided.

The set was composed by:
- An analysis form for each child;
- A yellow magnifying glass;
- A set of coloured cards;
- Sheets of paper;
- Coloured pencils and markers.

The analysis form was composed by four main sections: test of voice recognition, analytical observation, analysis of small components, test of colour recognition. In each section were listed a series of simple actions and questions for guiding children in the analysis.
This was designed combining the aim of promoting children's reasoning with the willingness of evaluating the robot according to common aspects, namely *"anthropomorphism, animacy, likeability, perceived intelligence and perceived safety"* (Bartneck et al., 2009). By following the form, children were able to find out the main features of the robot, that are the ability of perceiving sounds and colours, and the fact that colours are associated with memories, expressed through soundtracks.
This analytical phase was accompanied by a sort of brainstorming in which children started to make hypotheses about the robot functioning and how and why it ended up in front of the school. After that, children were asked to work in groups, each of which focused on a colour and the related soundtrack, for developing together hypotheses on which places the robot visited. These hypotheses were formulated in the form of drawings that children shared and discussed together.
In this occasion, children decided also to give a name to the robot, so Shybo V.2 was named "Pinocchietto", because of its aesthetics that reminds Pinocchio to children.

Day 2

In the second meeting the robot was brought back to the class, saying to children that the experts performed other analysis in their lab and that they found out further functionalities of the robot and pictures in its memory.

Fig. 6.25 - Day 3, a group of children is exploring the neighbourhood through Google Street View.

Fig. 6.26 - Day 3, a child is marking a point visited by the robot in the map.

In this occasion, a series of different materials were prepared:
- A set of musical instruments;
- A board game, specifically designed to replicate the "brain" of the robot;
- A multimedia interactive whiteboard (property of the school).

The data contained in the robot memory were extracted and presented to children through a computer. The pictures, contained in a folder named "journeys" and sub-folders with strange names, were all mixed with no logic. Thus, children were asked to help the robot to make some order in its memories. To do so, the soundtracks associated to colours were listened again and the peculiar sounds were isolated and described. Then, through a series of musical instruments associated for the similarity of the sounds, children made the robot listen again the sounds for letting him remember the places he visited and for reorganizing its memory. This phase was carried out by switching the robot in the "sound-training mode" in which it is possible to associate a certain sound to one of the five colour categories that the robot may show. Thus, group by group, children trained the robot to associate the sound of a musical instrument to a certain colour, referring to the soundtrack that were in the robot's memory.
The actual rearrangement of the files in the robot's memory folder was done secretly by the educator, but children had the impression that their training through musical instruments was actually affecting the organization of the data. In addition, the name of the files and folders were used to create a board game though which children, on the one hand, were introduced to some fundamental concepts of informatics, and, on the other hand, collected a series of paper folders with file names inside.
In this way, children had the chance to find out the

names of the streets that the robot visited and that were associated with the soundtracks that they found in the first meeting. The names of the streets and the pictures were then discussed together for focalizing the places that were explored by the robot.

Day 3

In the last meeting, children were invited to reflect again on the information that they discovered in the previous meetings. In particular, the names of the streets were used to search on Google Maps the locations that the robot explored. In addition, through the Street View mode, children were able to compare the pictures that they found in the robot memory, with the actual pictures of the streets, and to understand why the robot memorized certain sounds in relation to those places.

For each place recognized, children were invited to put a mark on a map of the neighbourhood, printed for this activity. After the all five areas of the robot journey were identified, children were invited to look around the neighbourhood, on the map, and to elaborate hypotheses about where the robot was coming from.

After little discussions, children agreed that the robot was probably coming from the Politecnico di Torino, and started to suggest strategies for bringing it home, such as sending an email, going there by walking, or making a phone call. The last option was chosen, and two children were invited to call a person at the university.

Another researcher, who was informed and prepared for the activity, answered to the phone call and confirmed to children that he lost a robot few weeks before. Thus, he said to children that he was going to their school for taking him back.

When the researcher arrived children told him “what happened” and how they found out that he was coming from the university. Then the researcher explained that he comes from a lab in which he and other researchers study and design robots. Then, he did a small lesson about robotics from pop culture to real applications, by actively involving children through a continuous debate.

This final meeting was meant to let children explore physically the neighbourhood and to visit the Politecnico di Torino, with the excuse of bringing the robot home. However, due to adverse weather conditions, this activity was rearranged in the class.

6.7.5 Evaluation

The evaluation of the pilot experience consisted of different methods, namely observation, group interviews, and *Assessing through Pretense* (AtP).

All the three methods were aimed at evaluating both the robot and the experience, with the intent of addressing both aspects regarding the purpose of the project and its features.

The observation was based on the video recordings of the experience, with a particular focus on the first two meetings. As done in the first test in China, the video recordings were coded with the aim of understanding the ability of the robot, and of the related experience, to engage and foster arousal.

The interviews, instead, were carried out with groups of four children and consisted in two main questions: *(Q1) what did you like the most about this experience? (Q2) What would you like to do with the robot if there is a chance to have it again the class?*

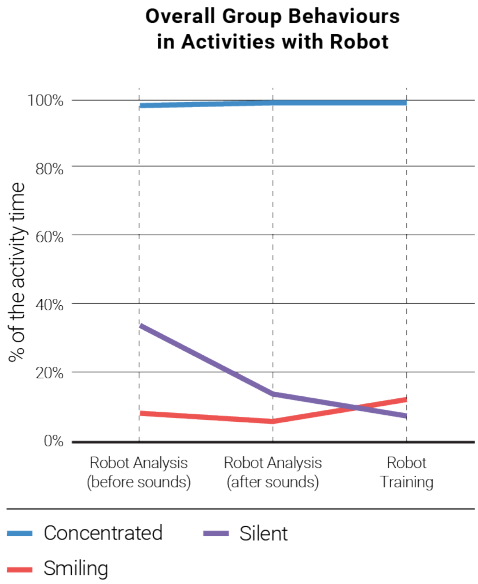
The *Assessing through Pretense*, instead, consisted of a method specifically designed for this experience. This was developed for addressing the need for an evaluation method different from the ones commonly used with adults. In fact, testing with children and evaluating robots according to metrics commonly used in the HRI field is often a challenging task. Developmental factors, such as language ability or temperament, can greatly affect the way children understand, interpret and answer to the questions (Read and McFarlane, 2006).

Thus, most of the evaluation methods that consist of self-reported data, in the form of questionnaires and interviews, result inappropriate. For instance, a widely used tool for evaluating robots in HRI is the *Godspeed questionnaires* series (Bartneck et al., 2009). In the previous test, this issue was addressed by elaborating a figure-based version of the questionnaire, a strategy adopted by many authors (Maćkiewicz and Cieciuch, 2016; Valla et al., 1994; Harter and Pike, 1984). This solution, however, resulted inefficient and the results were null. As a matter of fact, the concepts evaluated through the *Godspeed questionnaires*, related to animacy, anthropomorphism, likeability, perceived intelligence and perceived safety, are too difficult

for being directly rated by children. Thus, an alternative method was elaborated, with the intent of avoiding the methods that ask for self-reported data. The proposed method consists of taking advantage of the activity's storytelling for involving children as "researchers". Thus, with the pretense of understanding where the robot comes from and how it works, children are asked to observe and discuss about the robot. This analysis is guided by the activity conductors and an "analysis form" in which are suggested some actions and, above all, a series of simple questions, that can lead children to talk about aspects that refer to the concepts of common evaluations in HRI.
This kind of playful approach for conducting activities with children is not a novelty.
Narrative methods, in fact, are one of the main type of techniques that can be adopted in child-computer interaction for uncovering children views and for encouraging verablization of thoughts as a way to envision and articulate future possibilities in different contexts (Giaccardi et al., 2012).
Among narrative techniques, the use of storytelling supported by visual representations, materials crafted by children and physical acting, is an effective approach to leverage the natural children playfulness and imagination. Examples of different activities and methods designed around storytelling can be found in (Wright, 2007; Dindler et al., 2005; Benton et al., 2014).

Observation

The video recordings of the first two meetings were manually coded using Boris (Friard and Gamba, 2016), as in the first test. To do so, two main categories of behaviours were identified: overall group behaviours, and temporary individual or small group behaviours.
The overall group behaviours category included three main children's states: concentrated, silence, and smiling. The temporary individual or small group behaviours, instead, included laughing, wow, jumping and excited movements, and volunteering. As volunteering, in this case, is intended the gesture of rising the hand and asking the permission for talking or performing an action.
Surprisingly, all the reported behaviours resulted to have a positive valence. In fact, the list of observable behaviours was initially more extensive, including behaviours with a negative valence, such as bored, distracted, worried, and sad. These behaviours, however, have not occurred during the activities.
Given the primary interest on the robot and its role in the activities, the analysis of the data was focused on the parts of the experience that required the active presence of the robot. Accordingly, the results, showed in tables 6.8- 6.11, focus on three main phases of the activity: the analysis of the robot before discovering its sound memories, the analysis of the robot after discovering the sounds, and the training of the robot. Nevertheless, two other significant phases were reported to compare the trend of the behaviours, that are: recognizing similar sounds, and playing the game with rules.
As shown in table 6.8, children appeared totally concentrated on the activity for the whole time, both with or without the robot. No distracted behaviours were noticed, as it would be children moving around, children making noise and disturbing the activity. In some moments, children were actually making noise, but it was because of the activity, for instance, when they were playing the game they were inciting each other and screaming for the excitement.
The concentration on the activity was reinforced, in some parts of the experience, by the fact that children were making silence to pay attention. In particular, the first phase of analysis of the robot was characterised by children making silence for more than 30% of time. They were paying attention to explanations and observing who was doing the actions with the robot. Less silence was observed during the analysis of the robot and during the training. In these two phases in fact, children were constantly debating about the robot's abilities. Especially during the training, children were actually making silence when someone was recording a sound, while the rest of time they were commenting the robot's behaviours and playing the instruments.
However, by looking at the other activities without the robot, children resulted even more quiet. The silence during the activity regarding recognizing sounds was about 60%, which increased up to 80% when playing the game. These two activities, in fact, required children to reflect on sounds and to listen carefully the explanations of the educator. Especially regarding the game, children resulted really silent because of the initial difficulty in



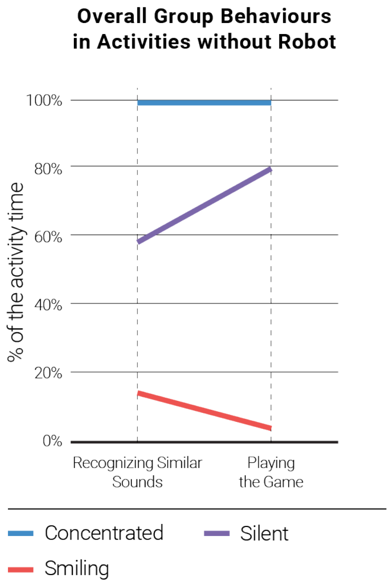
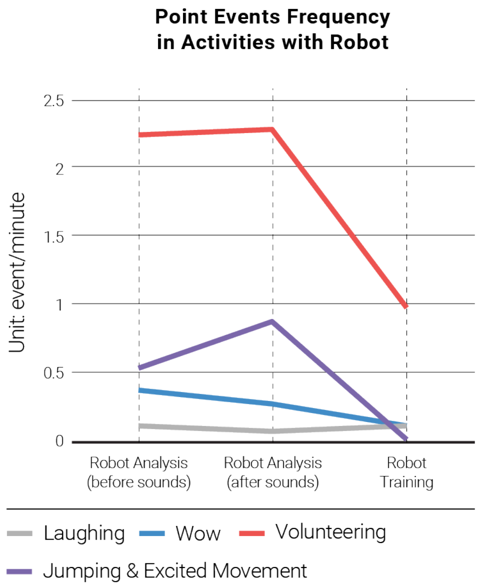


Table 6.8 - Overall group behaviours in activities with the robot.

Table 6.9 - Overall group behaviours in activities without the robot.



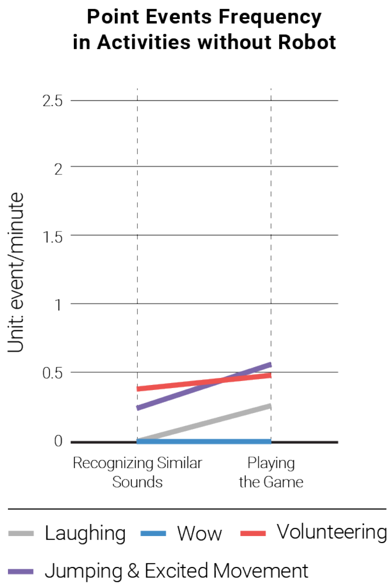


Table 6.10 - Point events frequency in activities with the robot.

Table 6.11 - Point events frequency in activities without the robot.

understanding the game rules. Nevertheless, after playing for a while and getting confident with the game rules, children started to get excited and making noise.

The fact that children were less silent during the activities with the robot is probably due to the fact that once they noticed a feature of the robot, they were all willing to tell their interpretation, showing also an impatient behaviour.

A third aspect illustrated in table 6.8 and 6.9 is the smiling behaviour. Both in the activities with and without the robot, the group appeared rarely smiling. During the two phases of analysis of the robot, the percentage of smiling time was about 10%, while a small increase was noticed in the training phase. The activities without the robot presented a similar trend, and the smiling time was even decreasing during the game. This might seem a negative feedback about the activities, and especially about the game. Nevertheless, the fact that no signs of distraction were noticed, and the comments of children during the interview (described in the following paragraph) revealed that they were immersed in the activity paying serious attention to what was happening.

Regarding the temporary individual or small group behaviours, shown in table 6.10 and 6.11, the trend of one behaviour catches the eye, namely

volunteering. During the activities with the robot, in fact, this behaviour was noticed with a considerable higher frequency. Especially in the two phases of the robot analysis, a mean of more than two children volunteering every minutes was noticed. In the case of the other activities without the robot, instead, the mean of volunteering was slightly under 0.5 for minute. This reaffirm the different characterization of the activities with or without the robot. The firsts, in fact, were characterised by a continuous debate and children desire to express their interpretations and stories. The others, instead, were more dedicated to listening and understanding.
Another behaviour that revealed interesting trends is the jumping and excited movements. Children, in fact, were showing excited behaviours around one time every two minutes, in the first phase, when they did know anything about the robot yet. By discovering some of the robot behaviours, in particular the sounds, children became more excited, showing this behaviour every minute. During the training instead, no excited behaviours were noticed. This was probably due to the high level of concentration required and the fact that children were asked to make a precise sequence of actions. In the case of activities without the robot, instead, the excited behaviours increased from around one every four minutes, to slightly more than one every two minutes. In particular, in the final part of the game, children appeared really excited.
A different sign of excitement is the surprise expression "*wow*". This behaviour was noticed only in the activities with the robot and it was particularly associated with the discovery of new robot behaviours, such as lighting up in different colours, getting scared, playing soundtracks and moving around.
This expression of surprise was usually accompanied by children describing the behaviour of the robot like "*it moved!!*", as to implicitly ask to the others if they too had seen it.
Finally, another behaviour that reveals the enjoyment of the activity was laughing. Nevertheless, this behaviour did not seem to occur frequently. During the two phases of analysis of the robot and the training, in fact, children were laughing around once every five minutes. Also during the activity about the sounds, children were not laughing. This behaviour occurred a little more frequently during the game, especially in the last part.
This low level of laughing, together with the little percentage of smiling, may be considered a negative result since it may be associated with a low level of enjoyment. However, the answers to the small interviews revealed the opposite.

Interviews

The interviews were performed in groups of four children, that corresponded to the groups that during the activities were working together on the memories associated with a certain colour.
The answers about the first question, namely what they liked about the activity, were all very positive. Nevertheless, some children were more specific, while some other said just that they liked everything. As shown in table 6.12, in fact, half of children stated that they liked everything.
Regarding the more specific answers, children mentioned some recurring aspects that they liked. For instance, some of them mentioned that they liked to find the robot home, where he came from. Other said that they liked to meet the robot, in general.
Some other children said that they liked the activity because they had fun. Another recurring answer, was that children liked to meet the team of the project. However, these statements came from children of the same group, thus it is probable that the statement of the first influenced the others.
Three children mentioned that they liked to play the game with rules, and a couple specified the aspect of finding the memories of the robot.
A series of other aspects were mentioned only once, but these can also be traced to some parts of the activities. For instance, one said that she liked to play sounds for helping the robot with the colours, and another said that enjoyed to play together. These two, together with the ones that liked the game, point out the positive perception of the experience as playful.
Another child mentioned that he liked to find the owner of the robot, while another said that he enjoyed to find the spots on the map. These, together with the ones that liked to find the house of the robot, highlighted the positive perception and the effectiveness of the story designed for the activity. Then, a girl pointed out the movements

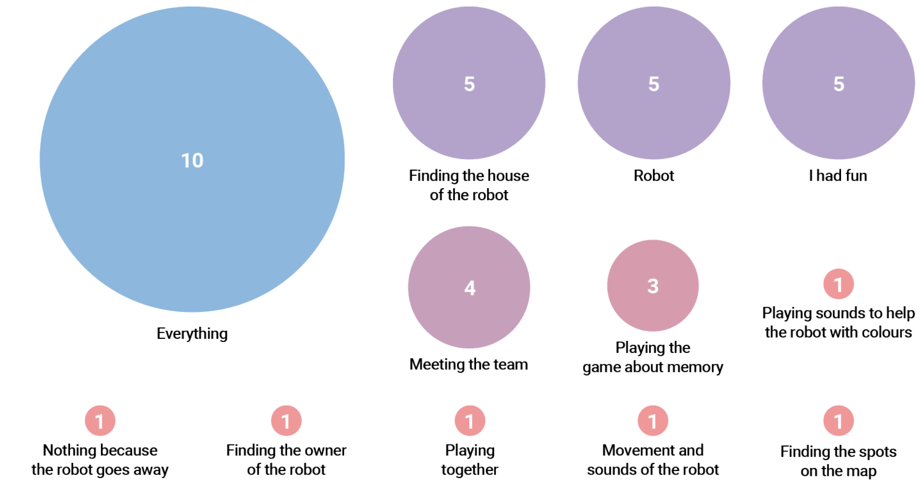


Table 6.12 - Comments of children regarding the aspects that they appreciated of the experience.

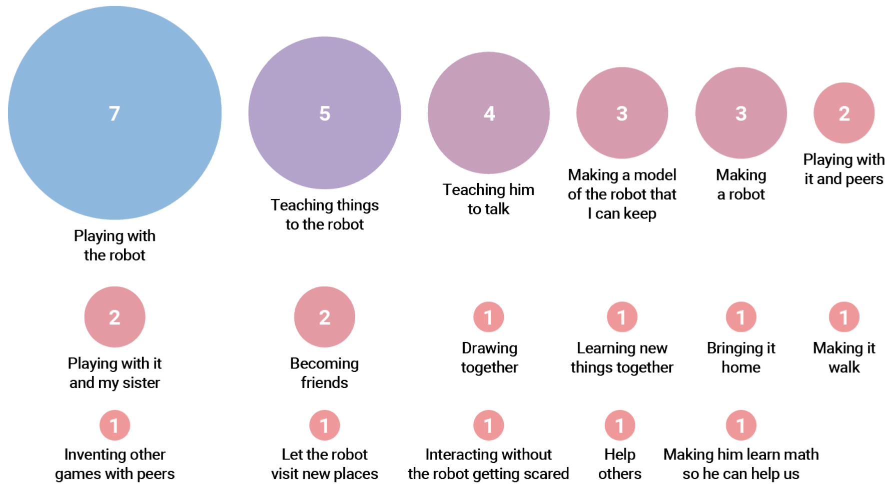


Table 6.13 - Comments of children regarding the things that they would like to do with the robot if there was a chance.

and sounds of the robot as aspects that she liked. This reaffirms that the robot was appreciated by children. Furthermore, positive relationship of children with the robot was reaffirmed by a controversial answer that a child gave.

A boy, in fact, stated that he didn't like anything about the activities. but when he was asked why, he said that it is because now that they helped the robot to find his home, his owner is going to bring him away. So the interviewer asked to the group if they had become attached to the robot, and they promptly answered all together *"yeeeees"*.

This connection with the robot was reaffirmed by the answers of the second question, about what they would like to do with the robot if they had the chance to have it in class again.

Three children, in fact, stated that they would like to make a model, like a copy, of him, so that they can keep it. A couple of children, stated also that they would like to be friend with it.

Other answers, instead, revealed that children would like to have an active engagement with the robot. On the one hand, three children stated that they would like to make a robot. On the other hand, many children said that they would like to teach him many things, five said so in general, while four specified that they would like to teach him to talk, and another child said that he would like him to learn math so that he can help them. The role of robot as a potential helper was reaffirmed also by another child who said that he would like to use it to help others.

Nevertheless, the majority of children referred to it as a companion with which they would like to play (stated by 11), together they could draw (1) or learn new things (1). A child also stated that he would like to show and let him explore new places.

It is interesting to notice that some children

specifically pointed out that they would like to interact with the robot with peers, and in two cases with the sister. This point out the children desire for activities with the robot to be social experiences.
Finally, some children pointed out features that they would like in the robot. For instance, a boy said that he would like him to have legs and be able to walk very well, and a girl said that she would like to interact with the robot without it getting scared.

Assessing through pretense

The form provided to children allowed to discuss with children various aspects of the robot that can give as an understanding how it is perceived by children in terms of animacy, anthropomorphism, likeability, intelligence, and safety.
Especially regarding animacy, the discussion revealed how children were strongly perceiving the robot as animated, pointing out its ability to remember, move autonomously, interact and get scared. At the beginning of the analysis, when children tried to talk to the robot and he got scared, the whole group started to repeat *"It is scared! It is scared!"* and one child explained that *"we're hurting its ears!"*. With this expression, the child attributed to the robot a feature of a living thing.
In the following parts of the analysis, children started to make hypotheses about the robot functioning, such as a girl who said *"we applauded and the robot understood that and then repeated the sound"*. A boy, instead, said *"in my opinion, the colours remember to the robot the places he visited"*, and this ability was reaffirmed by the comments of other children.
These statements reveal how children perceived the robot as animated and with the ability of performing autonomous actions, such as visiting places, but also to understand what happens around him. This introduced the aspect of perceived intelligence. In addition to saying that the robot can understand certain things and remember, when children were asked *"does it understand what we tell to it?"* they all said, promptly and firmly, *"yes!"*. And then, when the teacher asked to children if the robot is intelligent, they all said yes again. Then they kept discussing his abilities, making hypothesis about his cognitive abilities, as depending on *"a keyword to activate its behaviours"*, *"a different context that it doesn't recognize"*, and *"preferences about certain colours"*.
Connected to the aspects of animacy and intelligence, is the perceived safety. By discussing the behaviours that make the robot animated, in fact, children pointed out that the robot is not at all hostile, rather timorous and shy, and a girl said that it is maybe because *"it doesn't know us yet"*.
Then, by discussing the robot appearance, children affirmed that it is artificial, because it is made by humans, it is made of plastic, and it needs a battery to work. Nevertheless, they all affirmed also that it is in between a machine and a living thing. This topic was particularly complex to discuss and children were having doubts when formulating their thoughts. A boy, for instance, said that *"it is not a living thing because it has no heart, but it can perceive feelings even without a heart"*. The presence of feelings in the interaction with the robot was reaffirmed by a girl who stated that *"when we went to talk with it, it got scared, and then when Micol was talking about him it moved... maybe it has a bit of feelings"*.
A girl, instead, focusing on the morphology, said that *"it looks like a mushroom, and the mushroom is natural, so maybe it is an artificial thing with a natural appearance"*. Thus, according to children, the robot presents some level of biological appearance.
Regarding likeability, instead, few explicit comments revealed the attractiveness of the robot. In particular, a girl stated that it *"looks like a very nice little mushroom"*. Although the other did not express explicit compliments about the robot, a positive attitude was recognizable in the delicate way they were approaching the robot and in the similarities that they pointed out. In fact, during the analysis children were asked to say what the robot look like. The comments were various, like *"Pinocchio"*, a small car, a little train, a snow man, and a mushroom. Then, children asked what is the name of the robot and, given the story, the conductors of the activity said that they didn't know it. Thus, children decided all together to give it a name: *"Pinocchietto"*.
This activity revealed, then, how even the simple behaviours of the robot were effective for conveying not only animacy, but also intelligence, which was unexpected.
The children propensity to comply with the pretense

was also stronger than expected, and allowed to easily keep consistency in the storytelling through out the whole activity. In fact, even when the robot was malfunctioning, the pretence was simply adapted and remained consistent enough to let the activity going, without engagement and credibility issues.

Nevertheless, it has to be noted that this approach to testing with children may not be appropriate for all kind of robots. in this case, in fact, the story was used primary for constructing the didactic activity, and then used also as a strategy for getting children opinions about the robot. Using the same strategy in activities that do not already imply the use of stories may bias the robot perception.

6.9 Reflections and following work

The second phase of the project is still ongoing, nevertheless, the pilot experience allowed to get some insights and validation of both the robot and the experience.

Regarding the purpose, the initial idea of "*letting children play, with the physical environment, through a robot*" evolved toward a closer relationship with the educational environment. The parent's concerns about letting children attend a playful learning activity with this kind of robot instead of a class was answered through the collaboration with the educator.

From the collaboration emerged the interest and desire of the educator toward using and taking advantage of the robot in the construction of playful learning activities connected with the school curricula, making the educational outcomes explicit.

The robot, hence, becomes a tool for supporting children exploration of concepts from various disciplines, such as art, music, geography, and informatics. A formal validation of such a purpose, however, hasn't been carried out yet.Nevertheless, two key facts can be considered as implicit forms of validation of the project. On the one hand, the project was submitted to a call for a national award about innovative projects for education called "*Up4School*", and the project was selected among the ten finalists, out of more than hundred submissions. On the other hand, the teacher involved in the pilot experience expressed the interest to replicate the activity with other classes, and reported a school interest to introduce it in the three-year plan of the educational offer of the school. Although this is still an option that need sto be discussed, the interest in adopting it as an actual educational module for school reveals that the project achieved its goal.

Regarding the features of the robot, the pilot experience revealed the efficacy of the design choices made during the project and positive feedbacks about the whole experience.

However, some malfunctioning emerged during the activities, such as the robot getting scared when he was not supposed to do that.

The negative effect of this issue was also noted in some comments of children, during the interviews. A girl, for instance, said that she would like to interact more with the robot without it getting scared all the time.

Nevertheless, the comments of children were all very positive toward the robot, and they were expressing forms of affection toward it, starting with the fact that they were not referring to it as a robot, rather always calling it "Pinocchietto". Furthermore, a child, when he understood that the robot was going back to the university, cried because was sorry that it was going away. The same sad feeling was noticed in the comments of other children. One said that he was sad that it was going away, and others said that would like to build another to keep it.

This aspect introduced also a confirmation of the validity of the potential use of the robot as a platform for conducting different kinds of activities. Children, in fact, manifested a strong interest in teaching it new things and playing together. This aspect confirms its potential suitability for supporting various playful learning scenarios, with different degrees of complexity, that can be created by combining in a different way the robot's abilities. Thus, by looking at the robot as a platform for supporting several activities with a growing level of complexity, the pilot experience can be considered the introductory module.

Future work, then, will focus on defining possible playful learning scenarios and on testing them.

Chapter 7

Research Outcomes

The reflection on the developed projects and existing theories was identified, in the RtD literature, as a crucial phase of practice-based design research. Thus, the knowledge produced in the design explorations and the background research was used to reflect and define the outcomes of the research, that can be summarized in three levels of contribution: artefact, knowledge and theory.
The artefact level corresponds to the situated implementations developed through the projects. In order to be relevant for contributing to the discipline, each phase of the implementations was documented and reported in detail.
The knowledge level consists of a set of actionable principles, emerged from the results and lessons learned from the projects. These are described through their motivation and their possible impact on the design process.
Finally, at the theory level, a theoretical framework was proposed as a result of the research that may inform about the implications of designing for child-robot play and be used as a reference for the actual development of projects.

7.1 The outcomes of a Research through Design process

This research started with the intent of answering to two main questions, namely: *what is (or can be) the role of design research in HRI? How to design acceptable and desirable child-robot play applications?*
To do so, the background research, including a literature review and a scenario analysis, was combined with the development of two research projects, which were carried out adopting a Research through Design approach. Applied research, in fact, is critical to advance the understanding of design, since it seeks to establish connections among many individual cases (Buchanan, 2001).
Both the projects resulted in experimental applications carried out in a real context and the artefact and its related experience, assumed a central role.
Thus, a primary outcome of this research corresponds to these situated implementations, that are: a mixed-reality platform for playing with commercial robots, and two versions of a minimal robot for playful learning activities.
However, although artefacts, in RtD, are of fundamental importance, it has to be noted that *"to qualify the work of the design practice as research, there must be a reflection by the practitioners on the work, and communication of some reusable results from that reflection"* (Cross, 1999).
On the one hand, in fact, artefacts embody implicit theories, as explained by Gaver (2012) who affirmed that *"design examples are indispensable to design theory because artefacts embody the myriad design choices made by their designers with a definiteness and level of detail that would be difficult or impossible to attain in a written account"*. The author explained also that these implicit theories range from philosophical, to the functional, to the social, and to the aesthetic. Nevertheless, as pointed out by the author, design theory is not automatically encoded in the artefacts.
What makes design examples important for design theories, in fact, is that *"they make it possible for different researchers and groups of the design community to examine each other work and test out each other's theories by extending, copying, or testing individual efforts"* (Zimmerman et al., 2010). Thus, design examples are crucial for constructing theories, since they enable a reflective practice.
This central role of reflection was also pointed out by Zimmerman and Forlizzi (2014) who suggested it as one of the five steps for carrying out RtD. The authors highlighted also the fact that there is a precise distinction between RtD and design practice, and it is represented by the intention of the first of producing new and valuable knowledge. They also pointed out four main types of contribution that RtD can bring to HCI related disciplines, that are: producing technical opportunities that can feed the work of engineers, pointing out gaps in current behavioural theory, generating new situations that can be object of new studies by anthropologists and design researchers, and revealing design patterns.
Zimmerman and Forlizzi (2014), however, did not provide a focus on the contributions for the design discipline, especially regarding theory construction. A detailed analysis of that, instead, was provided by Gaver (2012), who pointed out four main types of theory. The first consists of *implicit theories* embodied in the artefacts that are recognized as such if described together with conceptual statements, articulated in general terms, and applied to multiple examples. A second type consists of *borrowed theories*, namely the ones that are used to inspire new designs and to articulate existing ones. A third type is *manifestos*, which is a form of theory that goes beyond theoretical reflections and suggests approaches to design. Finally, theory can be found in the form of *frameworks*, which are somehow similar to manifestos but differ in the level of normative stance. As explained by the author, in fact, *"frameworks are intended to allow flexible, design-centred research planning and opportunity seeking, and avoid prescribing appropriate methods"*.
Given the importance of both reporting design examples and abstracting them at a theory level, a further description of the possible outcomes of design research was found useful to guide the formulation of this research outputs. Although it is specifically referred to the Technology of Information System, Purao (2002) suggested that the outputs of a design research can be grouped in three main levels of contributions: artefact,

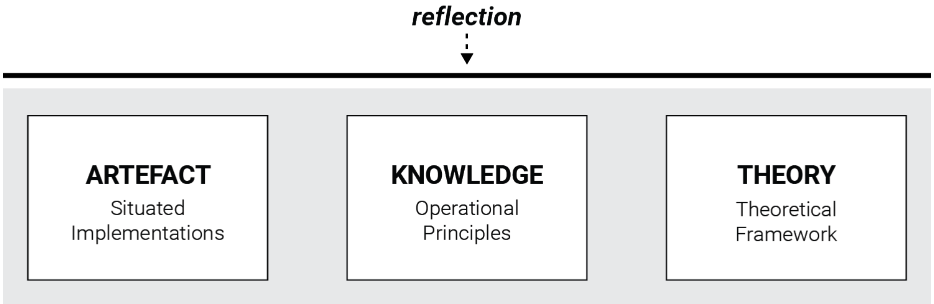


Fig. 7.1 - The outcomes of the research resulting from the reflective phase.

knowledge, and theory.
According to the author, the artefact level, consisting of situated implementations, is the most visible output of the research, but also the least important. The second level is the one of the knowledge and it includes operational principles, whose intention is to prescribe a desired approach to addressing a class of design situations. The theory, then, consists of a narrowed view of specific aspects of the phenomenon addressed, that is embedded in the artefact.
Referring to this categorization by Purao (2002), and the contributions of the authors mentioned earlier, the two case studies were documented and analysed in the attempt of constructing sharable knowledge consisting of situated implementations at the artefact level, operational principle at the knowledge level, and on a theoretical framework at the theory level.

7.1.1 Situated implementations

The level of the artefact, that includes the situated implementations developed during the research, was reported in chapter 5 and 6, with the intent of providing implicit theories. These were reported referring to the statements by Zimmerman et al. (2010), who explained that there is need for more rigorous documentation of progress and evolution of RtD projects, which should be covering the whole process from problem framing and the idealized preferred state to the final outcome.
Accordingly, the two projects, Phygital Play and Shybo, were documented and described paying particular attention to the explanation of the theme and purpose, and on how these were investigated through preliminary studies for informing the following work.

In addition, as suggested by Zimmerman and Forlizzi (2014), the reflective practice included also the dissemination of the work trough conference articles and journal articles, each aimed at providing a focus on different aspects of the projects and on sharing the process, so it might be object of critical analysis.
The dissemination occurred also in the forms of demos, in various contexts. The Phygital Play platform, for instance, in addition to the full paper (Lupetti et al., 2015), was presented as a demo at the International Conference on Intelligent Technologies for Interactive Entertainment, in Turin, 2015. The first Shybo prototype, instead, was exhibited at the first Rokers fair, in Turin 2017, and at the Mini Maker fair, in Turin, 2017. The second part of the Shybo project, then, was submitted to the Up4School award, and was selected as finalist.
Furthermore, a more detailed documentation of the artefact was provided for the Shybo prototypes, that were released on Open Science Framework, under a GNU General Public License.
In fact, the release of robotic artefact for HRI studies as open source projects can bring significant benefits. First of all, this approach can result in a reduction of costs. The use of open-source platforms is getting increasingly common in studies that employ robotics hands for leveraging low cost technologies such as 3D printing and open-hardware, e.g. microcontroller-based boards (Bulgarelli et al., 2016). A second benefit consists of the possibility of having full control on the robot's features. As a matter of fact, certain robot's features, such as appearance, locomotion mode, gender, and personality, can greatly affect people feelings and attitude toward a robot (Woods, 2006). A third motivation for employing open-source platforms in HRI is the replicability of studies. Many investigations, in fact, are conducted with custom

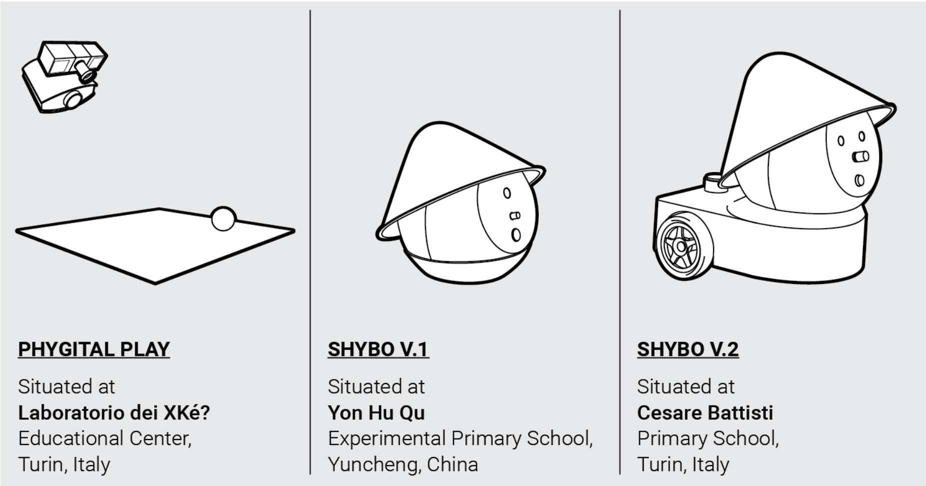


Fig. 7.2 - The situated implementations developed during the research.

hardware, which, in most of cases remains for the exclusive use of the authors. However, as explained by Baxter et al. (2016), the possibility of conducting the same experiment anew is functional for weaving a solid and scientific fabric, but unfortunately there is usually lack of replicability in HRI studies.
Also regarding applications for daily life contexts, such as schools, the adoption of open-source platforms can bring a reduction of costs. Gonzalez-Gomez et al. (2012), for instance, designed 3D printable and open-source mobile robot that can be employed in schools for educational activities, that requires a very limited cost: 57 €. The possibility of reducing costs is particularly relevant in school contexts were the activities are carried out with numerous groups of children and the costs multiply.
A second benefit for educational applications is the possibility of customization. By adopting open-source platforms, in fact, the robot can be potentially modified according to the purposes of the designed experience. For instance, non-verbal behaviors or physical features can be changed to match it with a specific storytelling, enabling stronger connections between the new activities proposed and the existing curricula. Finally, by adopting and releasing open-source platforms, schools and other educational entities might benefit from the increase of educational resources freely available, meeting the philosophy of the open education movement (Atkins et al., 2007).
Due to the strong involvement of the founding company in the development of the project, the Phygital Play platform was not released as an open-source project.

7.1.2 Operational principles

At the knowledge level, a series of fifteen operational principles were formulated by reflecting on the results and the lessons learned of the two projects carried out during this research.
Each principle is introduced through a brief motivation, emerged from the results and the lessons learned from the projects, and from literature. Then, an overview of the impact of each principle on the design process is provided through a figure. This illustrates the process and some example actions through which the principle under consideration might be addressed. These are, hence, described in the text.
The principles, in fact, are aimed at pointing out aspects that might be taken into account when designing child-robot play applications. These refer to different aspects of the projects, from the features of a robot and of the experiences, to preferred methods for evaluation in certain contexts. Some, instead refer to children's and adults' characteristics that should be used to inform the design process, or even be embedded in the design proposals.
It has to be noted that most of principle refer to child-robot play experiences developed as credible applications for real environments, especially educational contexts. This orientation toward considering the situating level of the design process a crucial aspect and the focus on the educational contexts emerged from both the literature review and the projects as relevant and meaningful aspects.

Be the first player

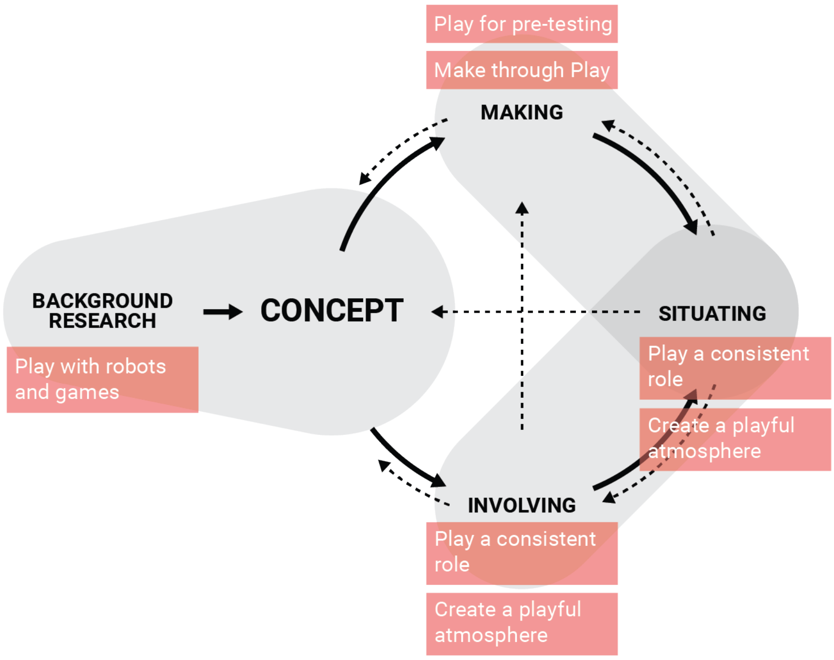


Fig. 7.3 - The impact of the "Be the first player" principle on the design process.

Although this principle might seem banal and obvious, it is rarely taken into account systematically. However, considering the designer as the first player can affect positively the whole design process, from the insight of the background research to the situated implementations.

Background research

Playing with existing robots (according to availability) and with existing games allow to familiarize with the proposed experiences, the logic and strategies, and the materials used. Thus, this practice should be integrated in the analysis of the scenario with the aim of informing and inspiring the design process.

Making

Designing through play means to actively interact with both technology and materials, for experimenting and learning their properties, which potentially allows to develop unconventional solutions.

In the making phase, being the first player means also to be constantly running preliminary testing, which is probably the most practiced action regarding this principle.

Involving and Situating

This principle can affect in a similar way both exploratory studies with potential users as well as the tests with the situated implementations. In this case, being the first player means that the design researcher (if actively involved) can play a role consistent with the activity, rather than being "the researcher".
Strongly related to that is also the aspect of creating a playful atmosphere. When working with children's shyness, fear of failure, and verbalization problems might negatively affect the activities.

Consider difficulty as a design material rather than an issue

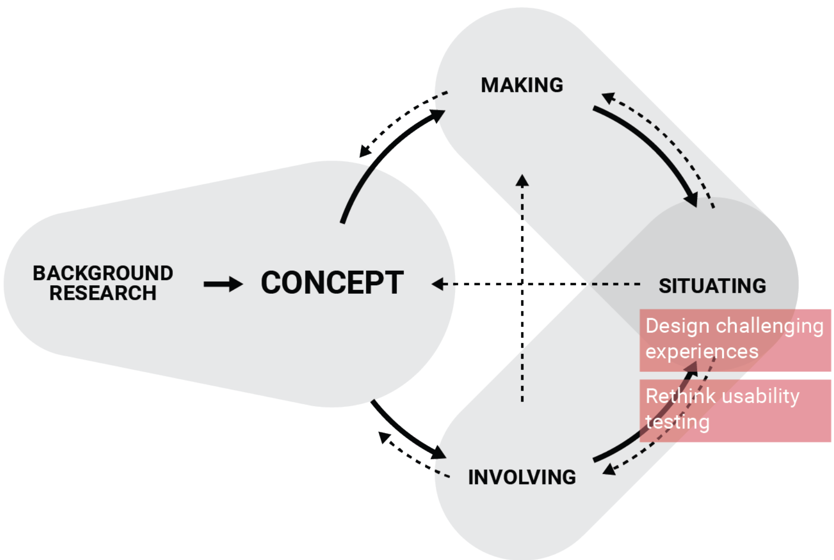


Fig. 7.4 - The impact of the "Consider difficulty as a design material rather than an issue" principle on the design process.

The ease of use is one of the main evaluation criteria in usability testing. However, when designing for children a distinction between the desired difficulty or the one resulting from design issues is required. This affect particularly the situating phase in which both the design of the experience and the evaluation methods need to take into account this distinction.

Situating

On the one hand, some level of difficulty has to be provided for creating a fun and an engaging experience. Challenge, in fact, is deeply connected to enjoyment. Thus, designers should pose challenges to children, who are usually eager to master the activities and show off their abilities. Nevertheless, these have to be carefully designed because if difficulty is not balanced with children ability, it might result in frustrating experiences.

On the other hand, the evaluation methods have to be selected and designed taking into account the distinction between positive and negative difficulty. During observations, for instance children experiencing difficulty can be observed as a unique behaviour but the understanding of its valence ask for observing and confronting the results regarding other behaviours, like concentration and excitement. It is also preferable to intersect the results of different data collection methods, such as interviews and comments transcriptions, so that the observed behaviours can be confirmed, contextualized and motivated with a greater detail.

Get results through implicit methods

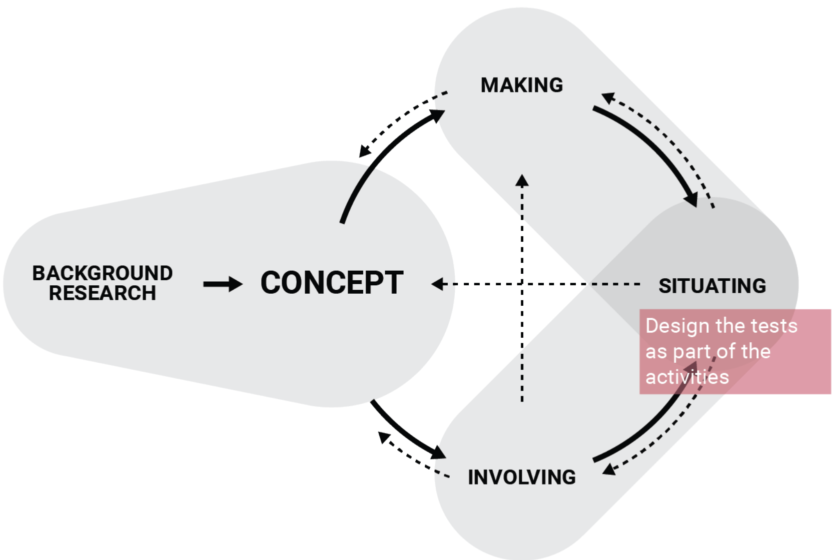


Fig. 7.5 - The impact of the “Get results through implicit methods” principle on the design process.

This principle applies to the collection of data, especially in the case of evaluative studies with situated implementations. It is primarily motivated by the interest toward conducting research with children in real environments, as credible experimental applications. This approach, in fact, imply a series of challenges, among which the inappropriateness of methods that require self-reported data from children. On the one hand, children can be affected by issues like shyness, fear of failure, verbalization difficulties, and influence of peers. On the other hand, explicit data collection methods require to move the focus from the main activity to the evaluation activity.

Situating
A good practice, when possible, consists of video recording the whole experience for subsequent analysis. However, the simple recording may not allow to reach a certain level of detail about the desired information. Thus, specifically designed methods might be employed by adapting the activity so that the intended topics are implicitly addressed. For instance, the introduction of both the robot and the activities might be done through stories, designed so that it provides a consistent motivation for covering evaluative aspects through the main activity.

Be aware of the robot attractiveness

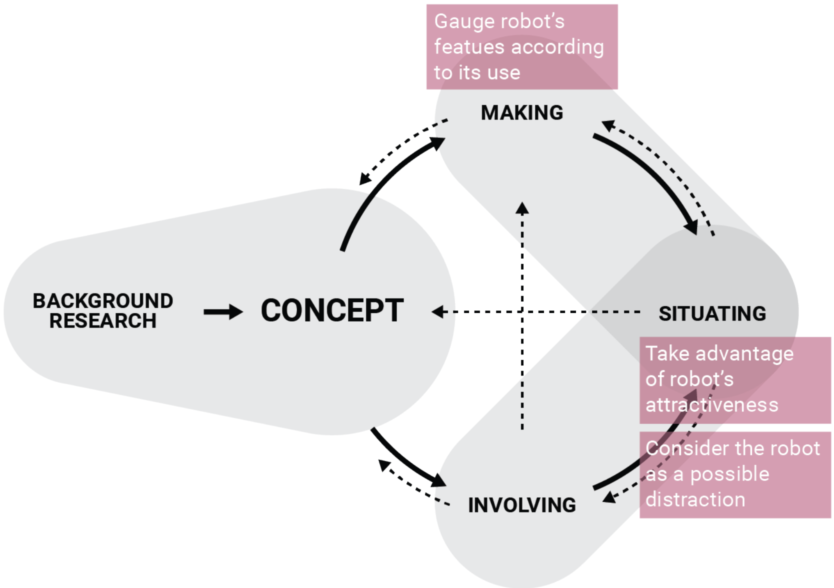


Fig. 7.6 - The impact of the "Be aware of robot attractiveness" principle on the design process.

Robot attractiveness and engaging potential is documented by several studies. However, this potential can have both a positive and a negative effect on the related activities. This depends on the type of activities and on the expected outcomes, but it is still little addressed in many HRI studies, that are largely carried out in lab and focused on assessing specific aspects rather that the role of a robot in a realistic experience. It has to be noted, however, that educational robots, in most of cases, do not present this issue that, instead, is more relevant in the case of robot able to show social cues.

Making
In the making phase, reflecting on attractiveness might affect the actual design of the robot. According to the intended use, in fact, a more minimalistic appearance might be preferred over a more expressive and detailed one. For instance, if the robot has to be used as a tool for a broader experience focused on various topics, a minimalistic appearance might be used for limiting the robot attractiveness and keeping the focus on the overall experience.
On the contrary, if the intended activity is focused on the robot and robotics, a more expressive and detailed design might help to highlight the functional elements as well as the abilities of the robot.

Situating
Regarding the design of the experience, robot attractiveness can be used as a tool for retaining attention. For instance, by allowing a gradual interaction with the robot, such as unlocking features a little at a time or allowing the interaction to one child at the time, attention and desire to participate can not only last, but also increase.
However, a robot might also result too attractive if parts of the activities are not focused on it and especially if children's actions can affect the robot behaviour. In this regards, a good practice is to provide a role for the robot in each activity that has to be carried out after it is introduced to children. Otherwise the robot can be an element of distraction.

Balance realism with research objectives

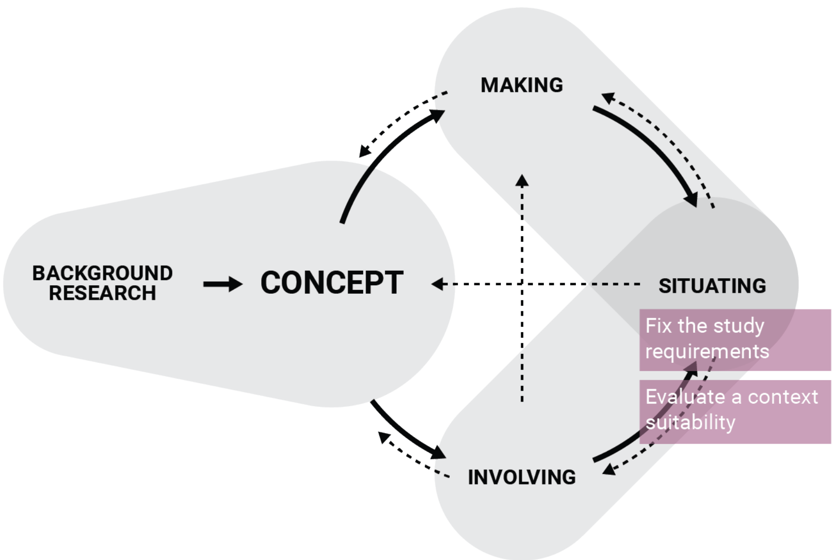


Fig. 7.7 - The impact of the "Balance realism with research objectives" principle on the design process.

Conducting studies in real environments may be beneficial for increasing the ecological validity of a study and it allows to develop projects based on real needs and opportunities. Nevertheless, in wild studies poses a series of challenges and limitations that may interfere with the research objectives. For instance, limitations regarding the possibility of recording the experience exclude the possibility of conducting subsequent analysis that may be crucial because of the nature of the activities, that are developed as credible experimental applications.
It has to be noted, however, that this principle does not apply in the case of predefined context, for instance resulting from an existing collaboration.

Situating
Situating a research project in a certain context needs to be preceded by a careful analysis of the study requirements. It is a good practice to define both fixed and negotiable requirements. These should be used to analytically guide the selection of the context. Very often, in fact, the prestige or the attractiveness of a context may lead to the selection of a context with a low suitability for the study.

Combine robotics with existing materials

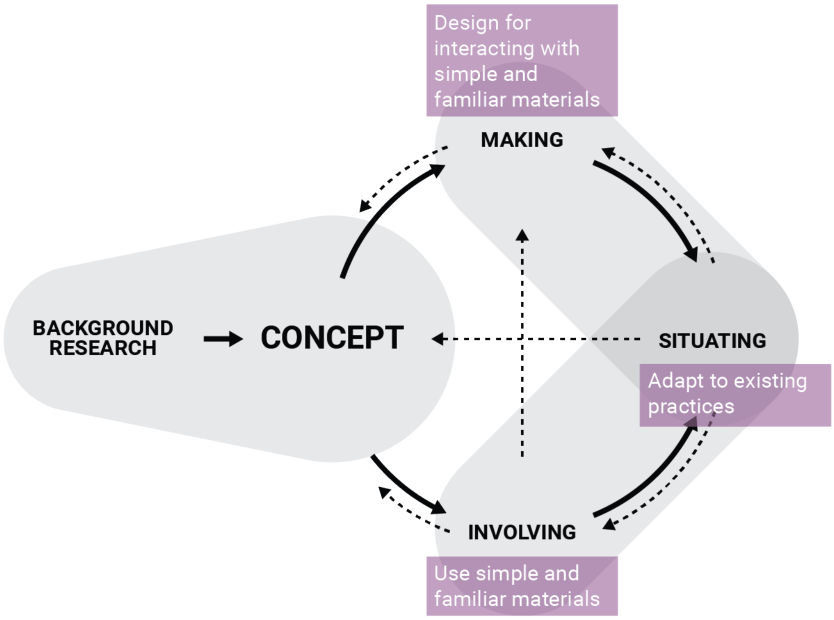


Fig. 7.8 - The impact of the "Combine robotics with existing materials" principle on the design process.

Paper, markers, cardboards, and musical instruments, just to name a few, are materials familiar to children who interact with them on a regular basis. Their use as supplementary materials, in fact, has become popular in activities that imply the use of robots in educational contexts. This allow to take advantage of familiar interaction modalities and to access easily available and versatile materials.

Making
At the making level, designing according to this principle means to include certain abilities into the robot, such as the ability of recognizing colours or perceiving sounds. Or, it can be the ability of following lines which could be combined with children drawings.

Involving
At the involving level, especially when conducting exploratory studies with children, adopting familiar materials facilitate the participants in approaching the activities. In fact, the acknowledgment of the benefits of using existing materials and familiar practices is pointed out by the large number of studies who adopt this approach.

Situating
At the situating level, working with existing materials is a way to adapt and integrate the proposed experience with the existing practices, increasing its compatibility. It also facilitates both children and educators who can combine the novel type of interaction with the ones that are already mastered.

Prepare backup strategies

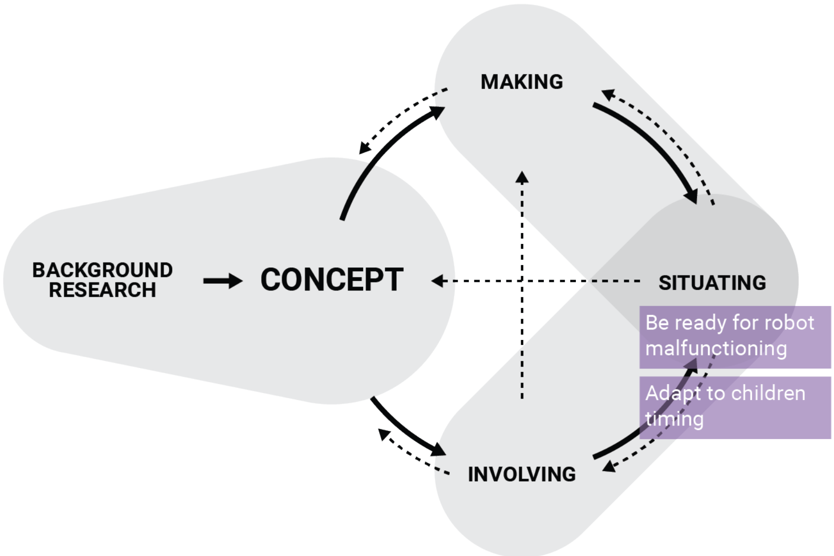


Fig. 7.9 - The impact of the “Prepare backup strategies” principle on the design process.

This principle refers both to the possible occurrence of malfunctioning of the robot and on the difficulty of precisely predicting children’s abilities. Carrying out studies as situated implementations in real contexts, with little level of control on the situational variables, is challenging. In particular, the robotic artefact is asked to work for an extended amount of time and with groups. Thus, if a malfunctioning occurs, the whole experience risks to fail. Thus, the robot has to be very robust and it has to be verified through several preliminary testing sessions. Nevertheless, in the case of prototypes, and especially in project developed in a limited amount of time, issues during the tests can occur.
Regarding children’s abilities, instead, there is the possibility that, even if the designed activity is generally appropriate and suitable, the individual differences of each child may lead to an increase of the amount of time required, or the activity focus may be deviated toward an unintended direction. Thus, both possible robot malfunctioning and children individual differences point out the need for preparing backup strategies.

Situating
Two main implications of this principle can be identified at the situating level. On the one hand, it is necessary to be ready for robot malfunctioning and this eventuality might be introduced as a consistent part of the storytelling, or by preparing consistent explanations.
On the other hand, a good practice is to take into account the need for adapting to children’s timing and to prepare the activity accordingly. For instance, the activities might be designed as modular, namely composed by smaller units that can be added or removed easily during the experience.

Take advantage of stories as strategies

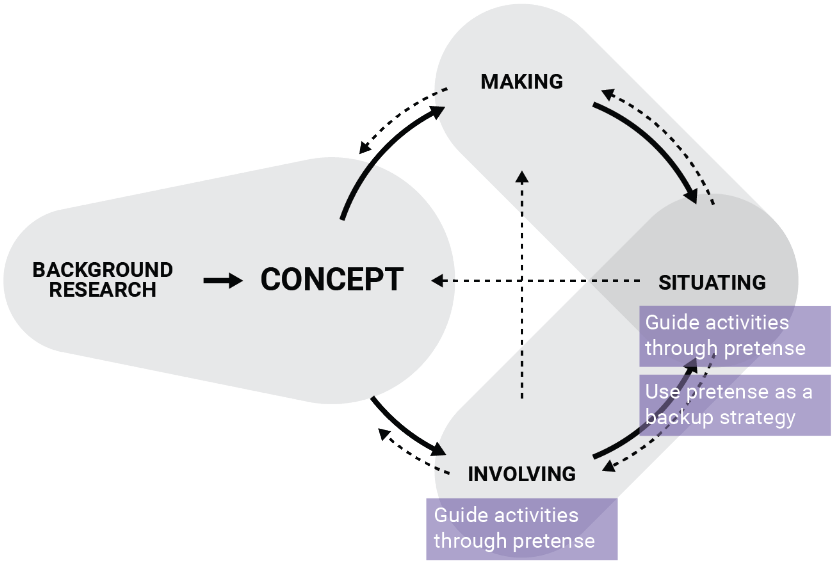


Fig. 7.10 - The impact of the "Take advantage of stories as strategies" principle on the design process.

Introducing and conducting activities with children, especially if related to robots, involve the preparation of a specific storytelling and related strategies. Depending on the focus of the activities, in fact, a robot might be introduced as a tool or a character, as well as its behaviours and functioning might be explained through a story rather that a procedure.

Involving and Situating

This principle affects the levels of the projects that imply the participation of children, namely the involving and situating levels. In both cases, a pretense might be used to provide a motivation and a context to children, regarding the introduced artefact. It can be used as a fil rouge to which the contents of the experience connect. Furthermore, in the pretence, a role might also be attributed to children, who, in this way, get motivation and commitment toward the activity.

Related to the situating level, is also the use of pretense as a backup strategy. A robot malfunctioning, for instance, might be justified through the story. Another example might be the use of a robot personality trait to obtain a behaviour from children, introduced through the story and manifested by its behaviours. For instance, a robot behaviour consisting on getting scared when there is too much noise might be used as a way to keep quite during the activities.

Design approaches rather than solutions

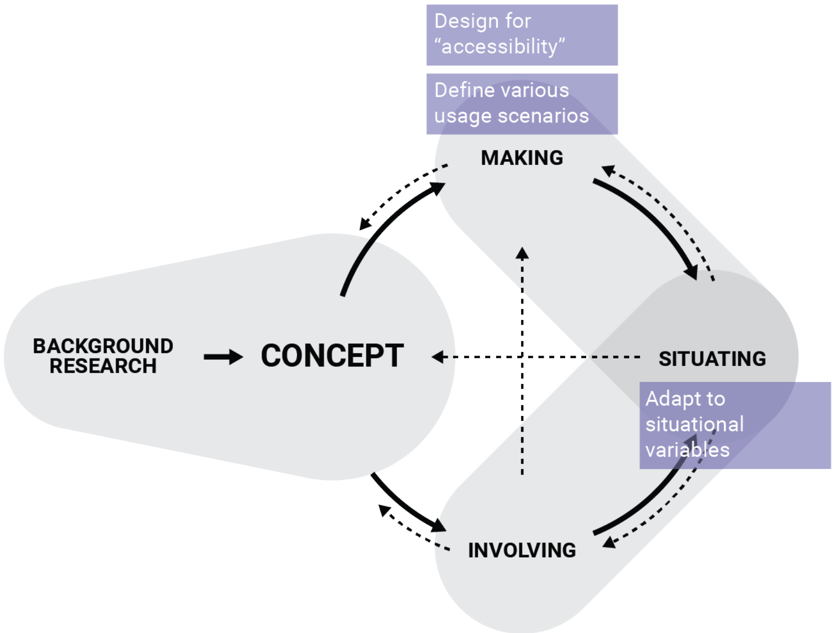


Fig. 7.11 - The impact of the "Design approaches rather than solutions" principle on the design process.

The design of child-robot play as credible experimental applications asks for understanding both the edutainment robots and the educational scenarios. In both cases, it appears evident diversity of the experiences that are developed over time, that includes both different types of interactions and materials. A high level of adaptability and versatility, hence, is required to the designed artefacts, and it can be achieved by a design focused on developing approaches rather than solutions.

Making
At the making level, this might be translated in two main actions. On the one hand, it is useful to design for "accessibility", namely trying to achieve a level of simplicity that would enable a dialogue with both adults and children, for customising, adapting, and extending the experiences.
On the other hand, a good practice is to imagine and define a set of meaningful usage scenarios that could potentially support each of them.

Situating
At the situating level, this principle might help to focalize on the experience rather than on the artefact, and on the process rather than on an hypotetical outcome (e.g. learning a specific concept or achieving a goal). A same approach, in fact, might be explored through the development of different experiences, whose characteristics result from the situational variables of the context, among which aspects related to the diversity of the people involved (such as educators' attitude toward the experience and technology, children cognitive abilities, children cultural differences, and many more).

Children are serious players

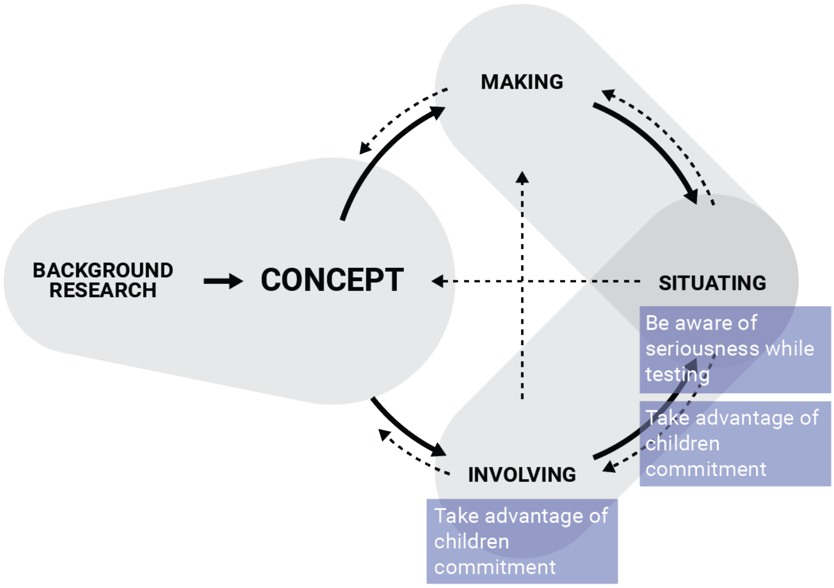


Fig. 7.12 - The impact of the "Children are serious players" principle on the design process.

One common mistake, when working with children, is to underestimate their potential seriousness and commitment. With the right motivation and activity, in fact, children can be easily engaged and their attention can be naturally retained if an interest is aroused in them. This seriousness can also be detected as related to the desire of showing off abilities and fear of making mistakes.
Given the fact that this principle is focused on children, this principle affects the levels of the design process in which their participation is required, namely involving and situating.

Involving
At the involving level, considering this principle might allow to take advantage of children commitment for collecting richer data through simple activities. Children, in fact, tend to go beyond what is asked to them, commenting, asking questions, and describing aspects resulting from their interpretations, even if it is not explicitly required to them.

Situating
At the situating level, the same approach of taking advantage of children commitment is also valid. In addition, their serious approach to play need to be considered also in the evaluation of the experience and in the design of the data collection methods. Facial expressions and other expressive behaviours, for instance, are often observed to assess children's engagement and enjoyment. Nevertheless, if children are concentrated and seriously carrying out the activities, most likely no excited behaviours and expressions would be noticeable, or even sulky faces might be noticed. Thus, the evaluation needs to be based on the observation of multiple behaviours, and on the combination of data from different methods.

Support educators' creativity... they are makers too!

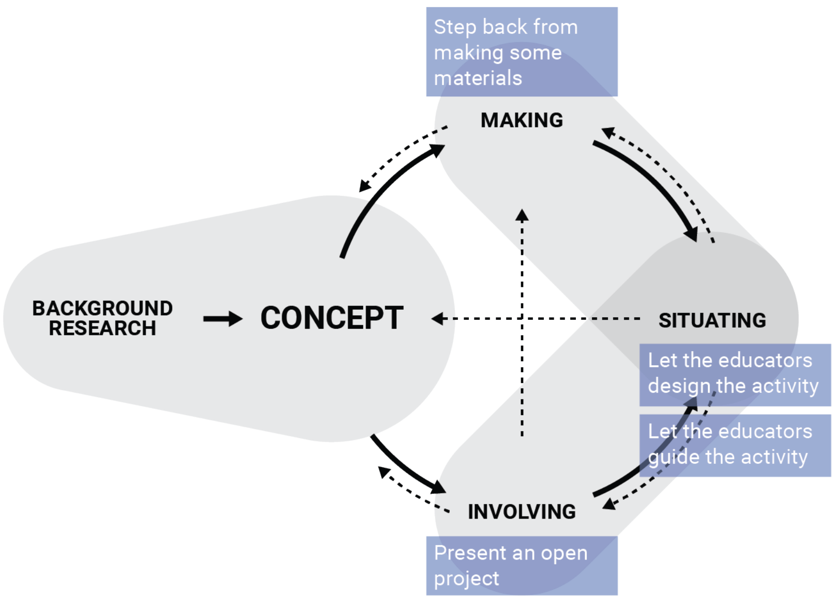


Fig. 7.13 - The impact of the "Support educators' creativity... they are makers too!" principle on the design process.

A very important aspect of child-robot play applications in real contexts is the role played by the adults involved. Adults, in fact, are the ones who might make, approve, and introduce technology, and related experiences, to children. In particular, educators are recently becoming the protagonists of the school renovation processes toward the introduction of new methods and programs for developing digital competences. Thus, it is of crucial importance to involve them in the design process as informant, as co-designers, or even conductors of the designed experiences. In this processes, particular attention has to be paid to the understanding of educator's as professionals who design, develop, and put into practice activities and related materials on a regular basis. This particular competence has to be enhanced through the projects.

Making
At the making level, this principle might be applied by stepping back from the design and development of certain aspects of the proposed experience, such as the supplementary materials. By doing so, educators can give an active contribution, which, most likely, will be appropriate and suitable, in terms of children's abilities and contents.

Involving
At the involving level, this principle can be applied by presenting an open project rather than a fixed proposal. Co-design activities should be preferred over a simple adaptation or data collection.

Situating
At the situating level, even more protagonism can be given to educators. In fact, on the basis of criteria established through the co-design sessions, the experience can be both designed and guided by the educator. This approach has also the positive drawback of revealing the effective suitability of the designed artefact for its intended use.

Structure the activity, but follow children

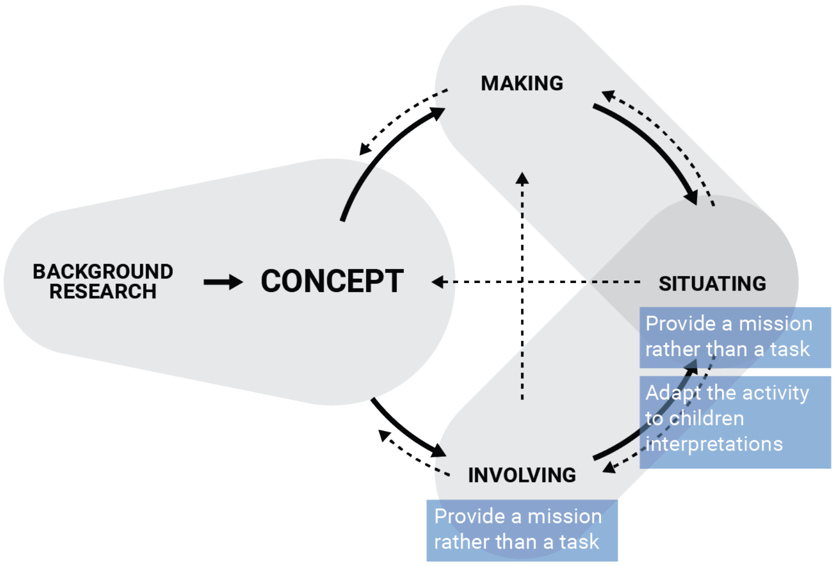


Fig. 7.14 - The impact of the "Structure the activity, but follow children" principle on the design process.

Both from the research and from the education perspective, there is need for structuring the activities to ensure that certain fixed aspects and contents are addressed. Nevertheless, the experience, when carrying out activities with children, rarely results in a linear process. Thus, it is a good practice to create structures that might be easily adapted, which is an approach strongly connected to the principle of "preparing backup strategies". In addition to backup strategies, however, the activities might be designed by focusing on children non-linear thinking for carrying out non-linear experiences.

Involving and Situating
At both involving and situating levels, this principle can be adopted by providing a mission to children, rather than a strictly defined task. In this way, children might get a clear motivation and behave with a high level of commitment to the activity.
Furthermore, especially at the situating level, the activity can be constantly readapted to children interpretation by including them into the storytelling.

Be aware of robot's implications

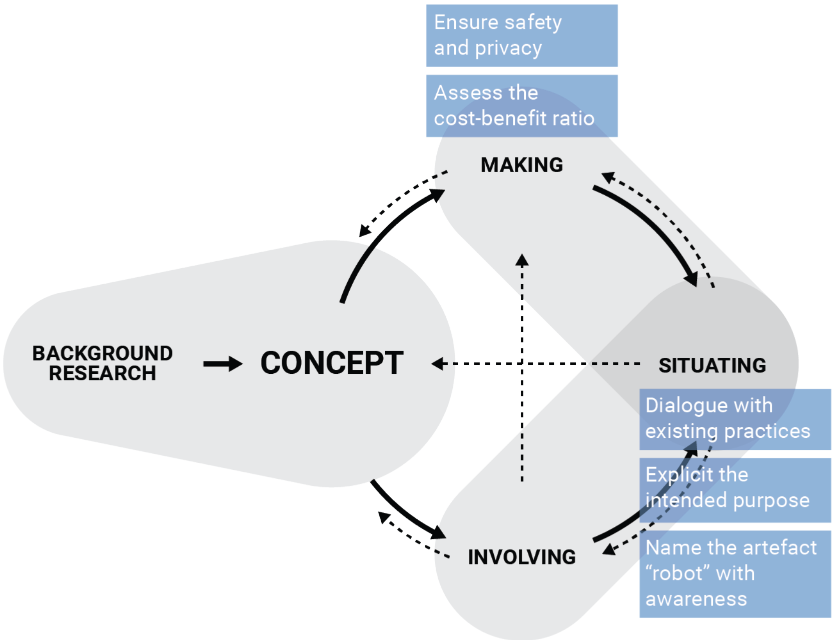


Fig. 7.15 - The impact of the "Be aware of robot's implications" principle on the design process.

Using robotic technologies with children must be a weighted choice. These, compared to other technologies, can have higher costs, can ask for a greater effort from educators, and can introduce different types of issues, such as privacy protection is the robot is connected. Many people, in fact, are sceptical toward robots' safety and actual usefulness. As a consequence, very often, robot-based applications are subjected to cost-benefit assessments and comparisons with alternative technologies.

Making
At the making level, being aware of robot implications means to focus on the assessment of both costs and benefits, with the specific intent of defining why a certain solution might be implemented only by using a robot, or why the use of a robot should be preferred over a purely virtual experience.

A second aspect, then, is to develop design hypotheses that have safety and privacy protection as prerequisites.

Situating
At the situating level, this principle may be applied by creating a dialogue with the existing practices aimed at pursuing compatibility.
The intended purpose of the proposed activities and artefact, then, has to be made explicit, so that adults, both parents and educators, can evaluate and interact with a project on the basis of a real understanding.
Besides, a different but crucial aspect is the act of naming or not the artefact as "robot". This naming, in fact, has to be carefully pondered, cause its employment recalls automatically imaginaries and some related preconceptions (e.g. a robot has arms), which might be inappropriate for some kind of experiences.

Take advantage of randomness

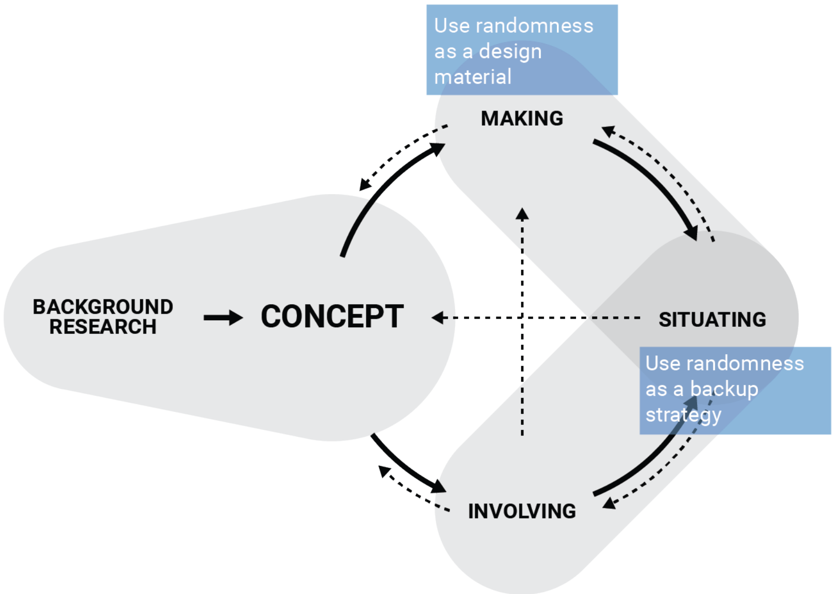


Fig. 7.16 - The impact of the "Take advantage of randomness" principle on the design process.

When dealing with experimental robotic artefacts there is a high chance that unintended behaviours and malfunctioning might occur. Although this is dependent on the artefact robustness that should be achieved in the making phase, being prepared for a random occurrence of issues is a good practice, and it can also be transformed into a strategy.
In fact, a robot that manifest some levels of unpredictable and mysterious behaviour allows to justify eventual unexpected behaviours as a phenomenon consistent with the ambiguous nature of the robot. Furthermore, randomness in physical behaviours might also be effective in terms of perception of animacy. Children, in fact, have much stronger responsiveness to robots than adults, and they are likely to attribute causality even to random behaviours.

Making
At the making level, this approach can be applied by using randomness as a design material for developing minimal robot behaviours and convey animacy. For instance, a robot that perform a variable expressive behaviour with a random frequency might convey the idea that the robot is lively and with his will.

Involving and Situating
At the situating level, this principle can be applied through the use of randomness as a backup strategy according to which, unexpected behaviours and malfunctioning might be justified as a behaviour consistent with the not completely understandable robot behaviours. In this approach, a crucial role is played by the storytelling.

7.1.3 Theoretical framework

At the theory level, a theoretical framework was elaborated on the basis of the knowledge produced through the projects and through the review of the literature. Thus, it results from a combination of existing theories and lessons learned from the two case studies. The framework, composed by *elements*, *areas of action*, and *influencing factors*, is aimed at representing the main challenges posed by the act of designing acceptable child-robot play experiences, and it can be used as a reference for developing projects.

The primary crucial elements of the framework are the three main *actors*, namely child/ren, robot/s and adult/s. the number of actors, both human and robotic, can vary according to the project.

The robot is illustrated as a general entity, but its nature can greatly vary, from a construction kit type to a character type, according to the project. Adults and children can assume a slightly different role according to the context and the intended purpose of the project. In a private context, such as the domestic environment, the child may be considered primarily as a player while in an educational context, such as a school, as a learner. Nevertheless, as pointed out by the literature review, the play and education are interrelated aspects of childhood development and it is inappropriate to consider one in the absence of the other. The two child's roles, hence, are pointed out as a way to help to focus on certain aspects of the experience, rather than others.

A similar distinction is defined also regarding the adults who play a role in the project. In fact, according to the context, they can be parents or educators. Although in both cases the adult is involved in the approval of a product, its introduction to the child and through an eventual support and collaboration in play, educators might also have the chance of becoming users too, together with children.

Educators, who can be both teachers and external professionals who run extracurricular courses, are the ones who often introduce and carry out courses with new technologies at school. Thus, they become a particularly relevant figure when designing for child-robot play, especially in public contexts (e.g. schools, museums, hospitals, toy libraries…).

However, although parents may not be directly affected by a project, such as in a solution for schools, it is a good practice to involve them as experts about their children, but also because they play a crucial role as decision makers and they can greatly affect the acceptability of a solution.

These role's differences highlight the importance of understanding the *context* of use of the proposed solutions, which is both a physical environment and as a socio-cultural environment. Adopting bottom-up approaches consisting of systematic investigations (Sabanovic 2010) and a framing (Forlizzi 2013) of the context of use is crucial for avoiding inappropriate solutions (Sabanovic 2010), for understanding the role of people within the system (Forlizzi 2013), and for unfolding those key emerging issues and phenomenon that Forlizzi (2013) proposes as "*descriptive statements that are used to guide the solution generation process*".

These main elements, namely the actors and the context are associated with the two main *areas of action* that need to be addressed through the design research process. These two areas consist of actions related to the purpose of a project and actions related to the features of a project. These, represented by the circles behind the human actors, are inverted in the case of adults and children. This is due to the fact that a play-based experience is expected to have a purpose by adults, while children do not have such expectation.

Play, in fact, is an intrinsically motivating activity that does not require further purpose, as long as it is challenging, gives a sense of control, and stimulate curiosity and fantasy (Malone and Lepper 1987). Fun, indeed, is considered the main purpose of play experiences for children which is determined by their user experience. Thus, the features of the project assume a greater role for children than for parents. On the contrary, in the case of adults, the purpose is the level of primary importance.

For both the areas of action of the purpose and the feature, a set of *influencing factors* is illustrated. These were identified from the literature review about acceptability in both HCI and HRI, and the assessment of fun in interactive systems.

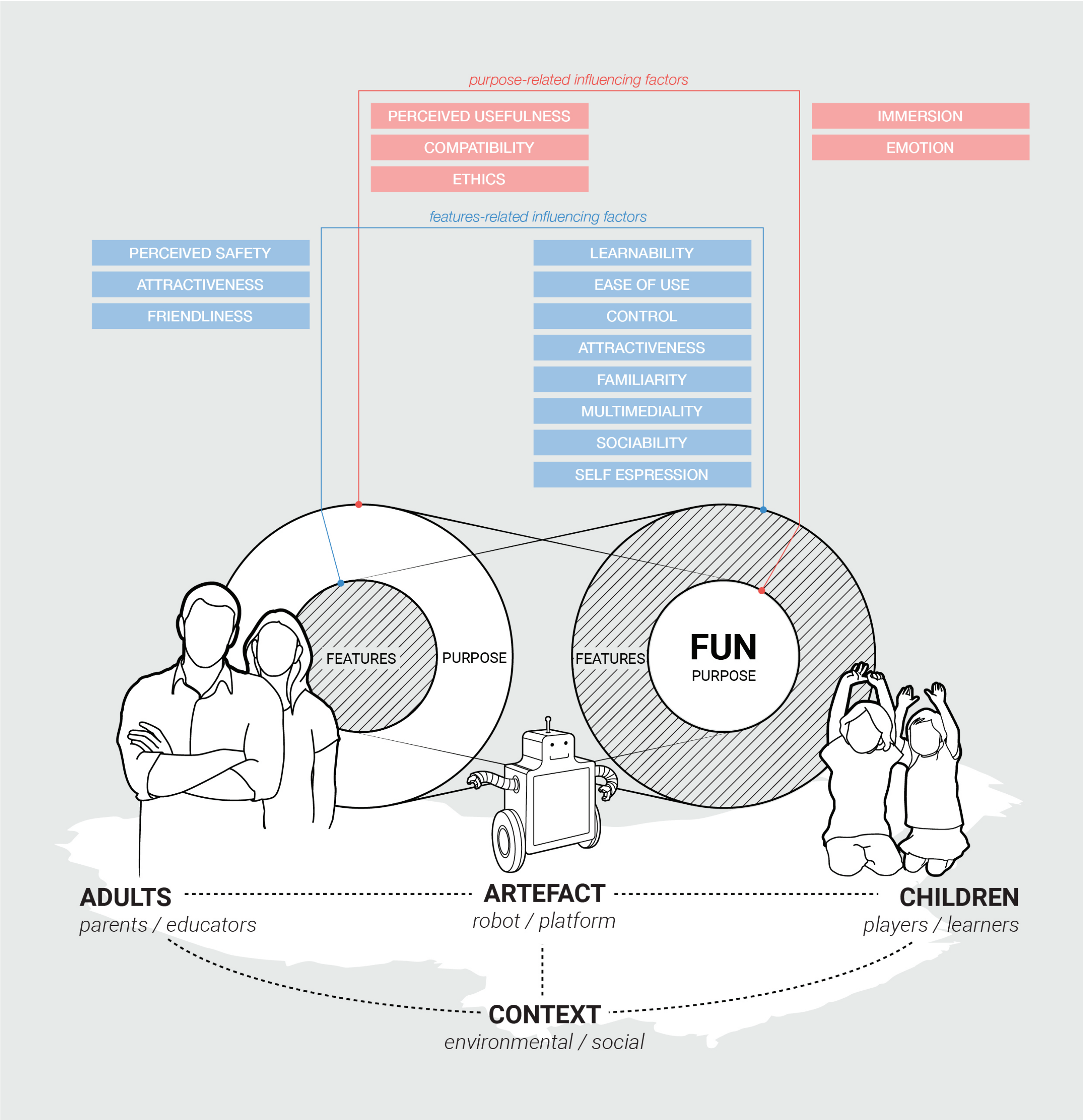
Fig. 7.17 - Theoretical framework of designing acceptable solutions for child-robot play.

From the child point of view, the purpose-related factors consist of the two main characteristics of fun, that are immersion and emotion, while the features-related factors are a larger, namely learnability, ease of use, control, attractiveness, familiarity, multimediality, sociability, and self-expression.

From the adults' point of view, instead, the purpose-related factors consist of perceived usefulness, compatibility, and safety, while the features-related factors consist mostly in perceived safety, friendliness, and ethics.

These three, however, are integrated with the children's features-related factors whenever the adult plays also an active role in the experiences and interact with the robot.

It has to be noted that the set of factors reported in the framework, especially regarding the features level, do not necessarily need to be considered all in each project, or exclusively. These can also be integrated or adapted.



Chapter 8

Conclusions

The final chapter consists of the conclusions of the thesis. This provides a final overview of the doctoral research with the aim of pointing out its main phases and the crucial aspects.
A series of limitations regarding the research and its outcomes are, then, pointed out in a dedicated paragraph which introduces also the subsequent one about future directions for research.

8.1 A final overview on the research

This doctoral research addressed two main research questions, namely what is (or might be) the role of design research in HRI? How to design acceptable and desirable child-robot play applications?
The first, of a more general nature, was aimed at investigating a new domain in which design is getting more and more involved, both for its own interest and for an interest manifested by robotics practitioners. This question was mainly answered through the analysis of the current research on HRI that manifest a relationship with the design discipline, and through a review of the literature regarding the role of design in technology-related research, especially HCI.
The second question, instead, was related to a specific area of application, that is the field of edutainment robotics, and introduced the themes of acceptability and desirability. In particular, this question was addressed by adopting a Research through Design (RtD) approach, that combines theoretical research to practice based design explorations, in which the development of artefacts plays a central role.
This approach, in fact, has the potential of transforming the "world" from its current state into a preferred one (Zimmerman et al., 2007), by producing artefacts that can be situated in real contexts.
Thus, the knowledge emerged from the review of the state of the art was used for defining a methodology based on the RtD approach, and for subsequently guiding the design process adopted in the design explorations. The resulting methodology consists of two main parallel actions, reaffirming the structure introduced by the two research questions.
On the one hand, the current state of research regarding the intersection between design, HRI studies and child studies was reviewed. This was also combined with an analysis of the scenario of child-robot play, which included an overview of the role of play for children and its typologies, an analysis of a set of popular edutainment robots for children and their characteristics related to the types of play, and an analysis of the contexts of play.
At the context level, the analysis of the scenario was also enriched by referring to current themes concerning the contemporary relationship between children, technology and society. This introduced a series of emerging issues and opportunities, among which the theme of the physically active play, and the theme of objects-to-think-with, which were addressed in the two design explorations.
On the other hand, in fact, the literature review and the analysis of the scenario were used to produce knowledge aimed also at informing the development of two design explorations, namely the Phygital Play projects, and the Shybo project. These two were respectively related to the themes emerging from the scenario analysis.
The projects were carried out by adopting iterative processes characterized by three main design phases, namely involving, making and situating. The specific actions for each phase were defined according to the specificities of each project.
The first design exploration, Phygital Play, was focused on the theme of physical interaction and movement and led to the development of a mixed-reality gaming platform in which children can play with or against the robot, by using the movement of their body. The project was situated in an educational center for children, in Turin (IT) whose specificities introduced the necessity of adaptation in terms of game contents but also pointed out the positive value of such kind of platform in terms of adaptability.
The second design exploration, Shybo, was focused on the theme of reflection through animated objects and led to the development of a low anthropomorphic robot that can perform minimal behaviours. By being able to react to properties of the physical environment, the robot is able to support playful learning activities that can start from the direct experience and that can be transformed and adapted to different storytelling.
This project was firstly situated in a primary school in Yuncheng (CN), for a short experimental application in which was designed a playful learning activity related to the themes of colour and sound. This first experimental application was, then, developed into a didactic module for schools, and a pilot experience was carried out in Turin (IT).
The process, results and lessons learned from the two projects were documented and reported.
The mere documentation of the design explorations

does not represent a research outcome per se. To be qualified as such, these, together with the background research were subjected to a phase of reflection in which the outcomes of the research were organized into three levels.
At the artefact level, the situated implementations were documented and disseminated so that can be potentially replicated, used as a reference, but also subjected to a critical analysis also from others.
At the knowledge level, a set of operational principles were defined. These consists of principles that are easy to implement and that can inform the design process of those who undertake projects related to the theme of child-robot play, especially in educational contexts.
Finally, at the theory level, a theoretical framework was defined. This collects the knowledge produced and used during this doctoral research and it is described and shared with the aim of providing a reference for the development of acceptable and desirable child-robot play applications.
Overall, this doctoral research produced positive results, especially regarding the design explorations which opened up new opportunities over time, and allowed to establish ongoing collaborations with local institutions. However, the research presented some limitations in addressing both research questions and some of these limitations will be objects of future research.

8.2 Limitations

Regarding the first research question which introduced the investigation on the role of design in HRI, some limitations emerged regarding the completeness and the level of detail achieved in the results.
The analysis, in fact, was carried out by focusing on a representative sample of papers of the HRI field, whose relevance was ensured by the prestige and the importance of the HRI conference. Nevertheless, other relevant sources should be taken into account for producing a more accurate and comprehensive overview of the state of the art regarding the relationship between design and HRI. Among the other possible relevant source, it has to be taken into account, first of all, the proceedings of the IEEE International Symposium on Robot & Human Interactive Communication (RoMan). Other relevant conference proceedings might the once from the IEEE International Conference on Robotics and Automation (ICRA) and from the Association for Advancement of Artificial Intelligence (AAAI) Symposia Series.
Other relevant articles might be found also in HRI related journals. For instance, articles published by the ACM Transactions on Human-Robot Interaction.
However, in addition to the analysis carried out in this thesis, a different kind of investigation might have been carried out. In fact, many design researchers are now entering non-traditional areas of research like robotics, but there is little knowledge and awareness of the various challenges and contributions that different researchers are facing in HRI from a design perspective. Thus, ethnographic studies aimed at bringing out these emerging practices should integrate the literature review on robotics.
Regarding the methodology, a limitation is the lack of systematic employment of similar processes. For instance, although the importance of involving systematically various representative actors in the design process emerged strongly from the analysis of the state of the art, this resulted in a challenging practice. Often, in fact, there is no possibility, especially for small research groups, to engage children, parents and educators in the various phases of the design process. In the design explorations presented in this thesis, in fact, the engagement of potential users was different according to the situation and to the external constraints.
This affected, for instance, also the design of the artefact. In fact, a good and well-established practice in Research through Design is to involve potential users in creative workshops for generating insights that might guide the projects, as well as in various preliminary testing phases in which the prototypes are subjected to a direct interaction and discussion, whose results are used to guide iterations.
In the two design explorations, instead, preliminary testing was performed with people from the research labs, which are not representative in terms of age. Other limitations emerged, during the design explorations, regarding the data collection methods. In the case of situated implementations, in fact, the design of the experiments and the

design of the data collection methods assumes a central importance. It might require adopting creative solutions and, in many cases, a real environment might impose a lower level of control of the situation and the use of alternative methods. For instance, for privacy issues, in many public children contexts the experiences cannot be video recorded, thus, alternatives have to be found for collecting data.

Finally, regarding the operational principles and the theoretical framework, their effective applicability and usefulness could have been explored by subjecting them to subjects non-involved in the research but still conducting projects and research related to the theme of child-robot play. For instance, if there had been time, short design sprints focused on child-robot play for education might have been organized for testing both the principles and the framework.

Furthermore, these two outcomes might have been also analysed with regards to other existing projects related to the theme of child-robot play, for understanding if these are still valid also in other projects.

8.3 Directions for future research

Future works will address, first of all, some of the aspects emerged as limitations of this doctoral research. For instance, ethnographic studies for understanding where and how the design discipline is moving. In particular, further investigation might be dedicated to the analysis of how design is evolving thanks to the relationship with this new domain, such as robotics. By starting from the new emerging skills suggested in this thesis, namely design thinking, staging strategies, and mechanical design, this investigation might generate knowledge that can contribute to both the understanding of how the discipline is moving, but also suggesting new directions for design education.

Regarding the validity and extensibility of the operational principles, further studies will also be beneficial. On the one hand, these will be compared to existing practices for identifying differences and common aspects. On the other hand, a set of different usage scenarios and related design hypothesis might be explored and developed by introducing the principles (one or sets of them).

Regarding the theory level, instead, further design explorations should be carried out by systematically referring to the theoretical framework will be carried out for both validating it and consolidating its relevance for the design of robot-based playful applications for children.

In addition to the investigation regarding the knowledge and the theoretical aspects emerged from this research, future works will be dedicated to the robotic artefacts produced through the design explorations. In particular, the second prototype of the Shybo project, that was specifically designed for being versatile and suitable for different activities, will be an object of future investigations and iterations. First of all, a decision of primary importance will be needed. The artefact, in fact, has demonstrated its positive potential in supporting the activities and educators and school teachers manifested an interest in conducting further activities with it. Thus, should the Shybo robot (V.2) be redesigned, refined and released as a product (with all the implications that this might entail)? Or, should it remain rather a research artefact? If so, how can it support further research, with a different type of purpose?

Finally, this second option introduces another direction for future research. The studies conducted with the robotic artefacts, especially regarding the second design exploration, turned out to be an interesting source of data regarding aspects that do not directly pertain the design domain. The data collected through the experiences supported by these robotic artefacts, then, might be subjected to investigations from other disciplines.

For instance, a first ongoing study, based on the data produced through this thesis, is now being carried out in collaboration with prof. Norese, from the Department of Management, Production and Design, at Politecnico di Torino. Thanks to this interdisciplinary collaboration, the experiences are now being analysed from a different perspective, more focused on cognitive aspects of the children experience with the robot. Through collaborations like this, novel methods for the analysis of the data might be used to address the issues and limitations related to the challenging fact of conducting studies in wild and with children.

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Annexes

Annex I

Shybo V.1 technical features

Shybo's functioning is obtained by combining open source software: *Arduino*, *Processing* and *Wekinator*. The *Arduino* runs a sketch that control the robot's behaviors and communicate via Bluetooth with a laptop used to run the sound-analysis middleware, designed in Processing by Romagnoli (http://doi.org/10.5281/zenodo.580300) and the machine learning software for classification, namely *Wekinator* (http://www.wekinator.org). The robot needs also to be physically connected to the laptop via USB, to get power. The use of the laptop is due to the fact that Shybo does not include a functioning microphone and a battery yet, and the machine learning software requires a Raspberry Pi board to be embedded in the robot. Although, all these elements are not yet embedded, this setup allows to prototype, easily and fast, a Shybo robot suitable for studies with users and educational applications.

Electronics

Shybo is composed by ten main electronics components. Figure A.1 provide a simple schema of the connections required to build Shybo and the pin used to connect each component to the board. This schema was designed with Fritzing, an open-source initiative that provide a software useful for documenting and sharing prototypes, and manufacturing pcbs. It can be downloaded at http://fritzing.org/home/. This schema was designed with the intent of illustrating the correct connections of the various components. However, the final assembly of Shybo requires the use of a small Protoboard (size: 3x7 cm) where the components have to be connected on both sides, as shown in figure A.2.

Shybo, in fact, was designed with the intent of obtaining a small size robot that can be easily handheld by a child. To do so, the assembly has to be compact. Nevertheless, it is recommended to build a preliminary prototype by using a breadboard as shown by Figure A.1. This allows to easily test the functioning.

Software

As previously mentioned, the Shybo's functioning requires the use of three software: *Arduino*, *Processing* and *Wekinator*.

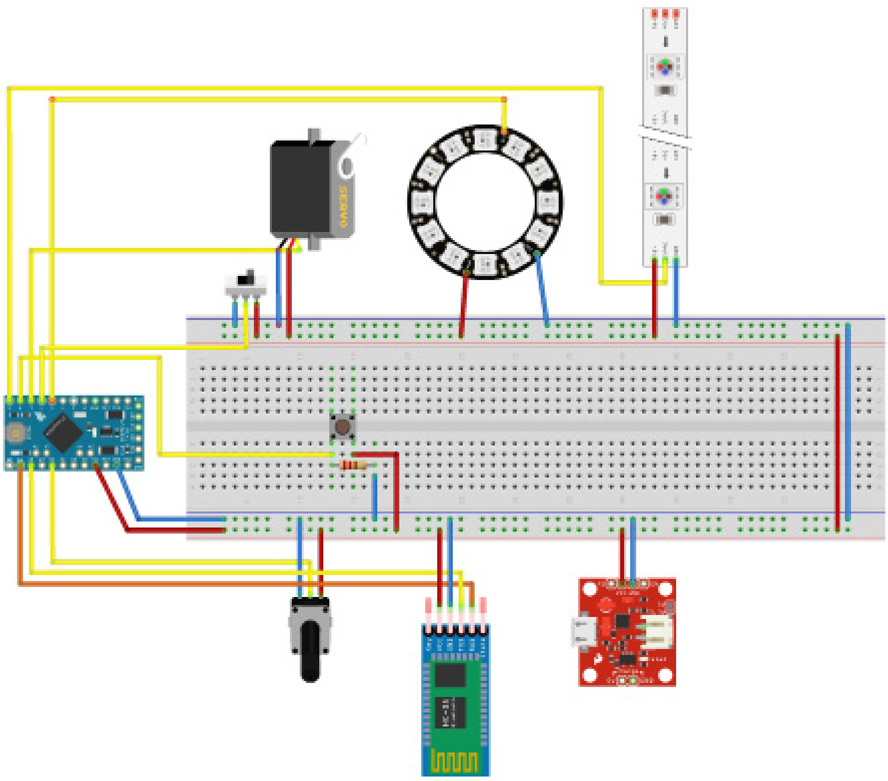

Fig. A.1 - Simplified schema of the electronics components necessary to build Shybo.

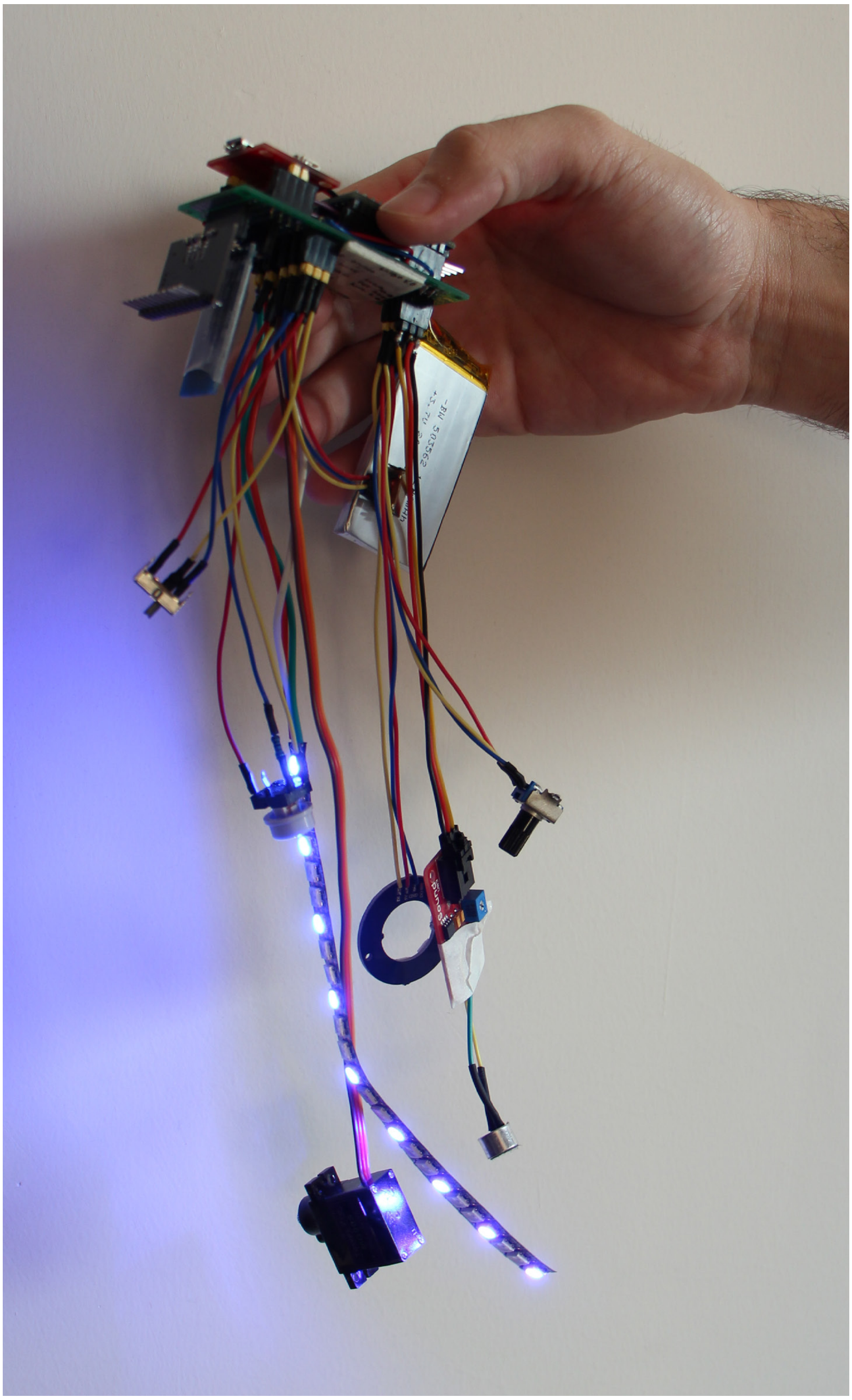

Fig. A.2 - Actual schema of the electronics components necessary to build Shybo. In the figure there are also two additional components, such as touch sensor and a battery, that can be easily added.

A complete folder, that includes the Arduino sketch, the Middleware and the *Wekinator* model, can be downloaded at https://osf.io/xk2r4/#.
The robot's behaviors were designed as a finite state machine, illustrated in figure A.3.

The *Arduino Ide* is used to design the sketch that will control the robot and it can be downloaded at https://www.arduino.cc/en/main/software. The *Processing* software (that can be downloaded at https://processing.org/download/) is used to run

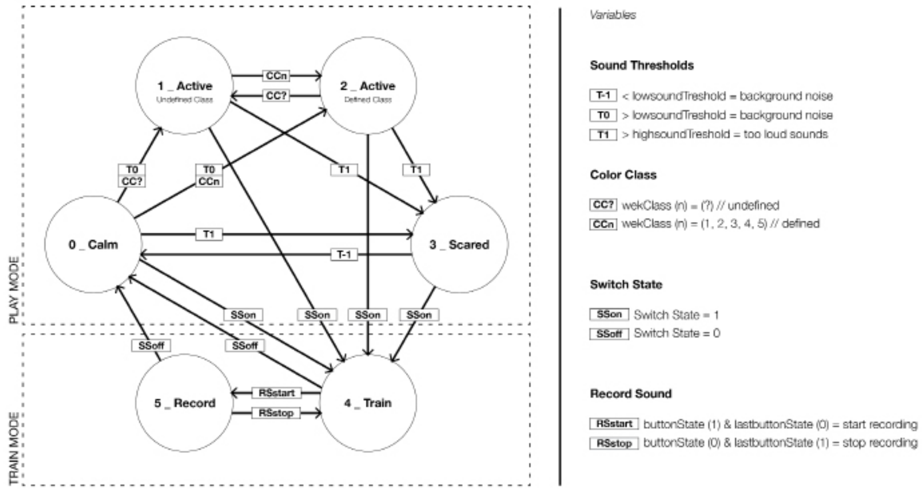

Fig. A.3 - Finite state machine that regulate the robot functioning.

the middleware, which has two roles. On one hand, it receives real-time sound data and performs a FFT (Fast Fourier Transform) splitting sounds in 250 bands. On the other hand, it exchanges data between the *Arduino* and the *Wekinator*, which is a free, open source software for machine-learning that allow to easily train and modify many standard machine learning algorithms in real-time. Figure A.3 illustrates the logic of the robot which was developed as a finite state machine, composed by six states. These states are associated to the two functioning modalities of the robot: play mode and train mode. The transition from one mode to the other is determined by the position of the left switch, located on the bottom surface of the robot.
In the train mode, the robot can send messages via Bluetooth to the middleware, which forward them to the Wekinator via OSC (Open Sound Control). It can send two kind of messages: color class and button state. By turning the potentiometer (the nose of the robot) it is possible to change the color class to which associate a new sound. The color class is visible on the body of the robot that lights up accordingly. When the button (the mouth of the robot) is pressed, instead, the status change from 4 to 5 and the Wekinator starts recording a new sound.
In the play mode, instead, the robot can change 4 states: calm (0), active with undefined class (1), active with defined class (2), and scared (3). All these states are determined by the loudness of the perceived sounds. The calm state is activated when the robot is switched on. If the sounds exceed the low-sound threshold the robot moves to the status 1 or 2, depending on if the robot was previously trained with the perceived sound. When the class is undefined the robot lights up in a sequence of colors rather than a single color. In status 2, instead, the robot lights up changing color according to the color-sound combinations trained to the robot. The recognition of the sounds and the activation of a color class is performed by the Wekinator, who receive sound data from the middleware.

Design

Shybo was designed with the primary intent of enabling a friendly interaction. This was pursued in two ways. On one hand, Shybo was designed to allow children to grab and hold it with their hands. For this reason, it has a rounded shape and a small size, showed by Figure A.3. On the other hand, both the morphology and the behaviors were designed to avoid uncanniness, by adopting an iconic style and using a hat and lights to communicate the states, instead of alternatives such as facial expressions. The hat can assume three positions, by rotating by 15 or 30 degrees.
As shown by Figure A3, the body of the robot is composed by four main elements: hat, front shell, back shell, and base. The front shell is designed to lodge the button, the potentiometer and the LED ring. The current design has also a hole for a microphone, which however is not used in this model. This can be used for iterations or for mere aesthetical purpose, replacing the microphone with a 3D printed cylinder of the same size (the precise size can be seen in the 3D model). Other smaller

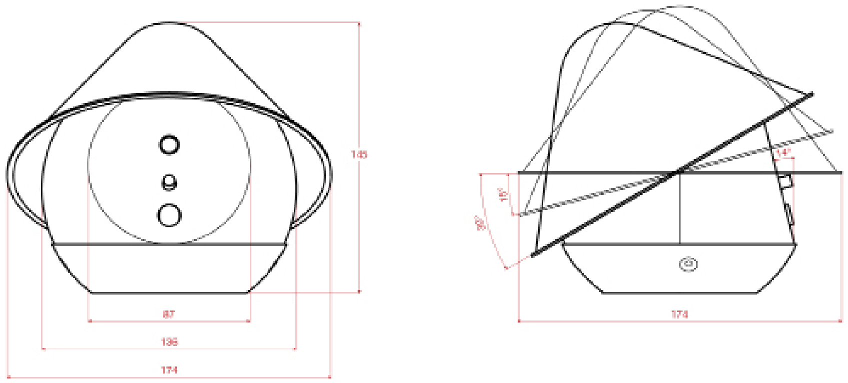

Fig. A.4 - Shybo's front and side view with main dimensions.

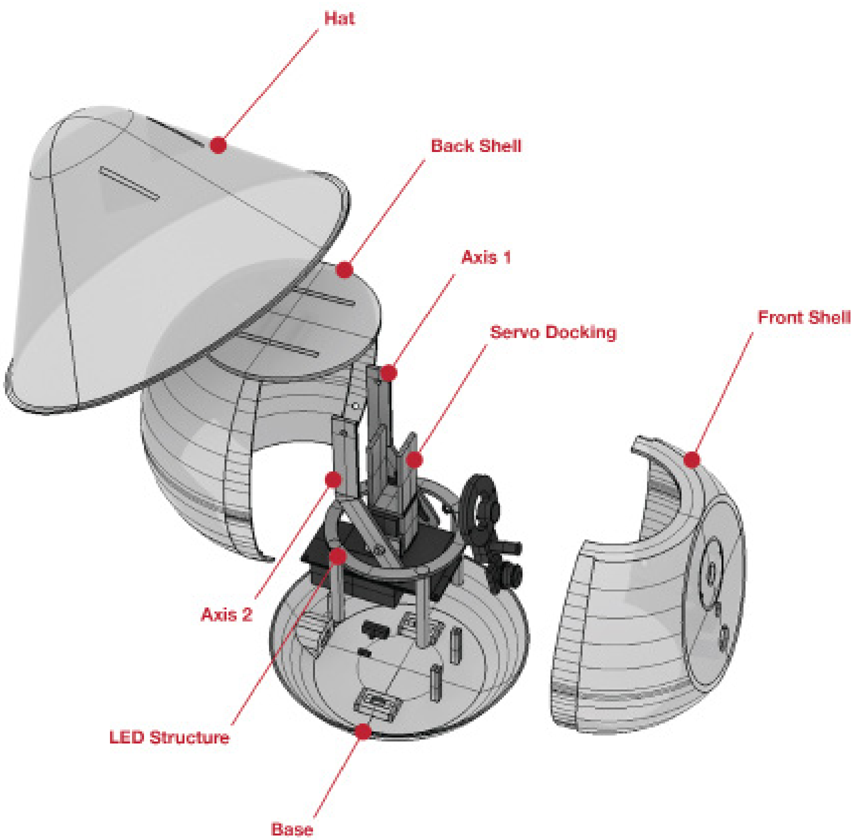

Fig. A.5 - Shybo's front and side view with main dimensions.

elements, namely the axis and the servo docking, are used both to hold the electronics and to connect the main elements. Only the LED structure is an exception, since it is used just to hold the LED strip. All the elements were 3D modelled using Rhino and 3D printed. The final model of each component is provided in stl format, while the entire model is provided in both 3dm and blend formats.
The elements were printed with an FDM 3D printer in white PLA, by a professional printing service. This choice was determined by time issues, however by printing in your own lab you should considerably reduce the costs of the prototype.

Fig. A.6 - Shybo's assembly process.

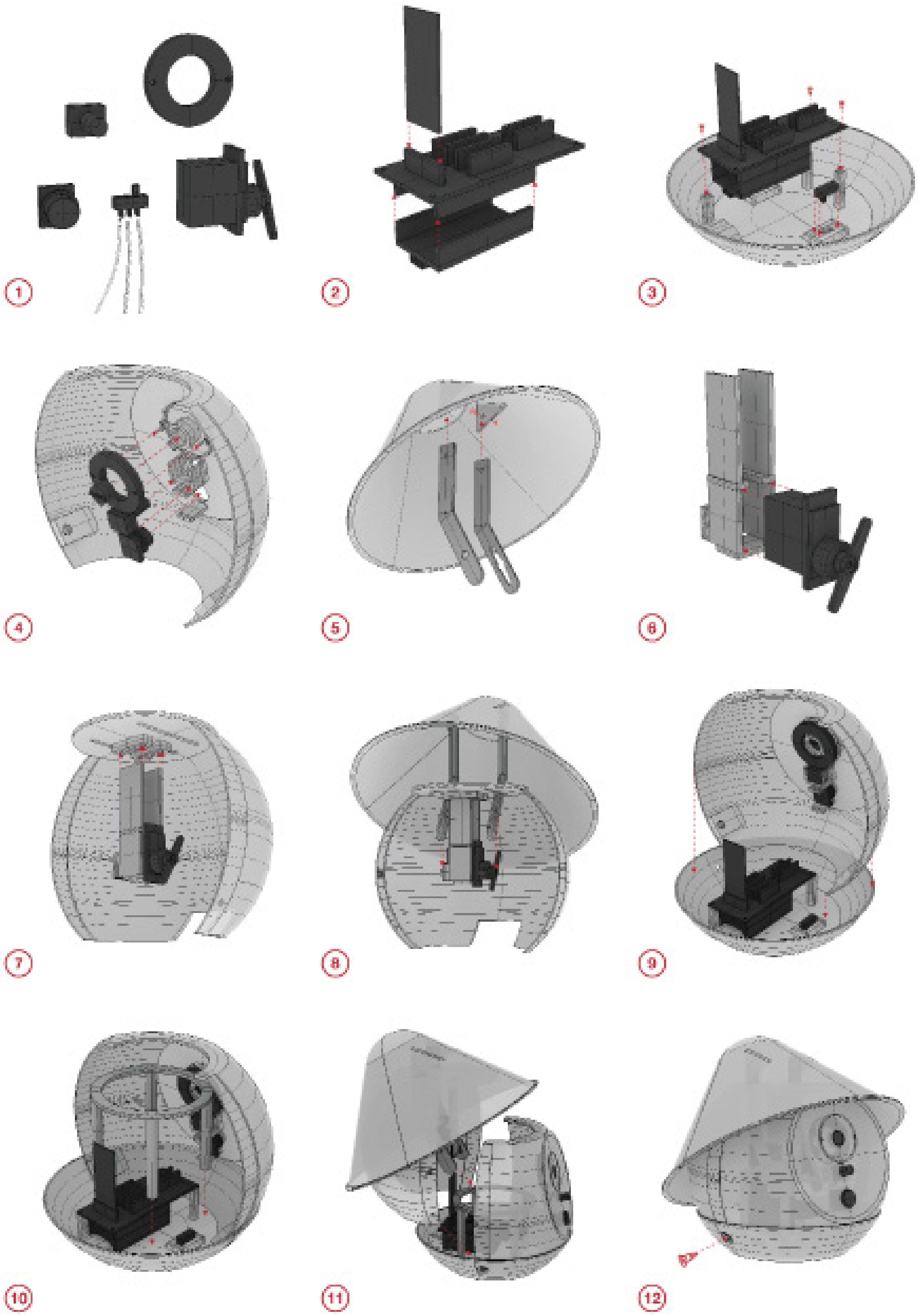
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Fig. A.7 - Shybo V.2.
Exploded view of the
3D model of the second
version of the Shybo robot.

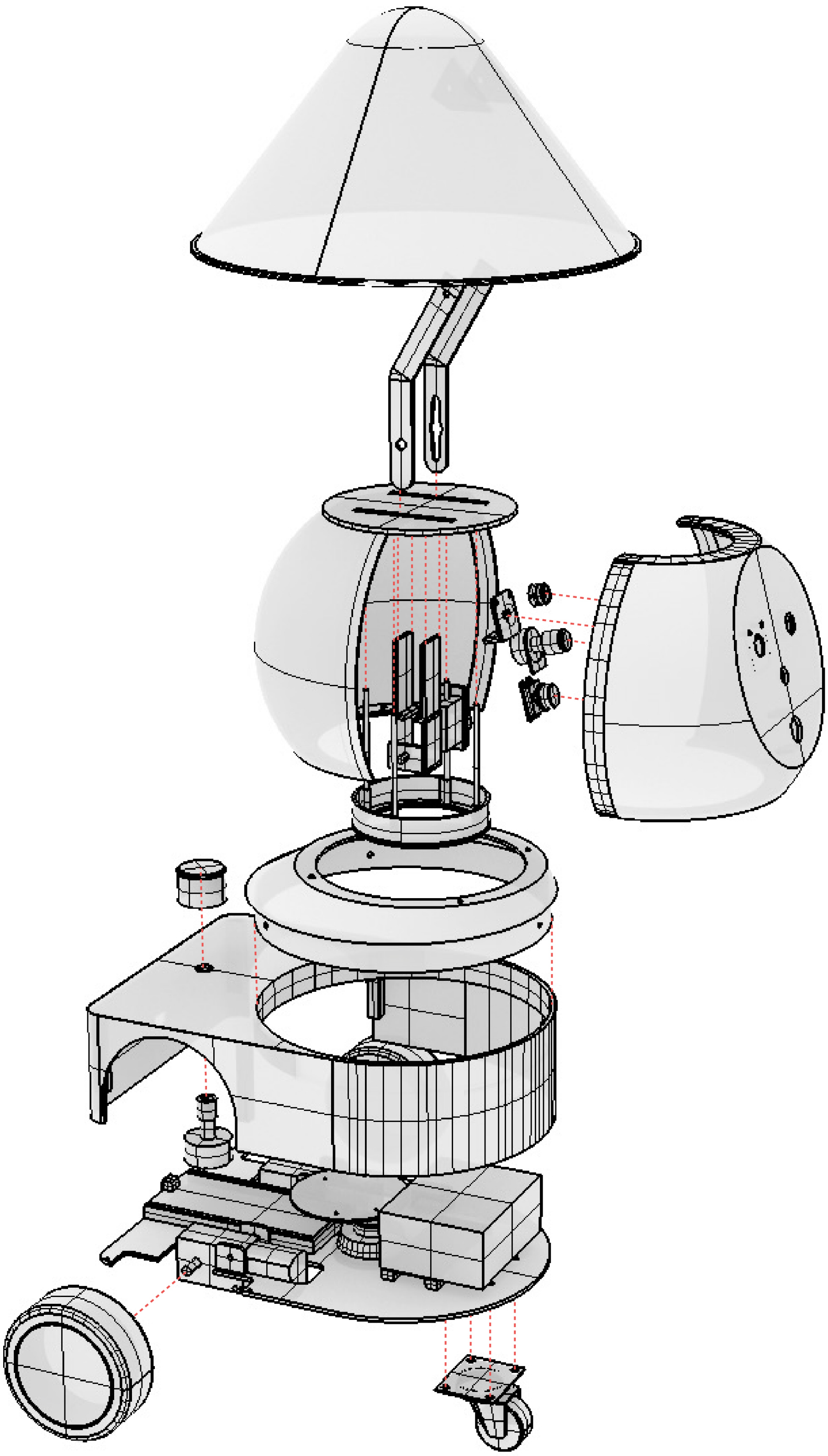
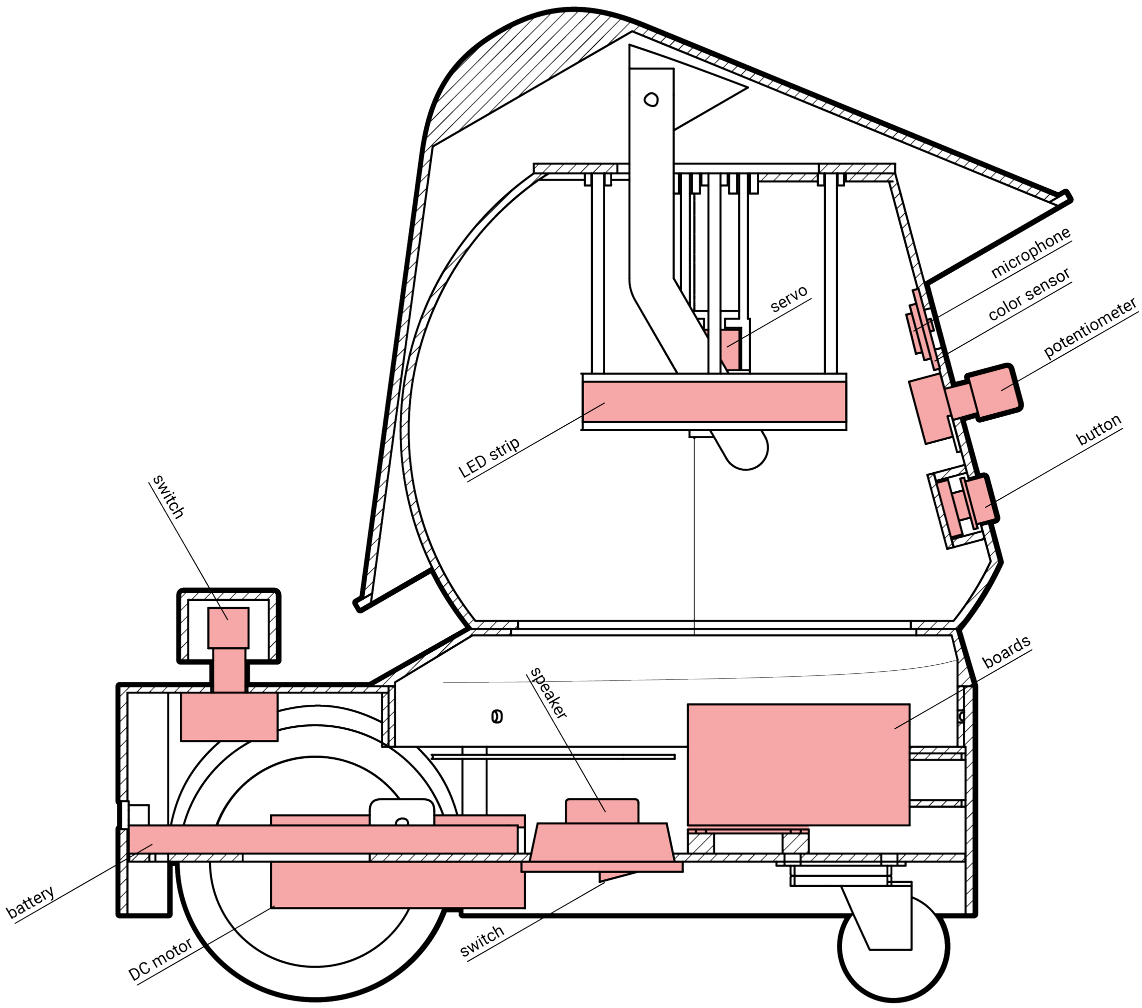


Fig. A.6 - Shybo's assembly process.

Shybo V.2

The second version of the Shybo prototype was designed according to the emerging need of extending the robot capabilities, both in terms of perception and action.
Thus, this second version was provided of the ability of moving into the environment thanks to a couple of wheels and relative DC motors on the back side, and a tilting wheel on the front side. Regarding the perception, the abilities introduced in the first version were supplemented with other that enable the opposite kind of interaction. Thus, the robot is provided of a microphone and a colour sensor, located in the front areas as eyes, that enable it to perceive sounds and colours. Then, as in the first version, on the front of the robot are located also a potentiometer and a button, which are used in the training modalities. This second version of robot has also the ability of playing sounds and, to do so, it is equipped with a speaker, located on the bottom surface, close to the on-off switch.
Given the increased number of abilities, also the modalities were increased. In the first version, the robot had two modalities, train and play. The second version has two train and two play modalities. Regarding the training, one modality is for associating sounds to colour categories and the other one is for associating colours to sounds categories / soundtracks. Regarding play, a modality is for playing with the robot that recognize the sounds, while in the other it recognises the colours. A unique play modality is currently being developed.



Annexes

Annex II

List of Publications

Extended abstracts

Lupetti M. L., Rosa S., Ermacora G., 2015. From a Robotic Vacuum Cleaner to Robot Companion. 10th International Conference on Human-Robot Interaction, March 2-5, 2015, Portland, USA.

Lupetti M. L., Designing Playful HRI. Acceptability of Robots in Everyday Life through Play. 11th International Conference on Human-Computer Interaction, March 7-10, 2016, Christchurch, NZ.

Proceedings

Lupetti M. L., Piumatti G., Rossetto F., Phygital Play. HRI in a new gaming scenario. 7th International Conference on Intelligent Technologies for Interactive Entertainment, June 10-12, 2015, Turin, Italy.

Germak C., Lupetti M. L., Giuliano L., Ethics of Robotic Aesthetics. Full paper in the proceedings of the 9th International Conference on Design and Semantics of Form and Movement, October 13-17, 2015, Milan, Italy.

Lupetti M. L., Design Research per HRI ludica. Il ruolo del Design per l'accettazione dei robot nella vita quotidiana. Atti di convegno del Forum Nazionale dei Dottorati di Ricerca in Design, (in Italian), February 25-26, 2016, Venice, Italy.

Lupetti, Maria Luce, et al. Design for Learning Through Play. An Exploratory Study on Chinese Perspective. International Conference on Cross-Cultural Design. Springer, Cham, 2017.

Lupetti, Maria Luce, et al. A scenario-driven design method for Chinese children edutainment. Proceedings of the Fifth International Symposium of Chinese CHI. ACM, 2017.

Lupetti M. L., Design, Robotica e Società. Un caso studio di robotica edutainment per bambini in Cina. Atti di convegno del Forum Nazionale dei Dottorati di Ricerca in Design, (in Italian), November 16-17, 2017, Venice, Italy.

Journal Articles

Lupetti, M. L. (2017). Shybo–Design of a Research Artefact for Human-robot Interaction Studies. Journal of Science and Technology of the Arts, 9(1), 57-69.

Lupetti, M.L.; Yao, Y.; Mi, H.; Germak, C. Design for Children's Playful Learning with Robots. Future Internet 2017, 9, V. 3, 52.

Lupetti, M. L. Shybo. An open-source low-anthropomorphic robot for children. HardwareX (2017).

Book Chapters

Piumatti G., Lupetti M. L., Lamberti F., 2015. Human-Robot Interaction. Encyclopedia of Computer Science & Technology, Taylor & Francis.

The emerging scenarios of human-robot coexistence are object of investigation for writers, artists, and designers.

More and more, they are asked to explore both opportunities and possible consequences of introducing robots in society.

Politecnico di Torino
2017