SOCIAL ROBOTS FOR ENACTIVE DIDACTICS

HAGEN LEHMANN

MEDIA E TECNOLOGIE PER LA DIDATTICA

FrancoAngeli
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Media e tecnologie per la didattica
Collana diretta da Pier Cesare Rivoltella, Pier Giuseppe Rossi

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The book was written by Hagen Lehmann. The sections “From constructionism to enactivism”, “The importance of feedback in teaching and learning processes” and “What is interactivism /enactive didactics and embodiment in learning” were written by Pier Giuseppe Rossi.

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Indice

Introduction

The use of robotic technology in eduction over the past 25 years has primarily focused on STEM education in schools (Benitti, 2012) and on computer science and engineering classes in undergraduate courses at universities (Benitti and Spolaôr, 2017). The increasing technological developments in socially evocative robotics has started to change this, and in recent years has led to an increasing number of social robotic platforms being integrated into classroom settings. Due to the relative short time in which the social robotic revolution has happened, there is a profound lack of grounding of social robots that are used in education into contemporary didactic theory, specifically when taking ideas from didactic mediation theory (Damiano, 2013) and Enactive Didactics (Rossi, 2011) into consideration. The consequence of this limited theoretical grounding is that despite the availability of social robots like Pepper (Softbank Robotics, 2018), their firm integration into school curricula around the world is still limited to only a number of cases, many of which still use the robots as experimental additions during the usual proceedings of the lessons.

Since embodied socially evocative technology, or in short social robots, begins to find its way more and more into human ecologies and starts to transform the behavioral patterns with which humans interact with each other, it is time to develop approached that allow a long-term, sustainably use of this technology in education in structured and widespread applications that are grounded in a theoretical didactics framework. We will therefore engage in our exploration of social robots for education through the perspective of didactics and explore how they can help to achieve long-term benefits for the learner, the teacher and the educational process in general. We will propose a framework that defines a position for social robots in an enactive approach to didactics, and ascribes to social robots a central role in the feedback processes between teachers and students.

Given the increasingly widespread integration of this new technology into commercial settings and their use as experimental platforms, it is surprising how limited the integration of social robots into school curricula around the world on a large scale is today. To give an example, after its release in 2014, the Pepper robot was officially introduced in 2016 in only a few countries and only to in a very limited number of specific settings. It has been used for example in Singapore, one of the few countries that strongly promote the concept of using social robotic technology in education. Since its introduction Pepper has been sporadically used in the functionality of various types of tutor in English language classes also in countries like Japan and South Korea for primary school children, in order to reduce the anxiety in shy children and enhance their social learning experience, but as of now it's position in the teaching process has not been firmly establish. The same is true for other social robotic platforms like RUBI (Movellan, 2009), TIRO (Han, 2012) or Robovie (Uluer et al., 2015).

There are different reasons for the lack of a firm inception of these robots in educational policy making. One reason are the limitations of the technology, which needs to be robust in order to be flexibly utilized in group settings typically for classrooms. Robust means in this specific case not only physical durability, but also reliable interpretation of sensory input like audio and visual cues. Specifically the limitations in autonomous navigation and language understanding in noisy environments still represents a considerable obstacle for social robotic mediators in the classroom. There has been however impressive development in this area and a lot of the issues related to human sensing will be solved in the near future. Another reason are the costs that prevents these robots from being introduced to schools on a large scale at the moment. The solution to this depends to a large extend on political will and how education is currently seen by policy makers. Besides these two obstacles, technical and financial, the reason which is central to the argument of book this book and which might be the biggest hindrance comes from a lack of theoretical grounding, which creates doubts and reluctance in the didactic community concerning the usability and usefulness of social robots in the classroom.

The reluctance stems on one hand from a specific characteristic of the field of educational sciences. It has always been forced, due to its forefront position in the knowledge construction process, to use technology that was developed for other purposes, instead of being in itself the purpose of technological developments (Laurillard, 2013a). On the other hand it stems from the complex and interdisciplinary nature of social robotics, which incorporates a strong influence from engineering, informatics and artificial intelligence research, with influences from psychology, ethics and philosophy. This strongly hybrid nature has so far, prevented a specific focus on the field of didactics, even though education in general has the potential to be one of the most promising fields of social robotic applications.

There are different concepts in the field of didactics that are particular relevant for social robotics, the concept of learning by experience, the concept of feedback and the concept of mediation. The concept of learning by experience has a long tradition in education. For the development of contemporary western didactics it arguably started to exert its influence with the Czech educator Komenský who wrote his *Didactica Magna* (Comenius, 1896) in the middle of the 17th century. His works reach into contemporary education theory through didactic thinkers like Rousseau, Pestallozzi and Fröbel, and developmental psychologists like Vygotsky and Piaget. The concept of learning by experience is based on natural learning or learning by exploration. It was this idea which inspired Papert to develop the Logo programming language, allowing children to communicate in a supposedly naturalistic way with computers and program them by exploring their capabilities. This development in combination with the use of simple robots called turtles, and later in combination with Lego Mindstorms led to the development of the most prominent branch of robotics for education – using robot as tools to teach informatics. Specifically due to the cooperation with Lego and in combination with project oriented education, it led to another important field of robots in education, in which robots are used as tools for teaching science.

The concept of tutoring in education dates back to antiquity, but gained inertia for modern western education with the grounding work of Rousseau. In his book *Emile ou de l'éducation* (Rousseau, 2010) he described the role and importance of a tutor in education. The influence of this work for modern education cannot be underestimated and laid the foundation for the development of the different functions a tutor can/should fulfil during modern day educational processes. This approach is particular relevant for social robots that are used for teaching, which is illustrated by the point that one of the first roles that was ascribed to social robots in education was that of tutors in second language classes (Han, 2012; Aidinlou et al., 2014; Vogt et al., 2017).

Didactic mediation is another concept from pedagogy that has been adopted by social robotics. Specifically in robot assisted therapy for children with special needs robots have been used as social mediators. This area of social robotics is probably one of the most extensively researched fields of applied social robotics, with studies dating back to the late 1990ies. There have been several robotic platforms used in this area to help children with for example autism spectrum disorder, attention deficit and hyperactivity disorder and Down Syndrome to learn appropriate social interaction strategies and in this way to support and improve their inclusion in everyday social activities with typically developing children and adults.

The dualistic origin of general educational robotics, stemming from constructionism and social robotics, which in itself has its origins in engineering and social psychology, points at the hybrid functionality social robots can have in the didactic process. They can either be used as tools or as educational agents, in other words as objects or as social partners in the learning process.

There is an ambivalence towards embodied, socially evocative, artificial agents like social robots, specifically when used in close physical and psychological proximity with vulnerable individuals like children, that originates in their socially evocative characteristics, and is not idiosyncratic to social robots used in education. It presents a general contemporary issue that is controversially discussed in philosophy and ethics (Dumouchel and Damiano, 2017; Turkle, 2017). The positions concerning this issue are the following:

- Social robots are machines like any other, and should be treated as such. They should not induce any emotional attachment in their human users, since any emotionality they can express is fake and will lead to a dehumanization of human society (Turkle, 2017).
- Social robots are, due to their embodiment and the resulting expressivity, capable to induce emotions via the human predisposition to anthropomorphise object that are not human. This process can be used to involve humans in dynamics with phenomenologically social and affective aspects, similar to the ones humans engage with other humans and animals. In this kind of context they can also express these functions. These dynamics can be used to induce empathic reactions towards robots, which under the right circumstances then can extend to similar cir-

cumstance during human-human interactions, and in this way improve human sociability (Dumouchel and Damiano, 2017)

It is easy to see the relevance of these positions for the use of social robots in education. As pointed out above, one of the ways social robots are implemented in education is as social partners. As such, they can fulfil different types of social mediator roles for example tutor, peer, or novice. There are still no concrete guidelines as to which extent robots should be inducing emotional responses in children/students, but it has been shown that emotional engagement induced by robots can be motivating for the learning process (Tanaka and Kimura, 2009).

Despite all the efforts of improving social robots for educational purposes, the most successful branch of robots in education is, at the moment, the learning by building approach. Since the robots are, in this approach, used as objects that can be constructed or dismantled in more or less complex projects, their use is straight forward and the educational objectives of their implementation are clear. They are intended to help the students to acquire knowledge and competences in mechanics, informatics and electronics, and additionally strengthen their problem-solving and collaborations abilities. On one hand this clarity is a consequence of the longer history of this type of application, but on the other it is also a result of the ontological representation humans still have of robots. Until recently it was clear that robots are machines that can be constructed and help with specific tasks. The way to communicate with robots was for a long time limited to computer programs that had to be written on a computer which in turn controlled the robot. The original idea behind using robots with this ontological perspective in education was to teach children to program computers, not necessarily to communicate with robots.

Due to the technological advancements of the last 15 years, namely developments in sensor technology and artificial intelligence our representation of robots starts to change, and now we are confronted with a generation of robots that allow us to communicate with them via human language and even non-verbal human signals like gestures. This creates high expectations in the human users about the capabilities of the robots, which in turn are, more often than not, disappointed. The resulting dissatisfaction leads among other things to the perception that these socially evocative technologies are not (yet) reliable enough for situations in complex social environments, like teaching in a classroom.

A further hindrance for the widespread use of robots in schools are the difficulties in evaluating their effectiveness in the classroom. Due to the complexity of the learning environment it is very difficult to adapt approaches from experimental psychology and use controlled experimental setups, because they would inevitably result in a reductionistic representation of the learning environment. In order to see the effects of robots being integrated into the curriculum, long-term, large scale studies would be needed, similar to the situation in the beginning of the 1980ies when Commodore PET computers were introduced on a large scale into the US American school system (Braun, 1981; Gleason, 1981). For this to happen it is crucial to clearly position social robots in the didactic process of transforming and constructing knowledge, and to define what their role in this process can be. It will be necessary to develop an perspective that goes beyond the current focus on efficiency maximization in the schooling system, which is becoming increasing ruled by neo-liberal principles. This will be particularly important since the effects of social robots in schools will not be visible immediately, but will manifest themselves in the form of long-term, sustainable changes in the knowledge structures build and internalized by the students. In order to convince the stake holders and policy makers of the benefits of these long-term effects, the first step is to evaluate what is possible with the current technology in the framework of modern didactic theory. A good starting point for this evaluation are from our perspective the concepts of Enaction (Varela et al., 1991) and Enactive Didactics (Rossi, 2012).

In summary, we will illustrate in this books how current social robotic technology can be used to shape future learning from the perspective of enactive didactics theory. We will do so by giving an overview of what constitutes the use of social robots in education today, what the roots of this approach and what its limitations are, and what is missing from current applications. In the 2nd chapter we will introduce our approach to enactive robot assisted didactics (Lehmann and Rossi, 2019). Our approach is based on the enactive approach to cognition, and is interwoven with ideas from didactic mediation theory. We will discuss the roles social robots can play in reinforcing the different types feedback mechanisms between teacher and students and answer some of the, from our perspective, central questions about the grounding of social robots in didactic theory:

- What can the role of social robots be in the didactic process?

- Where are social robots situated in the in the process of didactic mediation?
- Can the integration of social robotics in education be a sustainable progressive development?

In the 3rd chapter of the book will describe a current project in which we started to implement the theoretical principles discussed in chapter 2 in order to use a Pepper robot during university lectures for first and second year university students of pedagogy and didactics.

Chapter 1. Social robots in education

1.1. How are social robots used in education today

Robots started to be used in a structured way in education in the late 1970ies, when Papert applied a constructionist approach to teaching children programming and informatics. Despite this history of over forty years of using robots to various degrees in educational settings, it is fair to say that until now specifically social robots have not seen a widespread integration into school or university curricula anywhere in the world. A considerable part of the reason for this are the technological limitations of autonomous navigation and language understanding in noisy environments that still present an obstacle for social robotic mediators in classrooms or lecture halls. This in turn makes it difficult to evaluate the effects of robot assistance during the teaching process, and w ithout a structured evaluation it has been difficult for the social robotics community to convince the large majority of shareholders, including the relevant political bodies, school and university boards, and robotic companies to invest into the large scale integration of social robots into learning environments. However, the field of social robots has produced a number of approaches for education (e.g. Castellano et al., 2013) and a multitude of, to a large extent, experimental results that illustrate the possibilities of using embodied and socially evocative artificial agents in educational settings. Various studies have shown that the physical embodiment of social robots is, for specific tasks, more effective when compared to the presence of virtual agents, and that a robot's physical and social presence is crucial for a successful and positive interaction between an artificial agent and a human on different dimensions (Kidd, 2003; Li, 2015). One of the reasons for the positive effect robotic embodiments can have on the learning process is the increased potentiality for social bonding with an embodied agent (Tanaka and Matsuzoe, 2012).

The majority of the research and of the applications in which robotic tutors have been used in education were conducted with pre-school and young school children. Many of these studies have been conducted in Japan, South Korea, and Singapore in the context of second language English classes (e.g. Han et al, 2008). In their review Benitti et al. (2012) showed that in almost all cases in which robots were used in universities, they were part of the computer science curriculum and were used as tools to teach programming skills to the students. They found that the majority of robots used where either virtual, or based on the LEGO Mindstorms system. The most widespread used theoretical didactic approach for this type of implementation is the project-based learning approach (Bell, 2010), in which professors usually engage their students in activities that affords of them to build an artefact or product. The second most frequently used approach in this context are "experiential" and "constructionist" learning theories. Benitti et al. (2012, 2017) are using "constructionist" as being synonymous with the "learning by making" approach (Papert and Harel, 1991). Together with other reviews (e.g. Mubin et al., 2013; Belpaeme et al., 2018) they demonstrated that robots in the role of tutors or mediators are not yet widely used in universities, and that even when they are integrated in schools their application is restricted only to a few specific subjects. The underlying didactic theories are again usually limited to approaches that are defined by, or are closely linked to, collaborative project-based activities, which involve the use of advanced technologies as tools and objects, and not necessarily as social mediators between students and teachers, nor as tutor or motivational support for individual students.

However, specifically in last decade human-robot interaction research has worked hard to demonstrate that the use of social robots can be beneficial in didactic settings. As pointed out above, from the beginning of the 1980 to the end of the 1990, the main use of robots in education was based on Lego Mindstorms and the idea of understanding by building. This started to change with the development of social robots at the turn of the millennium. The result of the implementation of these new robotic platforms was a plurality of different experimental applications. This started to pose the problem of comparability, with respect to the results produced by these studies, specifically from the perspective of their effectiveness in improving learning. In order to structurally approach this problem, the implementation of robots in education has been categorised in different ways. Mubin et al. (2013) and Tanaka et al. (2015) for example classified two different modes in which the robots were integrated into classrooms (a) as educational tools, and (b) as educational agents. Since also other slightly varying classifications of educational robots have been given recently by different research groups (Gaudiello and Zibetti 2016; Belpaeme et al 2018), we will summarize these classifications from the perspective of the goal of this book, which is the grounding of social robots in enactive didactic theory.

A common aspect of most of the classifications of educational robots is the ontological nature of the robots. The robots are usually defined either as objects, or as educational agents. This categorization is based on the functionality the robots have during the class. On one hand when seen as objects, robots are mainly used in lessons concerned with informatics and programming, and domain specific project-based science and humanities classes. On the other hand when seen as educational agents robots can assume different social roles to support the teacher in the process of didactic mediation (Damiano, 2013), to motivate the students and to inspire their imagination.

Belpaeme et al. (2018) have examined the different roles social robots can assume in education. In their survey of social robots that were recently implemented into educational settings, they found that the functionalities social robots assume can be categorized into three distinct roles, that of novices, tutors, or peers. For each of these different roles different motivational mechanism have been used in order to engage the children and nurture their curiosity.

When fulfilling the role of *novice*, the robot makes mistakes, inducing in the students the urge to help, and allowing them to assume the role of a tutor and to teach the robot the content of a predefined topic. This helps the children to rehearse specific aspects of what they have learned and to gain confidence in the active use of their knowledge. The latter is specifically important when learning a second language (Tanaka and Matsuzoe, 2012), since an essential part of this process is talking and experimenting with the newly acquired knowledge. The efficiency of this approach is increased when the robots expressive capabilities are supported by multimodal displays of content, which in many platforms can be done via an integrated tablet or touchscreen. Robots in this role have been mainly used in countries like Singapore, Taiwan and Japan to teach English to children in primary schools (Tanaka and Kimura, 2009).

When the robot is fulfilling the role of *tutor* the function of the robot is usually that of assistant for the teacher, helping in the knowledge construction process. Similar to robotic novices, robotic tutors have been used in classes for children learning English as second language. The role of tutor for a robot is defined by Belpaeme et al. (2018) as an educator of a single pupil or a very small group. Strategies used in robot-based tutoring scenarios include for example encouraging comments, scaffolding, intentional errors and general provision of help (e.g. Leite et al., 2012). These strategies are similar to the ones teachers are using, however since at the moment robotic tutors are used mainly on a one-to-one or small group level, the robot can react more adaptively to the individual knowledge levels displayed by the children. Specifically the use of encouraging comments and the scaffolding, which are forms of direct feedback, are interesting aspects from the perspective of didactic mediation, which will discuss with a focus on social robotics in the second chapter of this book.

The idea behind having robots assume the role of a *peer* for children is that that they appear less intimidating compared to a tutor or a teacher. When behaving as peer the robot is programmed to give the impression to learn together with the students. It is presented either as a more knowledgeable peer that guides the children along a common learning trajectory (Belpaeme et al., 2018) , or an equal peer that needs the support and help of the children (Tanaka and Kimura, 2009; Baxter et al., 2017b). This can be used to induce a feeling of complicity between the students and a robot, increasing the students' motivation to cooperate with the robot. One of the functions of using robots as peers is provide motivational incentive for the students, based on the care-receiving robot (CRR) design methodology (Tanaka and Matsuzoe, 2012). The goal of this methodology is that the children, besides rehearsing their knowledge and gaining confidence, also establish a closer attachment to the robot which assures long-term interest, and practise their social skills helping others.

These three different roles focus in their functionality on the skill level the robot appears to have when being integrated into the learning environment with the students.

Another important role that has been given to social robots in education is that of social mediator. The difference to the three above described roles and this role is that it focuses on the social function of the robot. Social robots have been used as mediators in the recent past mainly in robot assisted therapy for children with special needs. Here the robot bridges the communication gap between the child and the teacher or parent in order to help, for example children with autism spectrum disorder, to develop adequate social skills that allow them to participate in educational settings with other typically developing children.

The use of robots as telepresence devices represents in many ways an exception for educational settings, since here robots enable the remote participation in social situations and settings like the classroom for persons that would not have this possibility without them. This has doubtless a high potential for different future uses, but will not be further subject of this book, since we are focusing on robots with an autonomous or semi-autonomous ontological status, whereas telepresence devices, represent in many ways a remote extension of one's own body.

An overview of the different uses of social robots in education can be found in Table 1. In this table we combine two different given classification schemes in order to illustrate our perspective on how to integrate social robots into enactive didactic theory.

Additionally to the roles social robots can assume in education, we also added in Table 1 the didactic objectives that are the underlying goals for the use of the robots in specific circumstances. These are, for scenarios which focus on the understanding by building approach, typically the acquiring of subject-related, as well as transversal, competences and knowledge by supporting cognitive, affective and social aspects of learning, and the development of knowledge in the fields of mechanics, informatics, and electronics.

Tab. 1 - Classification of current social robot applications in education (from Gaudiello and Zibetti, 2016; Belpaeme et al., 2018)

Application area	*Role of robot*	*Target Group*	*Didactic objective*
Educational agents	Peer, Novice, Tutor	Pre-, primary-, and secondary schools	Acquiring domain-specific knowledge
Robot assisted therapy	Social Mediator	Children with special needs	Learning appropriate social interaction behaviors
Telepresence devices	Extension of body	Children with special needs	Enabling inclusion in didactic settings
Educational agents	Peer, Novice, Tutor	Pre-, primary-, and secondary schools	Acquiring domain-specific knowledge

When robots are used as educational agents, the didactic objectives are usually an increase of motivation to acquire domain specific knowledge (e.g. in foreign languages, history, etc.), and an increase of interest in technology by discovering the possibilities and limits of the robots in a playful way through interaction. In robots assisted therapy the didactic goal is usually to teach appropriate social interaction behaviors.

Table 1 also shows that the focus of the use of robots in education in recent years was mainly on their integration in lessons for school children. However we think that social robots can also be used in universities for students of all ages and for life-long learning in general. In the third chapter of this book, we will discuss an application which we developed for the Pepper robot for university teaching in lecture hall scenarios. We will illustrate that social robots in this type of application can effectively reinforce the feedback between the teacher and the students.

In general a noticeable change in how robots that are used in education are seen seems to emerge. Lately their perceived ontological status seems to shift more and more away from being seen merely as an object, towards becoming more of an interaction partner (Gaudiello and Zibetti, 2016). This shift is interesting in itself and might shed more light on the effects social robot can have on future mixed human-robot ecologies (Dumouchel and Damiano, 2017). The status of interaction partner allows social robots to be seen as social agent and gives them an entire range of new applications. This also creates various ethical issues linked to potential dependencies of vulnerable people like the elderly and children with special needs on the technology and with this the danger of dehumanization of human society (Turkle, 2017).

In Table 2 we take a closer look at some of the social robotic platforms that have been successfully applied in different educational contexts. The social robots presented in this table are being used at the moment or have been used recently as educational agents in various different studies and applications, and have a humanoid appearance to varying degrees. The idea behind using humanoid robots for social interaction originates from the idea to use during their interactions with their human interlocutors not only verbal, but also nonverbal communication signals. We will discuss the importance of nonverbal in more detail in chapter 2. In short it can be said that a humanoid appearance gives robots the ability to express emotional states and to transmit information via body posture in an, for humans, intuitive and comfortable way, and that this has been shown to facilitates their integration in the teaching process and to ensure their successful use. Even though we will focus on humanoid robots in our examples and discussions, for the sake of completeness and in order to illustrate that successful social robots can also be zoomorphic, we included the new AIBO robotic dog in our list of examples. The AIBO dog has been successfully used in robot assisted therapy in the past.

Tab. 2 – Examples of different robotic platforms used in different fields of education

Robotic Platform	*Area*	*Role of the robot*	*Mode of Interaction*	*Didactic objectives*
NAO 	Primary and secondary schools	Educational agent	**Verbal:** speech recognition and generation **Non-verbal:** expressive whole body movement **tactile:** touch sensors	cquiring domain specific knowledge
RoboVie R3 	Primary schools	Educational agent	**Verbal:** speech generation **Non-verbal:** pre-programmed social interaction behavior scripts such as shaking hands, hugging and waving	cquiring domain specific knowledge
TIRO 	Primary schools	Educational agent	**Verbal:** speech recognition and generation **Non-verbal:** emotional facial expressions, applications on tablet	cquiring domain specific knowledge

Robotic Platform	*Area*	*Role of the robot*	*Mode of Interaction*	*Didactic objectives*
Maggie 	Primary schools, as guide in public places like museums	Social Mediator	**Verbal**: Automated Speech Recognition (ASR), Emotional Text To Speech (eTTS), speaker ID (SI), dialogue management **Non-verbal:** Body movements,	cquiring domain specific knowledge
Pepper 	Guide in public places like museums, airport, shopping malls	Social Mediator	**Verbal**: speech recognition and generation **Non-verbal**: expressive whole body movement, applications on tablet **Tactile**: touch sensors	cquiring domain-specific knowledge
KASPAR 	Robot assisted Therapy for children with special needs	Social Mediator	**Verbal:** speech generation **Non-verbal:** body movement, minimalistic facial movements	Learning appropriate social interaction behaviors
AIBO 	Robot assisted Therapy for the elderly, Pre- and primary schools	Social Mediator	**Non-verbal**: Expressive body movements **Tactile**: Touch sensors	Training memory functions, Acquiring domain-specific knowledge

In the next sections we will discuss in more detail the beforementioned different roles that have recently been ascribed to social robots in education.

Use as Educational Agents

The use of social robots as educational agents has been accelerated and subsequently received moved increasingly into the focus of attention not only in research, but also in the media in recent years due to technological advances in the general field of autonomous robotics. Consequently different types of social robots have been integrated in various teaching scenarios for testing purposes. These robots are usually used as assistants for teachers, e.g. displaying multimodal content, or learning supports for children and students, e.g. connecting images and words, or helping to memorize new words of a foreign language via repetition. As shown in table 2 the embodiment of most these robots is either humanoid or semi-humanoid (e.g. Robovie R3 (Kanda et al., 2004); Maggie (Gorostiza et al., 2006)) allowing them to use gestures and general body movements, which are intuitively understandable for their human interlocutors. Human features like a moveable head, moveable arms and actuated hands are most suitable for the implementation of human non-verbal communication signals. One of the most widely used humanoid robotic platform in this context is Softbank Robotics' NAO robot (Shamsuddin et al., 2011). However other robots, like RoboVie (Ishiguro et al., 2001) and Tiro (Han and Kim, 2009), have been successfully deployed and tested, and in the process provided valuable insights into the psychological dynamics characterizing social human-robot interactions in educational settings (Benitti, 2012).

It is worth mentioning that comic-like and zoomorphic looking robots also have been used successfully. For example the iCat robot (van Breemen et al., 2005) has been used to teach children how to play chess (Leite et al., 2011). The Keepon robot has been widely used in education (e.g. Kozima et al., 2009) and therapy for children with Autism Spectrum Disorder (Kozima et al., 2005), whereas the AIBO robot dog was used for therapeutic approaches for cognitively challenged elderly patients (Kramer et al., 2009).

When social robots are used as educational agents, this typically happens over a longer period of time. These long-term interactions, for example in classrooms, give rise to a variety of issues, one of which is that when the novelty effect of using robots wears off, which usually happens comparatively quickly, the children subsequently become bored. In order to create sustainable effects with the intervention with social robots, effects that carry over to other learning situations, these robots need not only to be predictively reactive in specific tasks and to provide adequate situational feedback, but additionally, they need also to provide appropriate emotional feedback. It has been shown that grounding robotic feedback behavior in children's memory models can be advantageous. First successful attempts in this direction have been made to support vocabular learning in primary school students (Ahmad et al., 2019). Specifically Asian countries like Japan, South Korea and Singapore have embraced the use of social robots in pre-schools and middle schools. Social robots like TIRO and Robovie have been tested in studies in which the robot were integrated in the school curricula and are supported teachers in the classroom. The majority of these applications were linked to second language learning and involve the robots linking new words and grammatical concepts to movements and gestures, and in this way helping multimodal anchor the newly constructed knowledge in the memory of the children.

Let us discuss some concrete examples for the use of the different robotic platforms introduced in Table 2. For the purpose of this book, "how social robots can be used in education based on didactic theory", we will focus on studies which were either based on concrete teaching strategies or theoretical concepts from social and developmental psychology. When investigating studies that have been conducted, it is interesting to see that even the more recent works are focused on understanding which could be the best behaviors to be expressed by the robot in order to facilitate learning, and then to find prove that the intervention with the robot had a measurable and preferable long-term effect on the knowledge construction and skill acquisition of the children. This shows that social robotics for education is a very young research field, still developing adequate evaluation measures and tools for the demonstration of the usefulness of the robots used in the classroom. By doing so, it is still driving the hardware and software development of the robotic platforms already in use. In the following examples it will also become clear that social robotics is searching for a grounding in didactic theory by testing different approaches from pedagogy and didactics.

We will start with studies involving the NAO robot, since is one the most widely used robotic platforms due to its competitive price and easy accessibility. The toy-like appearance of NAO makes specifically attractive for younger children, resulting in it being used in a large variety of applications ranging from dance therapy to language learning. The appeal of this robot lies in its humanoid form, which allows it to use primitive, yet understandable humanlike body language to express different simulated internal states like basic emotions.

In their study Senft et al. (2018) found that, in order for a NAO robot to improve its tutoring capabilities, the robot should be able to adapt to the learning specificities of each of their users. Even though this seems to be straight forward from a pedagogical perspective - every teacher knows about the individual differences of their students and adapts the learning strategy to them when there is time - for a robot this represents an important finding. It means that robots should provide not only general, but also personalized feedback about the learning progress of the students involved in the teaching.

The results of a study by Vogt et al. (2017) go in a similar direction. They found that the robot should remain within Vygotsky's "Zone of Proximal Development" (Vygotsky, 1978), adapting the difficulty of the learning task to the individual level of the child. This is another example of how social robotics for educational purposes uses theories form the fields of pedagogy to find a place for robots in the educational process. This example is particular important since it gives an idea for the position of the social robot in the teaching process. According to this study they should be located in the area between the biologically determined learning capabilities of an individual and the limit of learning that can be achieved by the individual with the help of social support. This social support can have different expressions, which have been defined and detailed as didactic mediators with various levels of abstraction (Damiano, 2013). This gives us already a hint of how social robots could be defined from the perspective of didactics. Since they have the capacity to express knowledge in different ways, they could be seen as multimodal didactic mediators.

As we pointed out before, a lot of applications of social robots in education have been done in the field of second language learning. A good example of this is the study by Kanda et al. (2004). They used the RoboVie robot (see Table 1) as a motivational agent during language classes of elementary school children and showed that the presences of the robot was beneficial for the learning progress of these children. Another study (Han and Kim, 2009) that used a different robot – TIRO – but also involved motivational support for the children again showed the effectiveness of a robot during music lessons, in this case with a specific focus on the coordinated movements of the robot as embodied agent. In fact it seems that currently the focus of many studies is to use social robots in order to increase the motivation of students, and specifically, like in the case of TIRO, to do so by using their entire body, including gestures and body posture, in a coordinated way. The use of coordinated movements to generate believable and naturalistic looking behaviors, which elicit the human predisposition to anthropomorphise non-human objects (Airenti, 2015; Damiano and Dumouchel, 2018) is an important aspect of the structured approach proposed by Damiano et al. (2015) for the integration of embodied artificial agents in mixed human-robot ecologies. We will discuss in detail how to effectively implement this approach in order to generate understandable robotic behaviors in the first part of the third chapter.

Another role important function social robots can have during lessons was tested and described by Han (2010). Their study showed that robots can be effectively used for class management and time keeping during class activities. This aspect is deeply linked to the topic of didactic functions and their management (Aebli, 1983) and is of central importance for the stress reduction in the teacher. The preparation of the lesson implies a sequence of activities that should roughly follow the structure: problem definition (disclosure of the cognitive conflict), working on the problem (solving of the cognitive conflict), exercise and repetition of the constructed solution, application of the constructed solution. Due to the limited time frame during lectures it is necessary to follow a more or less strict scheduling regime. A robot that functions as a mediator between the teacher and the students can help the teacher to keep the schedule in a stress reducing manner, and in this way improve the teaching experience for the teacher and subsequently the learning experience of the students.

Another example for the application of an didactic approach in social robotics comes for Tanaka et al. (2015) and takes advantage of the semi-humanoid embodiment and the integrated tablet of the Pepper robot. In their study the development of their application was guided by the *Total Physical Response* (*TPR*) approach to language learning from Asher (1966). The TPR approach proposes that students learn a second language better when they can respond to audio and visual input with their entire body. Translated into a social robotic interaction this means that children can for example see representations of words on the tablet of the robot, while hearing the corresponding audio stimulus and seeing the robot making gestures that represent the word that needs to be learned – a good example for this would be the word airplane. In Tanaka et al.'s study the children where ask to repeat the word and to imitate movements representing an airplane done by the robot. Additional to this imitation exercise Tanaka et al. found also that providing motivational haptic behaviors, like giving "high five" in combination with the use of the tablet reduced the stress of the children during the class and created a more relaxed learning environment. These findings point again at the central advantage social robots as embodied agents have over artificial virtual agents. They can use gestures and body movements to improve the interaction and use specific social strategies that have proven to be successful in human-human interaction.

The examples from the studies above show that the functionality of social robots in education can be classified as different forms of didactic mediation between the actors (active and passive) involved in the learning process. We will discuss didactic mediation as concept in more detail in the second chapter of this book. In this moment it is important to point out that the role of social mediator, which has been ascribed to robots by current social robotics research, is conceptually different from the role of didactic mediator. The latter requires the robots to be profoundly grounded in didactic theory and in doing so, as we will see later, we will be able to more clearly identify the position robots can hold in the didactic mediation process.

Social mediators in educational settings – The case of robot assisted therapy

Another very important field in which social robots have been used to achieve educational goals is robot-assisted therapy (RAT) for children with cognitive and social disorders, and specifically for children with Autism Spectrum Disorder (ASD) (e.g. Feil-Seifer and Mataric, 2008). Robots like KASPAR (Dautenhahn et al., 2009) have been used in the role of social mediator to facilitate social interaction among these children and between these children and their parents or teachers (e.g. Iacono et al., 2011). The main goal of using robots in this way is the improvement of inclusion of these children in everyday activities at school and at home. In this context the social mediator role in therapeutic scenarios serves the general the function of teaching children appropriate social behaviors via appropriate verbal and non-verbal feedback in different play scenarios. In general it can be said that when robots are used in therapeutic settings, they are used with the intention to change behaviors, emotions or attitudes of their intended audience in order to improve their quality of life. In the case of RAT for children with ASD, which is one of the earliest and most widely recognized applications of social robots in therapy, different methods have been developed. These typically involve different types of interaction games, which encourage the children to improve their social and cognitive skills. These games can be roughly classified into cause and effect games, imitations games and games that require turn taking (Dautenhahn et al., 2009). At the base of this approach is the idea that due to the social characteristics of most games, they are not accessible to all children in the same way. Children with cognitive and social disabilities are often unable to engage in such play activities, because it is difficult for them to establish relationships and to explore their social environment (Besio, 2008). This results in them playing alone or in limited dyadic interactions, which in turn leads to a lack of opportunities to learn social strategies and initiates a negative self-reinforcing circle. For social life in general the ability to engage in activities which require shared attention is the key to understanding social partners as intentional agents and to develop cooperative strategies based on this understanding. This function of games - to develop and improve social skills – is for children with special needs usually not given (Spitzer, 2008). The games that are played with robots like KASPAR or IROMEC (Ferrari et al., 2009) aim at creating situations in which the robot becomes the focus point of shared attention between the teacher and the child. When playing a game that requires turn taking for example, the child needs to learn how to wait for its turn to finish the game or ideally even how to cooperate with another child to achieve a common goal (Wainer et al., 2010). Imitation games on the other hand help to increase the body awareness of children with ASD by helping them to project the movements of the other, in the case of RAT of the robot, onto their own body (Costa et al., 2013). The goal hereby is an improvement of the capability to have appropriate physical social engagements. Similar to the turn taking games during the imitation games the robot functions as focal point of attention between the child and the teacher, and its physical presence is the central aspect these applications evolve around. The same is true for the cause and effect games. Here the robot is again used to as the focal point of shared attention, which allows the teacher to interact with the child on different levels of behavioral complexity, which in turn encourages the child to experience and test social problem solving strategies.

RoboVie R3 is another robot that has been used very successfully in a different kind of robot assisted therapy. It was for example used to teach sign language to children with hearing disabilities. The very interesting aspect of this application of a robot was its strong focus on the embodiment of the robot. In order to be able to sign correctly a robot needs to use arms, hands and fingers. Normally the hands of Robovie R3 have no single fingers and are in their appearance clamp like. To be used as support for sign-language teaching it was therefore equipped with fully actuated five fingered hands. In their study Köse et al. (2014) children with hearing difficulties interacted with the robot non-verbally, in gesture based turn-taking and imitation games. Their results showed that the children had no difficulties to learn from the robot. In follow up studies to their original research Köse et al. (2015) and Uluer et al. (2015) replicated their original results using Robovie R3 as an assistive social companion in sign language learning scenarios. They could additionally show that the interaction with the physical robot is more beneficial for the recognition rate of the gestures performed by the robot, when compared to a video representation. This again illustrates the benefits of having a physically, fully embodied agent, like a social robot, present in learning scenarios instead of an virtual artificial agent.

For the completeness of the discussion of RAT it is important to point out that there various applications that saw social robots used in elderly homes for people with dementia and to counter act the effects of loneliness. The most prominent example of these robots is PARO (Šabanović et al., 2013). This robot has the embodiment of a baby harp seal and is used in robot assisted animal therapy. Many studies have shown the positive effects of the exposure to this robots in their human users, as well as the advantage for animal welfare – for example reducing the stress of dogs that are used in regular animal therapy.

Use as telepresence devices

Even though this is not directly in the scope of this book, in the light of the current Covid-19 pandemic the use of social robots as telepresence devices is another application that is worth mentioning in the context of education. The reason this application is not directly in the focus of this book is that social robots as telepresence devices can only be called conditionally social, since they are teleoperated by their users and lack any form of autonomy. However this represents very interesting aspects with respect to embodiment and social presence. Originally these platforms were developed to enable persons that didn't have the capacity to participate in social activities, for example due to a physical impairment, to be present in these situations. In one concrete application these robots given to elderly people enable them to be more independent and to stay longer in their own homes (Cesta et al., 2016).

The appeal to use these robots also in teleconferences is easy to see, specifically when taken the economic and environmental costs of sending a person around the world to attend one or two day meetings. As a consequence different platforms started to be implemented by businesses and in academia (Desai, 2011). Originally these robots consisted of a mobile base and a screen on which the face of the user can be displayed, and most commercially available telepresence robots are still constructed this way. However android science has been working on the creation of naturalistic humanlike looking robots for the purposes of telepresence. Specifically the Japanese roboticist Hiroshi Ishiguro has developed likenesses of himself, which he calls Geminoids, which he has used on occasion to give his university lectures instead of him (Abildgaard, 2012). Until now this has generated only anecdotal evidence, but the potential of these robots is easily imaginable, specifically in situations in which social distancing is required.

What makes telepresence robots interesting for education is their embodiment. At the moment there are two main applications for this kind of technology imaginable. The first is closely linked to their original purpose and concerns the inclusion of students with disabilities. Due to their physical "body", the robotic platform allows these students the participation in social activities and to be "semi"-physically present in, for example, a classroom or a lecture hall. Additionally these robots can enable students with disabilities to express themselves in ways that might be impossible for them due to their disability.

The second application is connected to distance teaching. In situations in which the teacher cannot be physically present, the advantages of telepresence robot are easy to see. Instead of being "present" on a screen, the teacher could move around in the classroom with the help of a telepresence robot. Besides the physical aspect of this presence, this is would also enable the use of different didactic methods like supervised group work. Most of these ideas are still visions for the future, but in situations like the current COVID-19 outbreak, a development into this direction might forcedly happen faster than can be foreseen.

1.2. Origins of social robotics for education

The research field of social robots in education is very young and has still to establish itself as a science in its own right. Even though its theoretical influences stem from a plethora of scientific disciplines, two also still very young approaches can be seen as originators of this new field. One is the originally strongly informatics driven constructionist approach, and the other is the psychology and evolutionary anthropology driven approach of social robotics.

Constructionism - Tools for teaching programming, robotics and science

In order to be able to understand the current state of the use of social robots in education, it is important to have a brief look into how robots were used before the advent of socially evocative robotic technology. We will therefore start with how robots were used as tools for teaching informatics and science, since this is the oldest and was for a long period the most influential approach on how robots can be successfully integrated into the learning process.

Using robots as tools for teaching programming and robotics is based on the "constructionist" framework and the related "learning-by-making" methodology (Papert and Harel, 1991). In this approach robots have mainly been used as tools in schools for teaching robotics or, more broadly, engineering (i.e. mechanics, electronics, and programming), and the development of software applications (Hirst et al. 2003, Powers et al. 2006). In this function robots are used in a hands-on and collaborative way.

This methodology has its origins in Seymour Papert's idea of making computers and programming easily accessible to children [Papert, 1980]. Papert developed a programming language called LOGO [Papert, 1999] that would later help children to playfully learn how to create simulations on computers, and in this way help them to lose their fear of programming and to learn not only how computer technology functions, but also how to model complex natural phenomena like, for example predator-prey equilibria [Gkiolmas et al., 2013], and in this way understand the value, limits and dynamics of simulations. Papert and his colleagues created programmable robots for children called turtles. This robots were equipped with crayons on their bottom side. By programming the robots' movements via the LOGO programming language, children could create composite geometrical drawings, and by being creative with technology they could explore their capacity for finding solutions to new problems.

This approach was lifted onto an entirely new level in the second half of the 1980ies, when Papert's Media Lab at the Massachusetts Institute of Technology started to collaborate with the Lego cooperation. The result of this collaboration was a programmable Lego brick based on Papert's LOGO programming language. The first widely commercially successful product released from this project was the RCX programmable brick. The first educational robotics systems successfully introduced to schools was the Lego Mindstorms NXT [Lau et al., 1999] in the second half of the 1990ies. It was tested and integrated in middle schools and high schools to teach students the basic principles of programming, electronics and mechanics (Hirst et al., 2003; Powers et al., 2006). With these robotic systems students could familiarise themselves with robotic technology, learn its underlying principles, and construct simple applications. The didactic objectives of this approach are two-fold. On one hand it is teach children how to program, and on the other it is to strengthen their problem-solving skills.

Project based learning (PBL) (Carbonaro et al., 2004) became the generally used approach when using robots in this type of lesson. The PBL approach has its origins in the works of John Dewey, the American psychologist and educational reformer, who was an early proponent of the ideas of hands-on learning and experiential education (Dewey, 1897). His ideas found their way into educational robotics via the works of Jean Piaget (Piaget, 1936) on situated learning (Lave and Wenger, 1991) and cyberneticians like Heinz von Foerster (von Foerster, 2007) and his work on constructivism and cognition.

Tab. 3 - Examples of robots used in the constructionist approach

Robotic Platform	*Area*	*Role of the robot*	*Mode of Interaction*	*Didactic objectives*
LOGO - Turtles 	Secondary schools, High-schools	Object, tool	programming	Learning informatics
Lego – Mindstorm 	secondary schools	Object, tool	Physical assembly, programming	Learning mechanics, informatics, electronics Problem-solving, social competences, collaboration abilities
BEEBOT 	Pre- and primary schools	Object, tool	Keys on the back of the robot	Learning principles of mathematics

Starting with the early turtle robots, it was the cooperation of Papert's lab with the LEGO cooperation that gave rise to the Lego-Mindstorms EV3 which still represents the most successful system used for the learning by building approach.

Another way in which the constructionist approach has been implemented is using robots as tools for teaching science (Resnick et al., 1996; Papert, 1980). The areas in which robots have been used most in this capacity are mathematics and physics, more specifically electronics (e.g. Balogh, 2010; Mukai and McGregor 2004). A recent example that focuses on teaching primary school children simple mathematics concepts is the BEE-bot (Highfield et al., 2008; Church et al., 2010).The use of robotic systems in this way happens typically within in a larger project. The didactic objectives here are teaching students domain specific content (Barak and Zadok, 2009; Whittier and Robinson, 2007), and since this approach is project based (Bell, 2010) and requires the children to work in groups over a longer period of time, the work with the robots also facilitates the development of social competences or soft skills like conflict resolution and collaboration abilities, project management and complex problem solving (Ionita and Ionita, 2007; Sullivan, 2008). The general aim is to foster the four dimensions of learning – cognitive, affective, social and meta-cognitive – in the children (Catlin and Blamires, 2010). Typically the teacher develops a project whose solution involves a small group of students that needs to construct a robot with the task to reach a specific goal. During the project the teacher then takes the role of facilitator, who catalyses students' ideas around a concrete activity and guides their progress (Gatt and Vella, 2003, Sadler, 2009). This represents a stark contrast to traditional teaching methods, in which the teacher is the owner of the knowledge and the evaluator of the students' performance. It requires a shift from the frontal approach towards a progressive approach based on tutoring and transformative feedback. We will discuss this later in Chapter 2.

Tab. 4 - Overview of approaches which use robots as tools for teaching informatics and science

Application area	*Role of robot*	*Target Group*	*Didactic objective*
Tools for teaching programming	Object, tool	Secondary school	Learning about mechanics, informatics, electronics
Tools for teaching science	Object, tool	Secondary school	Problem-solving, social competences like collaboration abilities

It is interesting to see that when robots are used in this context they have been used in combination with two different specific didactic approaches, as the following examples will show. Kim (2010, 2011) used an approach called Robot based instruction (RBI) for elementary school children. In their work they showed that using a robot during class increased the immersion and participation of the children in the teaching process. Park and Cho (2011) showed additionally that using robots during class to give direct or indirect instructions created positive participation during class and the feeling of an authentic learning experience in the students.

The same group also developed the robot enhanced inquiry based learning approach (REIBL). The idea behind this approach is closely linked to inquiry based science education (IBSE) (Constantinou et al., 2018). Park (2015) demonstrated in a comparative study that using REIBL improved significantly both the motivation and academic achievement of the students.

Social Robotics

The distinguishing features of a social robot are its socially evocative characteristics. Social robots are capable of sensing and interpreting human social signals, and to react adequately to these signals. Compared to factory robots which are oblivious to the space around them and require from their humans users to adapt to them, social robots are integrated into a visual and acoustically noisy social environment and are required to adapt their behaviors to that of their human users in order to interact with them on human terms. This shifts the perspective of the definition of what robots are towards a human-centred view, away from the optimization focused robot-centred perspective of industrial robots.

Dautenhahn and Billard (1999) proposed the following definition of social robots:

> Social robots are embodied agents that are part of a heterogeneous group: a society of robots or humans. They are able to recognize each other and engage in social interactions, they possess histories (perceive and interpret the world in terms of their own experience), and they explicitly communicate with and learn from each other.

This early definition puts the focus on the robots' embeddedness in an environment with other social agents. It illustrates one of the early goals of social robotics, which was also its most ambitious – enabling robots to learn from their social interaction based on theories from pedagogy and social psychology. The main theoretical focus was from the beginning on the works of Piaget and Vygotsky. Consequently a considerable effort of the research in the 2000s and 2010ths has been put into developing paradigms to teach robots language via social interaction and use them as models to explore language grounding in humans (Cangelosi, 2008). These efforts were not limited to verbal communication, but also to non-verbal social signals. Solving the topic of language learning in robots is still ongoing and has become central to the field of developmental robotics.

The focus on social interactions was from the beginning in the center of another important research direction in social robotics – the development of applications for existing social robotic platforms. The biggest potential for these applications was seen in settings where robots could help people with special needs, i.e. children with Autism Spectrum Disorder (Vanderbrought et al., 2012), elderly people with cognitive abilities (Bemelmans, 2012) and hospital patients. These applications of social robots were categorized into what is now called robot assisted therapy (RAT). Zoomorphic robots like PARO (Chang et al., 2013) are being used in animal therapy in care homes, and humanoid robots like KASPAR (Dautenhahn et al., 2009) are playing an important role in RAT for children with special needs. The most recent application of social robotics is the use of social robots in education. As shown discussed above there have been a variety of approaches over the 10 years, however a unified theoretical framework and a grounding in didactic theory is still missing. Since the beginning of the development of social robotics about 20 years ago the field has developed considerably, which enables us to attempt a more differentiated and detailed definition of what social robots are. Based on the dedicated previous work in the field (e.g. Breazeal, 2002; Fong et al., 2002; Dautenhahn, 2002) the broad requirements which need to be fulfilled for a robot to qualify as a social robot are the following:

- Social robots need to be embodied agents. This point is true about robots in general, however for social robots the focus is on an embodiment that enables the machine to express social signals that are reliably interpretable by humans. It is therefore of little surprise that most social robots have a face with more or less expressive eyes in order to provide a point of reference for humans during interactions, and arms and hands with more or less detailed fingers for gesturing. The body of these robots is typically mobile for approaching movements of potential communication targets.

- Social robots need to be part of mixed human-robot ecologies. This again is a necessary but not sufficient characteristic, since it is also true for household robots like Roomba. However social robots need to be integrated in human ecologies not only in a physical but also in a psychological sense. They are required to actively be part of human interactions and adapt to the needs of their human users. This leads to the next requirement.
- Social robots need to actively engage in social interactions with humans in their environment. This requirement refers to their social dimension. They need to be able to sense and react appropriately to verbal and nonverbal cues given by their users. This includes situations in which the users might not actively engage the robot, but would require help. The robot should be able to sense this and engage the human.
- Social robots should behave according to human rules and norms. This point touches the ethical component that is necessarily involved when considering machines that have the potential to influence human emotions and relationships with other humans. Not only would robots, that are violating human conduct norms, be most likely rejected by their users, they could also potentially lead to undesirable changes of human sociality over time.
- Social robots need to have the capacity to trigger human social behavior. This point is closely related to the previous one. It makes explicit that for a robot to be considered social, the robot needs to have the ability to enter into human interaction dynamics and influence them. To what extent and in what way this should result in an active manipulation or adjustment of undesired human behaviors is still open to debate. The importance of this point becomes apparent when we think about applications of social robots in which they need to help elderly people by for example reminding them to take their medication, or in which they support and guide children to learn new skills. In both cases it is of great importance to define very clearly the extent to which robots should insist with humans in order to achieve the require goal.

These requirements illustrate again the social scientific roots of social robotics. The study of human social dynamics necessary to understand how social robots should look like and which behaviors they should exhibit in which specific situation, involves, besides engineering and informatics, disciplines like evolutionary anthropology, developmental and social psychology, and sociology. Due to this hybrid nature the general goals of social robotics are not limited to the technological advancement of robotic technology, but are the creation of robots with which untrained humans can communicate and interact successfully in complex social environments on human terms, and the generation of intuitive, flexible, and pleasant interaction possibilities between humans and robots. In other words social robotics aims at the integration of embodied artificial agents into mixed human-robot ecologies, in which they interact in close physical proximity with humans. The social environments in which this interaction happens can be as diverse as we can imagine them, ranging from private homes to public schools, and from shopping centres to hospitals. The focus of social robotics is on the specific social interaction dynamics in these environments. Ideally social robots will be able to identify the goals, intention and emotional states of their human counterparts and react to this sensory input reliably. These reactions should be expressed verbally and non-verbally, and all aspects of these interactions between humans and robots should be synchronized. This goal is of course still largely a vision for the future, but despite all the technical problems robotics - and specifically social robotics - is facing, great advancements have been made in this direction in the last 20 years and robots are slowly moving into human social spaces.

The functionality of social robots to be able to interact with humans in an intuitive and understandable requires them to be fully embodied agents and preferably humanoid in order to express human verbal and nonverbal behavior. Besides some limited uses of cartoonlike social robots like iCat (van Breemen et al., 2005) and Iromec (Ferrari et al., 2009) almost all of the social robots that have been used in the last ten years in educational settings fulfil these characteristics. This bears a great potential for the development of naturalistic robotic behaviors not only for the use in applications, but also for a further understanding of human social evolution. However, it also generates a problem. It makes the development and implementation of this kind of fully embodied agents in education much more costly and difficult, than the use of robots similar to the ones that can be constructed from Lego Mindstorms. Herein lies one of the reason why, until now, the majority of robotic technology was used as tools for STEM education in the past (Benitti, 2012; Benitti and Spolaôr, 2017). With the availability of more or less affordable humanoid robots like NAO this starts to change slowly. Nevertheless, the cost factor remains to be an ongoing issue and will require also changes in the perspective of the policy makers on the future of education.

1.3. Limits of current robots in use

The reasons that prevent the widespread use of social robots in educational settings have their origin in different factors. They are on one hand linked to technical limitations, and on the other to a lack of solid grounding into the didactic theory. They are also connected to economic and political reasons, and to general issues that occur when rapid technological developments have to be continuously integrated into a changing curriculum and adapted by the people that are required to reinforce this curriculum.

Technical limitations

Some of the biggest technical issues social robotics is still facing are linked to perception. In order for any interaction even to start, the robot needs to identify if someone is speaking to it and if yes who this and where this person is relative to its position. These sensory tasks involve mainly to systems – speech detection and face detection. Both of these detection systems are working, in the robots that are commercially available and affordable, still not as reliable as would be needed in visually and acoustically noisy environments like classrooms. It is therefore still difficult for social robotic platforms to deal with group situations.

Another issue, that is linked to the visual system of these robots is autonomous navigation. In environments in which the robot has "only" to navigate around humans, for example in wide hallways of shopping malls or waiting halls of airports, this works reasonably well. However, the classroom situation is again a very different matter. There the robots need to deal with a confined environment with very little space between rows of benches and tables. What makes autonomous navigation especially difficult in classrooms is the clutter that can usually be found on the floor around the classroom tables, like school bags, jackets, bag packs etc.. The most imaginable solution to this is a co-adaptation of classroom settings and the robotic technology. Smaller group sizes and more spacious setups of the learning environment could be way of dealing with these issues. However, the sensory problems these robots are still facing are on the base of a number of other issues that make a flexible and naturalistic interaction difficult. In order for the robot to respond to a person appropriately it would not only need to understand who is speaking, but also ideally what this person's goals are and potentially her/his internal states. Having this information the robot should then be able to communicate verbally and non-verbally – using speech, gestures and body posture. In order to be coherent in the signals the robot sends out, all aspects of its communication need to be synchronized between each other, e.g. correct gestures for the given verbalizations, and with what the human user is saying. This brings us to speech recognition, the robot needs to understand the content of what is said. Most people are familiar with technologies and like Alexa o Siri. These applications work well in their respective intended environment. But thinking about how one has interact with Siri – holding the phone somewhat close ones face and speaking directly into it – makes the differences to social robots apparent. In a group situation in a noisy environment, like a classroom, a person would need to stand right next to the microphones of the robot, which are not always located were the ears are in humans, and speak slowly and clearly directly into them. This defies the whole purpose of social robotics, which aims at naturalistic interaction between humans and robots. Social robotics is in the process of solving these technical issues and given the contemporary shortcomings of the current commercially available social robotic platforms, there are alternative solutions that have been integrated in most of these platforms. Usually they involve a tablet and applications that are used on the tablet in order to focus the attention of single users. Some of the social robots have been equipped with touch sensors, which enable them to react to being padded on the head or touched on the shoulders, forearms or hands. This provides another channel of communication with the technology and enables, for for example the starting of specific applications via touch. In the third chapter we will give a detailed description of our solutions for using a Pepper robot in a lecture hall setting as general and personal feedback device, by addressing the above mentioned issues in ways that enables the robots functionality in the role it is intended to fulfil.

Theoretical limitations

We mentioned briefly above that at the basis of social robotics are theories from developmental psychology and pedagogy. Pioneers of the field were strongly influenced by the works of Piaget (1936) and Vygotsky (1978). However this initial inspiration was focused on the simulation of social learning processes in robots, and in this way the creation of a form of artificial social intelligence in machines. As the field evolved, it became clear that this embodied socially evocative technology, socially evocative because it can trigger human emotions and change human intentions, can be used in situations in which the manipulation of human motivations is central. Therefore the intended uses of social robotic platforms outside of controlled laboratory situations became on the commercial side, the provision support for customers in airports and shopping malls, and on the social support side helping people with special needs either at their own homes or in hospitals, and supporting educators in teaching situations.

The initial use of social robots in teaching started by using them in schools for children with special needs for the support and development of social interaction behaviors in children with Autism Specturm Disorder (ASD). This type of application was initially based on the observation that children with ASD have an affinity to robotic technology. Following this line of thought the idea was to use the robot as a bridge or attentional focus point, in other words as a social mediator, between educators and children with special needs. A lot of this early research aimed at helping children with ASD to learn adequate social behaviors, which consequently would improve their inclusion in everyday activities with other typically developing children. The applications in this area were mainly driven by the technological possibilities of the time and the theoretical psychological underpinnings of ASD research. Due to the young age of the field the methodologies developed and applied were mainly exploratory, creating a variety of different interaction games that provided space for the educators using the robot mediator to use their personal abilities to successfully shape the interaction with the child. Many cases studies showed the success of these robots and this approach. However, due to the specific nature of ASD being a spectrum disorder and the limiting technological the procedural developments this work cannot be generalised to teaching situations in a broad sense or embedded in general didactic theory.

Another path that was adapted early on was the use of social robots in schools to teach young children a second language. In this area different research groups used different theoretical and practical approaches from different pedagogical schools, which fitted their robotic platform and their specific didactic goal best as theoretical underpinnings. Each of these approaches was demonstrated to be successful for the specific application in which it was used in, however the selection and application of the approaches themselves seem to have derived more from the fact that social roboticists were looking for an didactic methodology that could be applied for the specific robotic embodiment in use, rather than from the development of a specific robotic application based on a general contemporary didactic theory developed by educators.

This underlines one of the problems of the field. Not only the technical aspects of the field are driven by roboticists, but also the theoretical didactic development, creating a situation in which roboticists are forced to pick or develop methods that fit best their robot embodiments and the didactic goals they have in mind.

The issue of education lagging behind technological development is as old as teaching (Laurillard, 2013a). Even writing itself was developed 3400 BC in Mesopotamia for commercial reasons, not for teaching how to write, and today this is still the case with most information technology inventions, which are mainly developed for entertainment or commercial reasons and not for education. With the increasing speed of information technology innovation in the past decades this has become even more critical and created a gap between the latest generation of digital natives and their teachers. This "lagging behind" the technological advancements has created in education a situation in which a considerable number of students are more savvy technology users than their teachers, despite the fact that in many cases the teachers are required by the curriculum to teach how to use this technology in a responsible way. This situation has on one hand created insecurities and stress on side of the teachers, which ultimately results in a reluctance to engage with new technologies in the classrooms on a reoccurring basis, and on the other hand it makes students use new information technology in unguided and unreflected ways.

Since social robotics as a scientific field is still in its infancy, and due to its great potential for didactics and the evolution of teaching, the educational sciences are still in the position of staying in front of the innovation wave and of shaping the technology according to the needs of the teaching process. It is now time to use ideas from contemporary didactics to ground social robotics firmly into education and to initiate a co-evolution between the educational sciences and social robotics.

1.4. What is missing?

The examples of how social robots are used at the moment in education which discussed in this chapter illustrate that most of the development of applications and embodiments of social robotic platforms is driven by social robotic specialists in experimental setups, with little involvement of researchers in didactics and pedagogy. However, in order to successfully integrate social robots into school curricula, the stakeholders that are involved in the definition and implementation of the school curricula need to be the driving force in the theoretical development of the applications. There seems to be, from our perspective, a lack of communication between robotics researchers and educational professionals and theorists. In order for any technology to be successfully applied it needs to be accepted by the people that are going to use it. For this to happen we need an open discourse, that also involves the political decision makers, in order to create the preconditions for a co-evolution of social robotic technology and teaching environments on a larger level. It will only be possible to convince educators to use social robots without the continuous supervision of roboticists, if it is clear how the robot are to be incorporated into the school curriculum and into daily routines in the classrooms in general, and what the advantages of this integration are for the teachers, students and the teaching process.

In order to do so, clear definitions are needed of what the roles and functions of social robots are in didactics, and what it means for a social robot to be a didactic mediator. Even though social robots are mostly described in terms of social mediation in educational settings, when they are integrated into the didactic process, they become didactic mediators. This transformation needs to be discussed from a theoretical education and didactics perspective. A starting point for the grounding process is the enactive didactics approach by Rossi (2013). This theory applies the principles of enaction to the process of teaching in terms of feedback reinforcement, and defines the interaction between teacher and student as a process in which new knowledge is constructed. From the perspective of social robotics this theory lends itself to ask a series of questions:

- What can the role of social robots be in the didactic process?
- Where are social robots situated in the in the process of didactic mediation?

- Can the integration of social robotics in education be a sustainable progressive development?

In the next chapter we will discuss in more detail how these questions could be answered. We will illustrate how ideas from enaction theory have been introduced into didactics and how these ideas can be linked to social robotics research. We will introduce an Enactive Robotic Assisted Didactics approach, that incorporates these ideas and serves as the platform for our implementation of the semi-humanoid robot Pepper into university lectures, which we will describe in the third chapter of this book.

Chapter 2. Social robots in the process of didactic mediation

Humanity is facing various serious global challenges, ranging from pandemics to environmental change. Most of these challenges have their origin in the way we organize our societies. Since social organization always starts on the individual level and depends on how each of us relates to others and perceives her/his environment, it is safe to say that a lot of the issues our societies are facing have their origin in how we brought up and taught previous generations. The role of education is central for any change in the right direction to happen.

The exponential speed with which digital technology has evolved in the last 4 decades made one of the central issues between technology and education stand out even more clearly than it has in the past. The use of new technology in education is driven by the development of technology and not by the development of didactic theory. In the past this has not created problems since the speed of the technological evolution, even in the beginning of the industrialization, was slow enough for teachers to stay on top of it. At the moment however we have reached the point where the digital natives, the generation that was born into a world of cell phones and with the internet, know how to use these new technologies better than their teachers, which does not imply they know how to use this technology responsibly and appropriately for their and the betterment of humanity, or with the necessary ethical guidelines to avoid problematic social developments.

The issue that arises from this is based on the discrepancy between the promise of the new technologies and the reality of their implementation. In the early days of the internet in the beginning of the 1990ies it was hailed as a means to make knowledge freely accessible to everyone everywhere. In combination with anti-formalist approaches to didactics there was hope that children, or better students of all ages, will be able to find and explore the knowledge that would fit their needs best. There are two severe issues with this approach, which have become very clear. One is that knowledge has not become freely available to everyone everywhere with the widespread use of the internet, albeit the fact that knowledge is much more accessible now then it was even only 50 years ago. The other and much more serious problem is, that humans are not able to educate themselves by exploring randomly the plethora of information that is provided to them via the means of modern digital technology. They need to be given strategies, guidance so to speak, in order to meaningfully find their way in the mace of the abundance of knowledge past generations have accumulated and which is now provided in the world wide web in different pre-digested ways. Education should provide the means for this guidance and enable students to differentiate between useful and unuseful information, and news and fake news. Only by providing these kind of skills we will educate responsible citizens, which will hold up democratic values.

In order to do so the field of didactics faces two challenges. Since it has become impossible to teach everything in one lifetime with sufficient depth, so that knowledge can be applied in our highly specialised modern day working environments, a trade-off has to be made between what is being taught, and with what details it is being taught. We see from our cumulating crises, that, on one hand, an oversimplification of complex problems, like the environment or globalized economy, bears serious issues that can lead to disastrous consequences. On the other hand, it is necessary to develop specialized, highly detailed knowledge for almost all facets of modern industrial or research ventures. Modern, technology assisted didactics is in the ideal position to develop solutions and offer possibilities to tackle these challenges.

As much as it was unimaginable for the some of the readers of Papert's book (Papert, 1980) at the end of the seventies for children to have a powerful computer disposable at all times to aid their learning process, as much it seems to us today difficult to imagine that the generation that is born in this moment, in other words the class 2038, will have a personal robot to their disposal to help with their education/learning. Yet, extrapolating the current technological developments into the future, as Papert did in his book, there is a distinct possibility that exactly this will come to pass.

When introducing computers into the classrooms in the early 1980 the hopes were high, that this will transform learning and with it the entire scholastic system will be revolutionized. Unfortunately instead of computers generating a new way of learning, they were adapted to the old ways of teaching and learning, and subsequently used to reinforce the well beaten track of neo-liberalistic ideas that have transformed the educational systems of the western world into their current state.

It is important to prevent the same mistake from happening with rising robotic technologies and the potential they provide. For the first time we are confronted with a technology that is situated and embodied, object and social agent at the same time, and in this sense a truly hybrid of social and didactic mediator, a bridge between artificial and natural, or in terms of didactic mediation between active and symbolic (Damiano, 2013). For the first time we are confronted with a technology that has the potential to tap into human psychological mechanisms, like the tendency to anthropomorphise and the ability to empathize, and to use them to support actively the learning process to support social feedback structures.

Where computers were limited to simulations in the strictest sense, robots can interact with humans on human terms. In other words we are dealing with technology in humanities profoundest, species defining evolutionary mechanisms – complex and differentiated social interaction. As it has become normal for the generation of digital natives to use social media to communicate and to learn, for the next generation it will be natural to communicate with and via robots. Where computers could be used to present learning materials like maps, encyclopaedias and simulations to aid the didactic mediation, robots can become an integral part of the social feedback processes that construct these materials, if we use them as social mediators in didactics based on the principles of enaction.

In this chapter we will be looking at the role and importance of different types of feedback in didactics and give an overview of the principles of enaction and of the enactive didactics approach. This will lead to a reflection on the role of embodiment in didactics. Because the difference between robots and other intelligent tutoring systems is the physical body of the robot, we will discuss the uniquely human trait of active teaching (ratchet effect) and the importance of non-verbal communication for behavior coordination in human evolution and its implications for the use of gestures in human-robot interaction. At the end of the chapter we will discuss an enactive robot assisted approach to didactics and the position of robots in the process of didactic mediation within it.

2.1. Enaction and didactics

Enaction

Humans have been represented in different ways over of the past centuries. One recent way of representation is as complex self-organizing systems that are dynamically embedded in complex self-organizing environment(s) (von Foerster, 1960). In this theoretical perspective, the process of adaptation is often described in terms of "co-evolution". The idea is that of a close interaction, constituted of exchanges of energy and matter, between two operatively independent self-organizing systems. Typically co-evolution is characterized as a symmetrical relation of reciprocal perturbations and endogenous processes of self-regulation that coordinate the dynamics of a system with the dynamics of its environment. As long as the two systems maintain their form of organization, the dynamical evolution of each of them consists of a series of endogenously generated states of activity that are compatible with the self-organizing states of the other system.

Maturana and Varela, offered a particularly well-defined notion of co-evolution in terms of "structural coupling" (Maturana and Varela, 1987) within their theory of autopoiesis. Introduced by Maturana and Varela to conceptualize the adaptive coupling as a cognitive coupling, this notion indicates the capability, typical of biological systems, to effectively act within their domain of existence to maintain and develop their organization and their mode of existence. According to the theory of autopoiesis, at the level of the dense interactions between conspecifics characterizing social environments, structural coupling becomes "behavioral coupling": a symmetrical relation of reciprocal perturbation and endogenous self-regulations that generates the interdependence of the behavioral conducts of the interacting systems. Maturana and Varela hypothesize that in humans, behavioral coupling is the basic structure of social interaction based on communication (Maturana and Varela, 1987).

When developing the theory of enaction in the 1990ies (e.g., Varela et al., 1991), Varela gave this notion of structural coupling a central position. Figure 1 is a schematic illustration of this structural coupling between an individual and its environment. Changes in the dynamics of the environment generate perturbations in the dynamics of the individual, which reacts to these changes via different self-regulative behaviors to compensate them.

These self-regulative behaviors generate in turn more perturbations in the environment, and thus creating an ongoing self-reinforcing loop. In case of social interactions between two or more humans, the internal equilibria on one hand can be represented by the personal traits of the individual, which depend on her/his phylo- and ontogenetic history. The perceivable changes on the other hand can be represented by the different verbal and nonverbal communication signals.

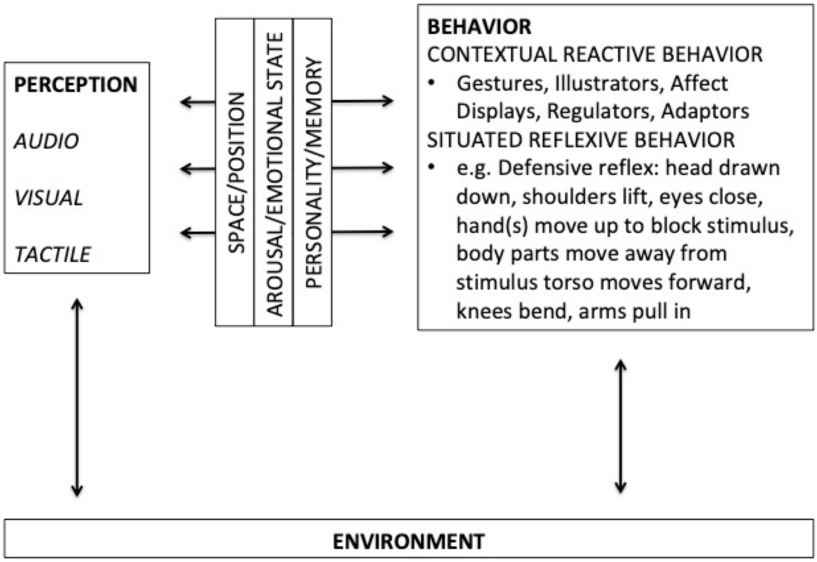

Fig. 1 - Structural coupling between environment and human perception and behavior. Behavior categorization into contextual and reactive according to Ekman and Friesen (1969)

In order for a social exchange to be successful, i.e. to communicate and achieve a common goal, which in its “simplest” form could mean to have a conversation, the behaviors between the involved individuals need to be coordinated (Oullier et al., 2008). This type of coordination can be found on all levels of embodied human behavior, ranging from voluntary verbal and non-verbal communication signals, like the use of a common language and culture specific gestures, to involuntary non-verbal signals like eye movements (Doughty, 2001), and even to coordinated neuronal patterns (Rizzolatti and Craighero, 2004).

The key point of the enactive approach brought forward by Varela et al. (1991), can therefore be defined as the disposal of the distinction between internal and external factors influencing the development of a system that exists in an environment. It replaces this distinction with the concept of structural coupling between the system and its environment. This structural coupling is characterized by a continuous mutual process that co-transforms the patterns of activity of the system and its environment. Through the expression of reactions, intended to maintain or re-establish internal equilibriums, the individual changes its environment and the process it interacts with it. In this way the system and the environment need to be thought of as two aspects of the same process. When applied to human communication, the means might be more direct – verbal and nonverbal, but the mere occurrence of their situatedness in the social interaction means that they change each other, and based on this dynamically ongoing changes also change the characteristic or context of the interaction.

Transposing these characteristics to didactics, it becomes apparent that the teacher influences with her/his presence the context of the teaching situation, the subject to be taught, and the student. The student in turn changes the teacher, and the context; and the context changes the teacher and the student. This procedural view of mutual influence shifts the focus of teaching away from the "What" to the "How", from the static content to the dynamic process (*Figure 2* – adapted from (Maturana and Varela, 1987)). Following this line of thought, knowledge then becomes a product of the teaching activity, the context of the teaching activity, the individual characteristics of the teacher and the students, and the culture in which it is developed and used (Brown et al., 1989). It becomes clear, that it is no longer possible to distinguish between the content that is be taught, the way this content is taught, and by whom and to whom it is taught.

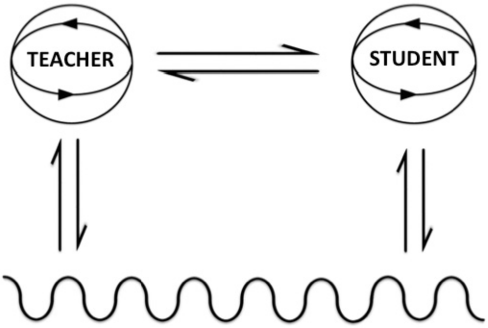

Fig. 2 – Structural Coupling between teacher, student and the learning environment

From constructivism to enactivism

At the end of the second millennium education theorists were divided between two opposing factions. Some followed the instructivist approach that derived from behavioral theories first and then cognitivist theories and that, while transforming and adapting to what was described as the information age, maintained some essential traits. These were the positions of Gagnè, and of Merrill, for example, whose main works identified the elements (Gagnè, 1965) or the principles (Merrill and Twitchell, 1994) of an effective teaching. On the other hand, there were the followers of the constructivist approach, starting from Piaget's ideas and the more radical ideas of von Glaserfeld (2013), who put the position of the student at the center and saw learning as a construction of knowledge. At the end of the century some authors began to point out that they were tired of the continuous unproductive "squabbles" and, as Wilson proposes, that it is necessary to reengage in teachers' practices and understand their dynamics and problems.

Since the end of the 80s of the last century, the constructivist world had presented itself not as a homogeneous field but with different perspectives. There was the situated approach initiated by Brown et al. (1989) with an article still at the center of the debate, and a few years later Lave and Wenger, who took up the more radical approaches by von Glasersfeld and that Jonassen (1994), which were more attentive to teaching and the role of the teacher. Jonassen highlighted the relationship between scaffolding and fading in the teacher's action. At the same time, the increasing presence of technology in education strengthened the perspective of social constructivism, which, taking up Vygotsky (1978), stated that the community played a central role in the construction of meaning. Examples of this are the works by Sullivan (2008), Engstrom (2003), Stahl (2006), and Scardamalia and Bereiter (2006).

The debate of those years had reached a stalemate. It was the confrontation between the two positions of learning that started from different premises and it was difficult for the discussion to generate new perspectives; each one remained on its own positions.

In reality, as Wilson argued, overcoming the blockade could only happen through a close confrontation with teachers' practices and the reflection on them.

The two approaches, behaviorist and constructivist, focused on learning processes and each of them had some valid points. But none of them spoke about teaching, or teaching and interactive processes that are defined in the classroom and that need to be analyzed to understand a rethinking of teaching.

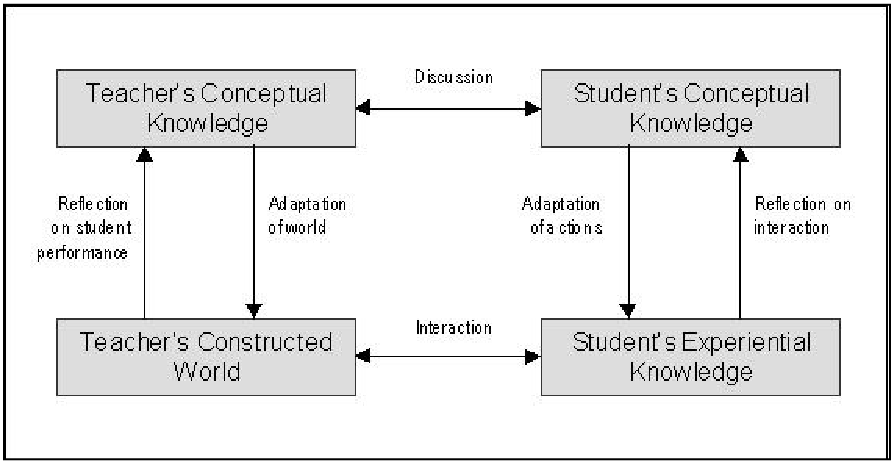

Fig. 3 – The Laurillard Conversational Model (Laurillard, 2013b)

It was in those very years that the studies of practice analysis emerged in France, carried out under the guidance of Altet, Bru and Blanchard-Laville (2012), and in Switzerland the studies of Durand and Piozat (2017). In the English-speaking world the interactionalist approach was developed in the university environment by Laurillard (2013). Her Conversational Framework, although designed for the university world, manages to describe well the relationship between teaching and learning. It does not throw overboard the psychological research on learning, particularly in the constructivist field, but it frames it in a more complex perspective that also takes into account the teaching processes.

In the conversational framework the student elaborates his knowledge (adaptation and reflection) in a recursive process in which the initial idea is regulated in itinere as a result of the inputs of the communication cycles (discussion and interaction) and practice that the student has with the teacher and her/his peers.

Therefore, a double process emerges: an internal process within the student of generating ideas and regulating ideas (a similar process also occurs, as shown in Figure 3, within the teacher, who puts his knowledge and assumptions into play in each phase of the work) and an external process consisting of communication and practice cycles between the student and the teacher, and the student and her/his peers. The communication cycles consist of question-answer processes or, in other words, question feedback cycles, while the practice cycles consist of the activities proposed by the teacher that activate the student to carry out tasks and provide feedback based on the proposals made by the students. Similar cycles exist between the student and her/his peers; feedback coming from peers also has a different role and weight than that coming from the teacher. Peer feedback presents a different perspective that must be compared with one's own and must be validated. It is a proposal that has the same "value" as the subject's idea, but may suggest other perspectives with which to find a way through the same concept or problem.

In theoretical terms this mode of teaching can be well interpreted by the enactivist approach. As we described before, in this approach every living system is an autopoietic system that has an internal organization according to which it acts, produces artifacts and knowledge, and builds itself. But it is a system that receives input from the outside and communicates with the outside world. These inputs, however, do not determine the evolution of the system, but can question the internal balance, can destabilize the system. It is up to the system and only to the system to reconstruct a new equilibrium.

Bringing the enactive model to the educational field, it emerges how it can make learning dialogue (what happens in the student) with teaching (the interaction between system and environment, between student and teacher), the external input that does not determine the evolution, but allows to destabilize the system and start new processes.

Therefore, enactivism does not deny constructivism, but puts it in a systemic perspective in which it does not focus only on the learning process, as constructivism does, but on the teaching-learning interaction. From constructivism enactivism recovers the idea that the new balance is the result of the work of the subject, it is a process of rebalancing as Piaget had intuited.

From critical constructivism essentially:

- the impossibility of avoiding undesirable results in the construction of knowledge;
- the influence of the dominant culture in education and the structure of knowledge;

- the underestimation of the structural coupling between teachers and students;
- the interest in the cognitive aspect of knowledge.
- Constructivism does not explain unformulated or unconscious knowledge, it does not consider how things could be known intuitively or instinctively, and it does not consider how emotions are constructed and what their role in learning is;
- the absence of explicit connections with the theories of learning proposed by cognitive neuro-sciences and neuronal biology (Begg, 2000, p. 2).

Going even deeper, the difference between constructivism and enactivism focuses mainly on how the relationships between the teacher and the student are specified.

Tam (2000) lists the following four basic characteristics of constructivist learning environments, which must be considered when implementing constructivist teaching strategies:

1. Knowledge will be shared between teachers and students.
2. Teachers and students will share authority.
3. The teacher's role is one of a facilitator or guide.
4. Learning groups will consist of small numbers of heterogeneous students.

In this proposal the teacher's world and the student's world seem to be divided and to be shared, but it is not specified how and with which processes, nor if sharing leads to new conceptualizations. In Altet's (1997) and Laurillard's (2013) interactionalist proposal, the focus is instead on interactive processes, which do not eliminate those within the student, but are parallel to them and equally important for the construction of networks of meaning. The non-mechanism of teaching on learning does not delete the role of teaching. Let us now try to understand what these processes are and how the teacher can operate.

How to make processes interactive? What to do?

There are two processes that need to be examined closer to understand how the teacher intervenes, following the enactive approach

- On the one hand, the processes through which the subject recursively develops his own network of sense. It is a process that sees paths of immersion in practices and reflexive distancing from them. In the words of didactics this means for the teacher to set up activities that see the student involved personally or in groups in the solution of authentic tasks and, then, leave time for reflection on this practice, but also provide a modeling of the procedures with which to reflect, distancing themselves from their actions and reorganizing their knowledge. Although the reorganization of one's own network of meaning is an internal process within the subject, this does not mean that the teacher cannot intervene in the ways in which the student implements, suggesting models for such processes. In the following of our exhibition we will focus on how the presence of a robot can support a habitus aimed at the analysis of such processes.

- On the other hand, the interactive processes between student and teacher. If the process of rebalancing within the teacher, i.e. learning, arises from the emergence of a state of discomfort, the role of the teacher follows these steps:
  1. A state of discomfort arises from a conflict between conceptualization and experience. Some of the student's conceptualizations may be misconceptions, i.e. they may arise from misreadings of experience and hide cognitive conflicts. The interactive process therefore requires the teacher, when dealing with any problem, to start from the confrontation with the student, analyze his conceptualizations and identify the cognitive conflicts present, conflicts between concept and experience, which the teacher rereads as conflict between the student's concept and wise knowledge.
  2. Once the conflict has been identified, the teacher focuses on them and proposes activities.
  3. During the activities, two processes alternate: the first is internal to the student, the second is interactive: it is the feedback between teacher and student, the series of questions and answers that make it possible to fine-tune the process, or rather, it is the inputs that push the two actors to rethink their systemic organization and reorganize their processes and concepts.

The two moments although described as separate constitute a single cycle in which the following processes are present:

- Discussion between the teacher and the learner
- Generation and adaptation (internal process of both the student and the teacher)
- Interaction between the learner and the teacher or the environment defined by the teacher

- Regulation and Reflection (internal process of both the student and the teacher)

The next paragraphs and in particular chapter 3 will identify how the robot can intervene in these two moments and four processes in university teaching.

To better understand how this can happen, it is necessary to see in a dynamic way the system with three agents: teacher, student/s, robot. In a dynamic way because in some cases the robot replaces the teacher providing, for example, feedback, in others the robot asks questions and intervenes as if it were a student, providing models to the student on the processes of the same and intervening on the epistemic cognition, i.e. on the postures with which the subjects are placed in relation to knowledge.

The importance of feedback in teaching and learning processes

The role of feedback for learning has been highlighted by various authors and in various researches and "based on the idea – that the quality of the students' interaction with delivered feedback is as important as the quality of the transmitted message – researchers have begun to re-conceptualize the feedback process" (Nicol, 2018, p. 48).

Hattie proposes that feedback is a strategy with a high impact on learning. Hattie and Clark (2018) have identified the elements that allow feedback to be effective: clear, propositional, meaningful and compatible with the students' previous knowledge, bearing in mind the cognitive load and the personal zone of proximal development and, most of all, it must help the student to build logical connections. They also point out that the tasks of processing, the regulatory and self-regulatory are interrelated (p. 102).

Laurillard highlights the importance of feedback as a central element of teacher-student interaction. By listing the teacher's actions that can promote learning. She proposes:
- align teacher-learner goals;
- set task goals that use concepts and actions that are available to the learner;
- clarify the structure of concepts to assist the organization of knowledge;
- construct an appropriate practice environment;

- monitor learner actions and articulations of their concepts;
- ensure meaningful feedback. (Laurillard, 2012, p. 98).

As we can see, feedback is one such action and at the same time favours other actions. For example, it facilitates alignment, clarifies the structure of concepts, and helps to control the learner's actions. Feedback can be related to the concepts processed by the students or the processes they activate. In addition, there is not only the teacher's feedback to the concepts and processes that explicit/activate the student, but also the student's feedback about what the teacher does and requires. Explaining what the teacher has understood in a lesson is very important feedback for the teacher.

Let's go back to Laurillard (2013b) who states:

The representation of the learner learning … shows that the actions generated are informed both by the goal the learner is trying to achieve, and their current concepts; and that the information that results from the feedback on their action then modulates their conceptual knowledge in order to improve the next action, and may also modify their goal. The cycle of goal– knowledge–action–feedback–modulation constitutes what is learned and how. What the concept of alignment recognizes is that unless the teacher addresses the full cycle the intended learning outcome may not be achieved. It might be achieved, if the learner is able to build for themselves the alignment between intended learning outcomes ←→ teaching–learning activity ←→ assessment, but the principle of alignment says that it is the teacher's role to ensure it." (pp. 99-100).

This also offers two ways to organize feedback:

- marking critical features of discrepancies between what the learner has produced and the ideal solution;
- demonstrating an idealized version of the act to be performed (Bransford et. al., 2000)

Laurillard concludes by saying:

The feedback is a critical element, and Bransford and colleagues argue for the importance of "having a 'coach' who provides feedback for ways of optimizing performance … it is not efficient if a student spends most of the problem-solving time rehearsing procedures that are not optimal for promoting skilled performance" (Bransford et al., 2000)." (Laurillard, 2013a).

It is therefore crucial to focus on feedback when talking about formal learning contexts.

Types of feedback

The classic feedback is the teacher's response/correction to the student's question/task. The feedback is based on the comparison between the expected result and the result achieved by the student and the teacher's ability to identify the cause of any misalignment. This approach is valid, if the result of the assignment is unique and predictable. But what happens if the result is open? In this case the teacher's comment is personalized and depends on the student's choices and decisions. The comment in this case is also on the method used in the execution of the assignment.

There is a third type of feedback - recursive and generative feedback. In many of the current perspectives of didactics, the path involves starting from the conceptualizations of the students and through comparison and their explanations to build new networks of meaning. In this case the feedback is biunivocal: from the student to the teacher when s/he makes her/his own concepts explicit, from the teacher to the student when s/he organizes and restructures these concepts.

It is difficult to arrive at a definitive result, in the sense that each concept expressed by the students is on the one hand the arrival point of a process and on the other the starting point for the following steps. A concept is always evolving, it is fluid and never definitive and that is why we talk about recursive feedback, which underlies a didactic cycle and recursive knowledge.

The feedback, in this case, is generative as it provides the elements to proceed and provides fragments to build the next network of meaning. In the first case it only allows to verify if the fragments proposed by the teacher had been acquired and inserted correctly in a sense network.

Laici and Pentucci (2019) argue that the constructionist vision manages two types of feedback playing different roles in learning: intrinsic and extrinsic (Laurillard, 2012). The first, intrinsic feedback, is inside the action and is its direct consequence. It is supplied by the environment, by the context itself, and the student conveys it to be able to use it. The extrinsic feedback, instead, is outside the didactic action. It is supplied by a subject that tries to reduce the distance between the student and the learning objective (William, 2010).

Such types of feedback fall within a concept of single-directional feedback mainly focused on the effects that they have on knowledge building and on the student’s learning process. Even when the feedback supplied by the student is considered, in addition to the feedback supplied by the instructor, it is accepted from the point of view of the benefits it implies for the student himself (Nicol et al., 2014) and generally in terms of peer feedback (Serbati et al., 2019). The most recent reflections on feedback introduce the concept of the feedback loop, meant as a triangulation between student, peer group and instructor, where there is an alternation of discussion, questions and answers, activating a cycle that involves both the students and the instructor, which is needed to adjust the actions of the latter to ensure an impact on the students' learning (Carless, 2019). Without this information, instructors are blind to the consequences of their actions and cannot, therefore, act effectively to improve the quality of learning. It is an interactionist vision of feedback. (Rossi et al., 2018)

Rossi et al. (2018) propose that a cyclic and recursive feedback allows the students to have not only interpretative skills, but also the ability to activate an argumentative process with the instructor, an *open* and dynamic process to which the people involved are committed in mutual alignment. Laici and Pentucci (2019) propose further that:

The dialogic dimension of the feedback highlights its nature of being a discursive, adaptive, interactive and reflexive process (Winstone and Carless, 2019), due to which a new didactic attitude is actualised. According to Nicol (2018), the feedback has a generative value, that is, it activates in the student an inner process through which he constructs knowledge about his own ongoing activities and understanding through his own evaluative acts. Students are the definitive source of all feedback as it is, they who ultimately generate it and it is this that generates learning (Andrade, 2010).

Therefore, the concept of generative emerges that is in line with many of the current didactic and pedagogical suggestions in which it is emphasized that the school, more than guaranteeing information, favors structures that are useful to create networks of meaning.

The role of technologies

In university didactics the need to rethink feedback is even greater because the only indications from the teacher to the students are given during the examination, too late to affect the processes and to start adjustments in itinere.

On the other hand, feedback located in itinere is hardly sustainable if university classes see the presence of many students, which makes it difficult for the teacher to provide timely and personalized feedback. In such situations, technologies to overcome previous problems have long been tried and tested (Keough, 2012).

Experimentation of clickers as Personal Response System (PRS) started about 20 years ago and different modes have been used to identify tools that enable interaction in class: classroom response systems (Salemi, 2009), personal response systems (Beekes, 2006), group response systems (Carnaghan and Webb, 2007), student response systems (Cunningham, 2008), electronic response systems (Hatch et al., 2005), personal response units (Barnett, 2006), audience response systems (Caldwell, 2007), classroom performance systems (Petersohn, 2008), wireless course feedback systems (Rice and Bunz, 2006), classroom communication systems (Nicol and Boyle, 2003), electronic voting systems (Stuart et al., 2004), and voting machines (Reay et al., 2005).

The systems adopted now require instead of expensive devices a simple smartphone that all students already have and the use of apps that are often free to use: Mentimeter, Kahoot, Socrative, Todaysmeet, Slido, Polleverywhere, Zeetings (Compton and Allen, 2018),

In any case it should be stressed that the adoption of feedback and online tools must be aligned with the pedagogical-didactic approach and that the use of the clicker should never be seen as the inclusion of an activity already planned and independent from the clickers. Feedback changes the path and should be integrated into it. For example Fang (2019) shows a study integrating the 5-Star Instructional Model with a series of CIRS answers to improve teaching and learning in an Internal Medicine course and 5-Stars is a model designed by Merril.

Laici and Pentucci recall other experiments that involve the use of feedback. They start from the contribution of González (2018) that proposes a path that integrates games with the SRS, with the objective of motivating and involving the students, providing them prompt feedback and helping them to grasp the contents of the session in the two Civil Engineering modules.

Different contributions consider in particular the role the peers have in the feedback process quoting as pedagogic reference approach the paradigm of the Peer Instruction by Mazur and colleagues (Crouch and Mazur, 2001; Mazur, 1997, 2009; Watkins and Mazur, 2010) foreseeing a structured questioning process usually organized as follows: the students answer/vote individually; feedback (the percentages of the answers) is presented to the students by the SRS; the teacher asks the students to discuss their answer with peers (only if a low percentage of answers are correct); the students revote (crucial phase as it invites the students to reflect and consider the feedback received either in automatic form by the answerer and by the peers); the students receive corrective feedback and engage in a class discussion where the instructor supplies further detailed studies (Papadopoulos et al., 2019).

The essay by Pearson (2017) shows the experience led in a Chemistry course within the Project Ponder project-oriented to track the pedagogical benefit of clicker technology when applied to problem-based learning (Laici and Pentucci, 2019). Laici and Pentucci also report that Chi's work (Chi, 2008) connects the use of feedback with the conceptual change to identify and modify in particular the false beliefs and robust misconceptions. Liu (2018) provides evidence for the use of Twitter-based synchronous activities as path for feedback.

In the summary Laici and Pentucci's review highlights how from technology supported feedback the three types of feedback that were previously identified emerge:

- The lower and less incisive level on the general didactic process is the feedback defined by Nicol (2010) as **transmissive process**:

Teachers 'transmit' feedback messages to students about what is right and wrong in their academic work, about its strengths and weaknesses, and students use this information to make subsequent improvements" (Nicol and McFarlane-Dick, 2006, p. 201).

- The essay by Liu (2018) illustrates an experiment of **communicative feedback** between instructor and student supplied through Twitter, to encourage students to stay engaged and attentive during lectures by providing them with the opportunity to become active participants in the learning process and to enable students to receive immediate feedback.

These activities can also be useful in courses with technically complex content, where timely feedback may be particularly helpful to students in solidifying their knowledge" (Liu, 2018, p. 2052),

- The essay by Pearson (2017) finally introduces the concept of **iterative feedback**, as it proposes a series of questions repeated during the different weeks of a two-years course. From the instructor's point of view, the SRS "is also mindful of instructors' requirement for logistical ease when delivering to large student cohorts" (ivi, p. 1866). By interactive feedback is meant a dialogic form activated between student and instructor, a

> rethinking the unilateral notion of feedback from one in which information is transmitted from the teacher to the student to a bilateral and multilateral one which positions students as active learners seeking to inform their own judgements through resort to information from various others" (Boud and Molloy, 2013, p. 700).

Previous authors, as the review shows, underline how the use of interactive feedback changes teaching strategies: The alignment between student and instructor is, therefore, one of the products of this kind of feedback, which can be defined as recursive and systemic, while not the simple planning of feedback activities becomes fundamental, but the outlying of a training learning ecosystem with suited feedback functionalities: an ecosystem in which, differently from what happens in the ecosystem meant according to natural sciences, the adjustment of the parameters does not happen in a completely automatic way, but which requires the instructor's intentional action, who supersedes the balance of the learning system to keep a constant alignment between the progress of his didactic action and the progress of the students' learning (Bonanno et al., 2019).

The transformative value of the feedback is expressed at different levels of depth: the feedback of a transmissive type, with an informative value for the student; the feedback of an interactive type, enabling the student to amend the misconceptions and to act on the cognitive conflict from the beginning, while giving the instructor the possibility of regulating his teaching in action. Finally, the feedback of a recursive type, educating the student as s/he enters the learning process in a deep way and giving the instructor useful information not only to adjust but also to rethink the general scaffolding of the course (Laici and Pentucci, 2019).

Feedback and robots

If the literature highlights the role of feedback, our research must identify whether the presence of a social robot brings added value to the feedback process.

It should be pointed out that the robot intervenes in our experimentation in different ways:
- As a lecturer when students ask outside the classroom for comments on their work;
- As a student when it takes the questions inserted by the students and asks them to the teacher.

In fact, both actions can be performed without a robot. Personalized answers can be read online, doubts can be read directly by the teacher. The experimentation in progress tries to compare the two modes of delivery and wants to examine if different results are obtained due to two elements:
- The robot as embodied artificial agent is different from the teacher, and therefore the emotional implications that characterise the relationship between the students and the teacher do not exist in the student-robot relationship;
- Because of its ontological difference the robot can highlight how the doubts expressed by it and by the teacher's comments are not the teacher's doubts, but are actually the students; in other words, it should encourage a greater identification by the students and ensure their greater emotional and cognitive participation in the process.

2.2. The role of embodiment in didactics

Non-verbal communication in human evolution

Human social evolution is largely driven by the human ability to communicate about past experiences and thus to pass on knowledge and accumulate cultural techniques (Tomasello, 1999; Tennie et al., 2009). It appears that the process of direct active teaching, despite some very limited (and to some extent controversial) exceptions, is a uniquely human characteristic (Caro and Hauser, 1992; Kline, 2015). Even the most direct and probably earliest forms of teaching, for example demonstrations of how to catch and dismember an animal, most likely contained a wealth of different signals.

These signals can be roughly divided into verbal and non-verbal signals. Verbal signals include speech and utterances, such as shouting and laughing. Nonverbal signals include touch, facial expressions, posture and gestures. In human social exchanges these signals are typically used in various combinations with each other to avoid misunderstandings and facilitate efficient and pleasant information transmission.

Additionally people display a variety of non-verbal behaviors simultaneously, many of which are displayed unconsciously. The expression of these behaviours as well as their recognition involves almost the entire body (Scheflen, 1972). Humans are able to use the posture of their conspecifics, the way they move in terms of speed and expressiveness, their tone of voice and their general appearance in order to deduce or even understand inner states such as emotions or the degree of arousal. This understanding is at the very core of human social evolution, since it enabled people to feel empathy for each other (Kacperck, 1997), a capacity that plays a central role in the formation and maintainance social cohesion in large, hierarchically organized groups of individuals, like human societies (van Vugt and Kameda, 2012). Most of the cues used to "understand and feel" the others are non-verbal, hence the importance of non-verbal communication for human social evolution cannot be overestimated (Burgoon e al., 2016). Face, eyes and hands play a central role in this process (Müller et al., 2013). Decisive for interaction with others are unconscious eye movements such as dilation of the gaze and pupils as well as hand and arm gestures (Argyle and Ingham, 1972). Most of these non-verbal signals have facilitating, regulating and illustrative functions (Knapp et al., 2013) and are as such part of the embodied exchange of information that enables coordinated communication between individuals and groups of people.

The importance of hand and arm gestures for non-verbal communication is central. In social exchange, where one does not have "all hands full", hands are usually used to illustrate and emphasize what is being said and even thought, and to regulate the conversational dynamics of an interaction. This is usually done through a series of culturally sensitive gestures. These gestures are essential to ensure a comfortable and intuitive social exchange. Unlike other unconscious non-verbal communication signals, gestures are population dependent (Ekman, 1972; Kendon, 1988).

Communicative gestures have developed in different parts of the world that have been isolated from another in the past. This, in combination with the physical constraints of the human body, has led to the effect that the same gesture can have very different meanings in different cultures. In some cases the differences can be quite striking. For example, if you travel from Europe to Japan and see a Japanese person waving his or her hand in front of your face and turning your face towards you, this can lead to a serious misunderstanding. This gesture, which is commonly understood in Europe as an insult meaning "Are you crazy?", is meant as an apologetic negation in Japan. But even within Europe the differences are very striking. In Southern Europe, especially in Italy, gestures are used much more frequently in conversations compared to the countries of Northern Europe. A comparison of the frequency and expressiveness of the use of hand gestures during a discussion among Scandinavians or Italians would make this clear.

However, it is important to point out that despite these differences, it is possible, albeit at a very basic level, to communicate successfully with gestures between members of very different cultural backgrounds. Specifically iconic gestures (McNeill, 1985), which are usually related to attributes of someone or something, or spatial relationships between entities in an environment, are easy to interpret across cultures. This points to the long history of gestures as a channel of communication in human evolution.

All the above shows that gestures, playing a crucial role during the early social development of our species, remain very much alive in contemporary human social communication. Research investigating various aspects of human cognition has shown the universal importance of gestures for improved information transmission (McNeill, 1992) and lexical retrieval (Morrel-Samuels and Krauss, 1992). It has even been shown that the use of gestures helps to reduce the cognitive burden of explaining complex problems to others (Goldin-Meadow et al., 2001). In this way, gestures not only reflect our cognitive state but also shape it.

One of the theories about the origins of human language is the gestural origin hypothesis (Corballis, 2002). It assumes that the use of gestures occurred before the development of verbal language. There is archaeological, physiological and behavioural evidence to support this theory. For example from a phylogenetic perspective, paleoarchaeological evidence shows a different growth rate between hominid brain regions linked to language use and the vocal apparatus (Lieberman et al., 1972). From an ontogenetic perspective, human babies show gestural communication before they speak

(Petitto and Marentette 1991). This illustrates even more that gestures are deeply rooted in the social evolution of primates. In combination with the facial expressions typical of apes and humans and the vocal signals typical of apes and humans, they added a layer of flexibility to the behavioral repertoire, which allowed for a greater communicative complexity, thus driving the social evolution of humans to its current level.

Embodiment in learning

Given this long evolutionary history of non-verbal communication in situations that can be defined as teaching and learning activities, it is not surprising that the field of didactics has always included, in a more or less structured way, the physical expression of the body and the use of gestures as a method of transmitting knowledge. After the very productive period of academic research on non-verbal communication in general, and its evolutionary roots in particular, in the 1970s and 1980s, there have recently been many studies that have taken a structured and descriptive approach illustrating how important it is for teachers to have the capability to not only confidently send, but also to be able to receive non-verbal communication signals (Miller, 2005; Padalkar and Ramadas, 2011).

Various studies showed for example a strong correlation between gesturing the solving or faultless describing of spatial problems. For example Rauscher et al. (1996) were able to demonstrate that if persons were prevented from gesturing while speaking about spatial problems, then they had an increased rate of dysfluencies per word compared to persons who were able to gesture freely. Other studies, which aimed more specifically at learning situations, demonstrated on one hand that when children perform gestures mimicking movements, they were able to solve spatial transformation problems more easily and correctly (Erlich et al., 2006), and on the other that children that were allowed to gesture while solving mathematical issues performed better when compared to children that were not gesturing (Cook and Goldin-Meadow, 2006).

In general it can be said that research in the last decades has accumulated sufficient evidence demonstrating a strong positive connection between body movements and learning success, to ensure that the use of this kind of embodied communication should find its way into didactic practise and theory. As discussed in the first chapter one of the better known approaches, and one of the oldest, in this direction is the Total Physical response (TPR) approach for language learning (Asher, 1966). The theory behind this approach is that a coordination between movements and language facilitate a better and faster learning of the new language.

However recently there have been other more general approaches applying the principle of integrating body movements and specific gestures into teaching and learning situations. Roth (2000) showed in his work the importance of gesturing for the development of scientific understanding and language in highschool students. He concluded that especially in the beginning of the learning process, when the scientific principles are not yet very clear to the students, the use of gestures to represents a valuable conversational resource that helps the students to develop domain specific knowledge.

In order to make the use of gestures during class feasible, it is important to understand to which degree teachers are able to consciously alter their body movements and use specific gestures at the right moments during their class. Hostetter et al. (2006) tested whether this is possible. They found that all the teachers in their study were able to control their nonverbal communication signals and alter their gestures according to the content of the lecture, making the structured use of gestures by teachers a promising and viable method to enhance the learning experience for students. How effective this method can be was demonstrated by Alibali et al. (2007). In their study the teachers used successfully gestures to scaffold learning during algebra lessons, improving the understanding o the students. The same research group (Alibali et al., 2013) additionally showed the amount of content students can learn during lessons increases, if teachers use gestures effectively, or more specific using the right gestures at certain moments during the knowledge transmission process.

In another approach Kastens et al. (2008) could show how the use of communicative gestures can improve problem solving not only in the person that is observing the gestures, but also in the person that is doing the gesturing. They illustrated in what way gestures can be used beneficially during science education by the teachers and how teachers can create situations that foster student gesturing and in this improve the learning experience.

From the exemplary studies discussed above, which represent only a fraction of the available evidence, it becomes evident that from the perspective of embodied cognition non-verbal communication and gestures can and should play an integral part in learning and teaching processes, not only in a theoretical, but also in a very practical sense. This importance of the body as conduit for non-verbal communication signals and positive facilitator of social learning is another factor that makes social robots an ideal technology to be integrated into educational processes. In the next part we will see how body movements are already successfully used in Human-Robot Interaction research and how central the role of gestures is for the success of HRI.

Gestures in Human-Robot Interaction

For the inclusion of robots in mixed human-robot ecologies (Damiano et al., 2015; Dumouchel and Damiano, 2017), it is important that not only their verbal, but also their non-verbal behaviour is geared towards the human expectations. Since human non-verbal behaviour includes a large variety of signals, the same should apply for robots, especially when they are going to work in close physical and even social proximity to humans (e.g. in schools, elderly homes, hospitals). This specifically to context-dependent reactive behaviour such as gestures.

Research has shown that with increasing degrees of autonomy and human similarity in the appearance of robots, their human users tend to humanize them (Riek et al., 2009; Eyssel et al., 2012; Damiano and Dumouchel, 2018). For example different blinking patterns of robots can influence the perception of the robot (Lehmann et al., 2016), and the more naturalistic humanlike the blinking patterns are the more people tend to accept robots as competent interaction partners.

Since the goal of social robotics is to enable intuitive and comfortable interaction between robots and humans, robots should be equipped with behavioral coordination capabilities that enable them to become part of the structural coupling of humans and their environment. In other words, if we understand both human-human interaction and human-robot interaction as co-evolutionary processes or processes of structural coupling, we can apply the principles of interaction to the design process of robot behavior.

The understanding of the importance of non-verbal communication in combination with the technological progress of robot embodiments that allow the expression of non-verbal signals has led to different approaches in recent years to implement and test communicative gestures in humanoid and non-humanoid robots. These implementations were carried out from different perspectives and were based on different research questions.

Ono et al. (2001) for example presented in their work a model of embodied communication that includes both gestures and utterances. They tested their model with the Robovie platform in an experimental setup in which the robot gesticulated to varying degrees while explaining the path to a specific goal to a human interlocutor. They were able to show that (a) the more the robot systematically gestured, the more often the gestures of the human subjects became, and (b) the more the robot used gestures, the better the humans understood its utterances about reaching the goal.

Others have investigated the role of gestures in the process of starting a human-robot interaction, maintaining it and perceiving a connection to each other (Sidner et al., 2005). The results of these experiments showed that humans pay more attention to robots and find their interactions with the robot more appropriate when gestures are present in the interaction. Riek et al. (2010) tested the effect of different aspects of interactive gestures of a robot on the ability of humans to cooperate with the robot. They found that humans cooperated faster if the robot made abrupt, front-oriented gestures.

Beck et al. (2011) tested whether it is possible with a robot to express emotions with body language in a way that children can understand and interpret them. Their robot expressed different body postures for typical emotional states such as happiness, fear, anger and pride. Their results underlined the importance of the position of certain body parts, i.e. the head posture, during the expressed emotion to ensure the interpretability of the expression.

Another very interesting insight into the use of body language and gestures during human-robot interaction comes from Ham et al. (2011). They used different gestures and gaze behavior to test the persuasive power of a narrative robot. In their experiment the participants listened to a robot telling a classical Greek fable. Their results showed that only a combination of appropriate head gaze and accompanying gestures increased the persuasive power of the robot. The authors pointed out that in the state in which the robot did not look at the participants and only used gestures, the persuasive power of the robot actually decreased because the participants felt not addressed. This illustrates an important point for research into the use of social robots in education. It is not enough to consider only different aspects of body language and then model them separately on the robot, but it is at least as important to focus on their integration to achieve a holistic behavioral expression during interaction.

Huang and Mutlu (2013) used a narrative robot equipped with the ability to express different types of gestures. They designed deictic, percussive, iconic and metaphorical gestures following the terminology of McNeill (McNeill, 1985, 1992). Their results showed interesting effects for the different types of gestures. For example, deictic gestures improved the information recall rate of the participants, and iconic gestures increased the male participants' impression of the robot's competence and naturalness. An interesting aspect of their results is that metaphorical gestures had a negative influence on the participants' engagement with the robot. The authors note that the large number of arm movements associated with this type of gesture may have distracted participants.

In addition to the knowledge that this research provides about how people use and understand gestures expressed by robots, it also has very practical and applied benefits. Especially in the last five years, a variety of robotic social platforms have been used in areas ranging from schools and airports (e.g. Tonkin et al., 2018). International projects such as the Mummer project (Foster et al., 2016) experiment with social signal processing, high-level action selection and human-aware robot navigation by introducing the Pepper robot for a long-term study in a large public shopping mall. The results of this project were applications that enable the robot to talk to customers and entertain them with quiz questions and give them orientation by describing and indicating paths to specific destinations in the mall.

This research over the past 15 years underlines that for almost all of their future applications, specifically in educational contexts, social robots will need to be able to interact with humans in a human-like manner. Once the robots leave controlled and rigid environments like laboratories and factories, their communication skills must be suitable for naive users, i.e. they must be able to communicate in an intuitive way accessible to humans.

What is interactivism / enactive didactics and embodiment in learning?

In the previous sections we have highlighted the role of the body and of the movements/gestures during interactions. In this paragraph we would like to face a connected, yet in many ways, different topic. The analysis that follows starts from some hypothesis the authors can only partially validate and only from the point of view of the didactic results, while they cannot verify the neuroscientific implications.

The starting point is that knowledge is often seen as the clarification of concepts whose elaboration is considered as mental manipulation. In reality the elaboration foresees some processes concerning our space-time, bodily and mental way of acting, related to others in our environment and to ourselves. The processes of knowledge are plunging and distancing ones, plunging in space-time situations and distancing from them, where the distancing is not only from the other but also from ourselves, taking allothropic points of view, instead of autothropic ones. In design, for example, simulation has an important role (Gero, 1990; Gero and Kannengiesser, 2004; Rossi, 2009) and this often requires either a physical or simulated repositioning, in space and in time, living a situation as if we would be in it. In the same way in didactics the teacher's modelling, that is action and not only description of the action, has a pivotal role. In other words, conceptualization is never separated from the action, if it foresees situations in which there is no action or possibility of action, for example when one mentally simulates the lesson for the following day, in reality the conceptualisation process foresees the simulation of the action.

The previous reflections start from assumptions derived from research in the field of neuroscience and therefore are, for the authors, only working hypotheses, as they are based on theories that do not belong to didactics.

In particular we will try to develop a series of reflections starting from mirror neuron research (Rizzolati, 2006), and from the concept of embodied simulation (ES), introduced by Gallese and Sinigaglia (2011), a concept they developed based on the theory of mirror neurons.

The research started in Parma by the team of Rizzolati on mirror neurons shows that these neurons activate not only while one is performing some actions, but also when the subject sees that others are performing the same action.

Sinigaglia and Gallese (2011) extent the complexity of this process by introducing the concept of Embodied simulation.

> Embodied Simulation theory provides a unitary account of basic social cognition, demonstrating that people reuse their own mental states or processes represented with a bodily format in functionally attributing them to others (Sinigaglia and Gallese, 2011, p.512).

In the same direction goes the concept of body format (Caruana and Borghi, 2016) according to which the representation of some concepts passes through a representation of sense-motor processes. Sinigaglia and Gallese (2011) ask how mental simulation should be understood and focus the attention on resemblance and reuse, and on the relationship between inter- and intra-personal processes.

Its core meaning has been discussed by emphasizing two different but not mutually exclusive features: resemblance and reuse. On the one hand, mental simulation has been essentially conceived of as a form of **inter-personal** similarity: a subject's mental state or process simulates another's mental state or process just in case it resembles the second state or process in some significant respect and in doing so fulfils one of its functions or aims (Goldman, 2006, 2008, 2009). On the other hand, it has been proposed that reuse rather than resemblance captures the core meaning of mental simulation: inter-personal similarity between a simulator's and a target's mental state or process does not qualify as mental simulation unless it arises from **intra-personal** reuse of the simulator's own mental state or process (Hurley, 2008; Gallese, 2011) (Rizzolati and Gallese, 2011, pg. 513)

ES for the authors is not only at work during motor actions, but also in the sharing of the same kind of neural and cognitive resources. In different paper Cuccio and Steen (2019) underline how the sensor-motor system participates to cognitive activities and how "recent studies of a behavioral kind (e.g. Glenberg and Kaschak, 2002), a neuroimaging kind (e.g. Kemmerer et al., 2008) and a neurophysiological kind (e.g. Papeo et al., 2009) have shown that the sensorimotor system is involved in language understanding", even if "the role of Embodied Simulation in the construction of figurative meaning is still controversial (Cuccio et al., 2014; Gallese and Cuccio, 2018).

As stated by Sinigallia and Gallese (2011) "'Embodied' usually means that body parts, bodily actions, or body representations play a crucial role in cognition" and the embodied simulation enables the interpretation of the way such process takes place.

In relation to didactics and knowledge processes it is necessary to deepen the insight into precisely these processes to understand what embodied cognition means in the specific case, how to activate it and how to support it. It should also be pointed out that ES is not activated in the same way when the same process is activated, because the repetition of the same process allows an assimilation of the processes that become gradually "mechanical" and incorporated in such a way as to require a different mode of ES.

In the field of education the embodied vision opposes a fully cognitive vision of knowledge, as if the knowledge process was an exposure and acceptance of conceptualizations which does not require an interaction between subjects and a space-time positioning of the person.

The processes observed in the classroom are much more complex. Think of a student listening to a lecture. It is not only an acceptance of what the teacher says, nor is it only an understanding of what is proposed. Critical listening requires grasping, evaluating and reorganizing what is said and proposed. This process requires a succession of positions that modify the spatial relationship of the subject with the other first, and then with her/himself. There is a succession of positions of the subject towards the other, the teacher in this case, not only towards what the other affirms. A critical approach requires an immersion in the other's world in order to understand the meaning, or rather the sense that the other attributes to what s/he is affirming, and then to distance oneself and assume a different perspective and observe what is said as if it were an object to be evaluated. Subsequently, we analyse what the other person proposes according to their own world and also in this case are processes phases of immersion, in which we ask ourselves what the other person's proposal means in their own world and how we modify it. A critical approach does not mean a posture of continuous analysis, but a succession of immersion and distancing, of identification with the other before, and with ourselves after, and a detachment from the other and from ourselves. In the distancing phase the object-concept is also moved to a different world, that of the student; using what Rizzolati and Gallese said, it is necessary to move from an interpersonal perspective to an intra-personal perspective.

As one can see, it is not only a cognitive process, but a process that requires a continuous relationship of the person, in its totality, with the other person's world and with the other, to then return recursively to one's own world that however has its own space and physical dimension even if only internalized. The process of simulation previews to inhabit the situation and such worlds, that are three-dimensional, made of languages, affections, emotions, sense-motor activities and, in synthesis, of actions.

Such a process therefore can be described in form of spatial actions/metaphors. The same terms of immersion and distancing refer to sensory-motor and spatial processes.

In teaching, special attention is paid to these processes when talking about skills and the acquisition of reflective and metacognitive positions. The experimentation at all school levels has shown the effectiveness of modeling to learn similar attitudes. The teacher reflects, and while s/he reflects explicitly the internal processes s/he implements are much more effective than a lesson on reflection.

The enactive approach takes into account both the interaction between the inter-personal and intra-personal world, as previously described, but also the role of embodied cognition. The knowledge process is primarily an action. Action and knowledge are inseparable.

The question that needs to be asked at this point is whether the use of the robot can support the processes previously described. In chapter 3 we will show how Pepper was used in teaching processes in a university classroom. At this point we will anticipate only some aspects to connect the use of the robot to the previous reflections.

If complex processes, reflective skills and critical postures require the involvement of the person as a whole, mind and body, and if the modeling of the teacher is in literature considered an effective tool to facilitate the acquisition of such processes, then the presence of a robot could help in the simulation of the process of reflection or immersion and distancing.

In other words, could modeling be achieved by assigning to the robot, depending on the processes, the role of the student or the teacher? It is possible to assign to the robot, for example, the function of explaining the questions that a student could ask, the doubts that could be expressed while a teacher is explaining?

While designing or during a university lecture, while explaining, the professor asks her/himself a series of questions concerning what s/he is saying and the problems s/he thinks the students are facing when learning. S/he often makes examples and deepens some aspects according to those questions. Making those questions explicit, and, therefore, the attitudes s/he undertakes in relation to what s/he is saying and the way s/he thinks the others (the students) put themselves in relation to what s/he is saying, could represent her/his activity of modeling. Not always can s/he be credible, neither can s/he can always stop to make those questions explicit. But what if it were another one, a robot for example, to make those questions explicit? If the robot questioned the professor stopping a lesson and raising some doubts as if it were a student to make it? Isn’t it in this way providing a model of how a student should question her/himself during the lesson? Could such an intervention not prompt a reflective attitude in the student? Couldn't this be a way of providing models of how to question oneself while the other explains, how to acquire a critical attitude towards the other and the knowledge that the other expresses?

Another attitude in which the process involves the other person is to make the evaluation of a task explicit. The students ask the teacher to have details about their work and to understand their mistakes, but it is not always sustainable for the teacher to give all the students such feedback. What if it is the robot, in this case acting as the teacher, who returns the assessments and indicates the teacher's comments?

The two cases exemplify two situations in which the presence of the robot allows the situation to be recreated and to reify it. In those cases, thanks to the robot, the action is recreated and the processes of reflection, criticism, reconstruction and evaluations are not just only mental processes but interactive ones between two agents with all the consequences and the implications that this entails. The first one of highlighting how reflexive processes imply attitudes that are not only cognitive, but also sensor-motor ones between the subject and the other or between the subject and himself/herself as seen as the other, going from an auto-trophic to an allotrophic one.

2.3. Enactive robot assisted didactics

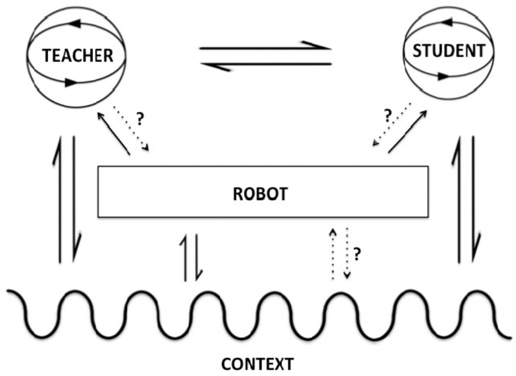

Fig. 4 - Structural Coupling in an Enactive Didactics approach with an integrated robotic tutor (Lehmann and Rossi, 2019)

Due to the specific properties of social robots, i.e. being embodied agents capable of expressing a variety of social interaction behaviors, they have the potential to increase the complexity of interactions between the different elements involved in the enactive didactic process (teacher, student and knowledge) by enhancing their interconnective properties. Used in the right way, social robots have the potential to become the gateway that allows students to interact with their environment and their teachers on their own terms. A social robot is potentially more than just a tool for achieving the teacher's goals, it is instead a mediator between the three elements involved in the teaching process.

In the case of special education, for example, robots can help children with different types of disabilities to construct their own social reality, which enables them to establish new rules for social interaction with other social actors (humans) in their environment. For typically developing children, robots can be used to support learning processes related to kinesthetic and emotional aspects of social interaction (Barakova and Lourens, 2010).

What enables us to attribute these roles to robots are their unique characteristics within the social exchange process. Since they have a body equipped with sensors and effectors, which enable them to react to their environment and engage actively and in a humanlike fashion to other social actors in their surroundings. The way social robots express reactions and behaviors is determined by the type of application they are used for. The most important factors for meaningfulness and interpretability are appropriateness and continuity of their expressions. Beyond these factors the design and implementation of their behaviors will depend strongly on the didactic objective of the context in which they are used. As described in Table 1 of Chapter 1, these can range from acquiring domain specific knowledge to the inclusion of students with special needs. Social robots could for example intervene when the didactic process becomes dualistic rather than enactive, i.e. they could ask specific questions to the teacher and provide feedback about the level of understanding of the students at certain points during class. In this way they would help to shift the teacher's sense of authority "from knowing the answers and transmitting the true knowledge" to moderating the enactive learning process. This would shift the climate in the class more towards a discourse and process of discovery, which potentially would make the teacher feel more comfortable without putting her authority in question, which in turn would improve the didactic process.

A social robot integrated into the classroom could also provide intrinsic feedback to the students, enabling them to understand where there problems with the new knowledge are, revealing the cognitive conflict between their current interpretation of reality and the new one proposed by the teacher. Understanding the issues created by the cognitive conflict through intrinsic feedback processes provided by a social robot in the function of a social mediator, could potentially ease the transition process of the student, creating a self-motivated and sustainable base for the new knowledge. This would lighten the weight burdening the teacher in interpreting the knowledge constructed by the student with the procedures that the teacher has implemented in the student. However, social robotic mediators should be flexible in the interpretation of the new knowledge produced by the student and, similar to an intelligent tutoring system, learn their cultural peculiarities and their mistakes in order to provide meaningful feedback.

In this way the robot would participate in the definition of the mode in which the student thinks and generates models. The student would construct knowledge to which the robot would give direct feedback by working either correctly or incorrectly.

Figure 4 illustrates a model for Enactive Robot Assisted Didactics. In comparison with the Enactive Didactics approach (see Figure 2), the robot occupies a central position in the didactic process. The solid arrows show how robots like NAO (Fridin, 2014) or Pepper (Tanaka et al., 2015) are currently used in the educational context. Their presence has an impact on the teacher, the student and the curriculum. However, for this approach to become truly enactive, the complexity of the structural coupling between all agents in the systems needs to be increased. The dotted arrows illustrate this increase. For the robot to become part of the dynamic changes within the learning process, its reactive flexibility must be increased. It must be able to adapt to the behaviors of the teacher and the students, and to the progression of the curriculum. These adaptive capabilities involve a high level of learning on the part of the robot, which would require strong artificial intelligence application.

2.4. Summary

The last ten years have seen more and more social robots being integrated into for example primary school language classes and in robot assisted therapy settings for children with special needs. These robots are usually humanoid and serve in the function of social mediator.

As pointed out in section "Enaction", in order for social interactions to be successful, behavior coordination is central. This is specifically true in educational contexts. Hence mechanisms to provide appropriate feedback from robots in tutoring situations have moved into the focus of research on social robots in education (e.g. Haas et al., 2017). This feedback is usually based on different sensory inputs from human social signals, and on the processing of these social signals. Social signal processing with the goal of improving robot feedback has been at the center of various recent social robotic projects (Belpaeme et al., 2015; Foster et al., 2016).

When used in education social robots are used in an area in which they are not considered mere tools. The function of the robot changes form object to educational agent involved in the construction of new knowledge. This moves the robot into the center of the teaching process. As we discussed earlier in this chapter, human culture has a cumulative nature and our social evolution is "ratcheted up" by active teaching (Tomasello, 1999; Tennie et al., 2009). This process is inherently human and the cultural techniques linked it to follow a trajectory that intuitively connects individuals and increases social cohesion in groups. They are necessarily based on verbal and non-verbal communication techniques and involve the entire human repertoire of social signaling. If we ascribe robots an active function in this process, it stands to reason that they need to be equipped at least to some extent with the capability to use body language and gestures.

Chapter 3. An example application with the Pepper robot

In this chapter we will give a detailed description of the implementation of the previously discussed theoretical principles in a university lecture hall setting with a humanoid robot. We will start with a description of *synthetic method* that provided the methodological guidelines we used during the process of designing the interaction scenarios and behaviors for our application. After this we will give a brief overview of the Pepper robot which we used for applications. The largest part of this chapter is dedicated to the detailed description of our implementation and a critical analysis of its impact. In this application we focus on the following didactic principles:

- Providing structure during the lesson
- Modeling the students reflective process
- Proving feedback for the teacher and the students
  - General feedback about the content of lesson via questionnaires to the entire class
  - personalized feedback about results of the questionnaires linked to lesson to each individual student,
  - personalized feedback concerning the grades and judgement by the teacher
- Providing relaxing and motivating entertainment during the breaks

At the end will give an outlook on the extension of our implementation currently in work.

3.1. The synthetic methodology

In order to be able to illustrate how meaningful interaction behaviors are created for social robots in general and specifically in the case of educational settings, it is important to discuss the underlying idea and methodology. Following a scientifically structured plan that is grounded in the enactive approach was one of the priorities in the preparation of our application.

The guiding methodology we used for addressing our work was the *Synthetic Method* laid out by Damiano et al. (2011). This methodology provides a structure for the successful implementation of embodied artificial agents in general into human-ecologies based on the principles of enaction. As we seen in chapter two, these principles postulate that behavior cannot be seen as based on an individual, but is always the result of the interaction between at least two social agents in a specific environmental setting, that in itself has a strong influence on all social actors involved in the interaction. In other words, following the enactive perspective means further that the dynamic coordination of two or more agents is more than the sum of the individual behaviors exhibited at any time during a social interaction. It is therefore misleading to observe only parts of an interaction and describe the observed phenomena, in the case of social exchange the interaction behaviors, in terms of an individual involved with taking the dynamics of the interaction into consideration. These ideas are strongly influenced by the complex systems approach (Wiener, 1948; Bateson, 1979, 2000).

For the integration of social robots into human interaction dynamics this means concretely that our development plan takes three different procedural levels into consideration to be successful. The **first procedural level** links Human-Robot Interaction research with psychological research on anthropomorphism and behavioral psychology. From the perspective of robot development, it is dedicated to the selection of social behaviors, which strongly facilitate the human tendency to anthropomorphize, that is, to ascribe mental properties (beliefs, wills, emotions, etc.) to anything other than a human. Current psychological research specifies that usually humans express this tendency by attributing to artefacts or animals the role of interlocutor within dyadic dialogs, that is, dyadic interactive situations involving turn-taking and different levels of communication, ranging from bodily or vocal imitation to conversation (Airenti, 2015). For the development of social robot applications for educational purposes this implies for robots the selection of behaviors that are typical of the dynamics of human-human educational settings, since these behaviors are likely to elicit in the students the propensity to perceive and treat robots similarly to human interlocutors – and, in this sense, build trust and confidence in the robot, independent of its social role during the didactic process. When selecting the behaviors for the robot the specificities of the robotic embodiment need to be taken in consideration from the perspective of two aspects of interindividual behaviour, in order to make them meaningful when executed by the robot.

Social behaviors are usually expressed via a series of movements that are coordinated within the individual. For example when speaking humans usually move their heads and both arms and blink in certain ways. The motions of the different body parts are synchronised with each other and it can cause feelings of uneasiness when talking to someone who has, for example as result of a disease, an uncoordinated jerkiness in her/his movements. For robot this means, that we need to watch not only one body part, but the coordination of different parts. For the human expectation to be initiated, the robot has to have of course the corresponding body parts, for example a robot that has no eyelids, is not expected to blink. This implies for our purposes of integrating robots into the didactic process, that it is, from the stand point of behavior development, not always advantageous to strive for very naturalistic embodiments, which create high expectations, but that simplified embodiments potentially increase the success of the robot behavior during didactic mediation, since they reduce the expectation of the students towards the robot.

The other aspect of human behavior that needs to be taken in consideration when designing robot behavior is the inter-individual dynamical coordination of the movements of the social actors. When humans engage in social interactions their behavior, i.e. body movements synchronize. This is specifically true for dyadic interactions. A good example for this kind of synchronization is the nodding of the head or the body posture. In order for a robot to be believable it must be capable of synchronizing its movements during conversations with the students, specifically in small group settings or during personal feedback in which the robot interacts with one student directly.

The **second procedural level** of the synthetic method is related to the first and implies interdisciplinary cooperation between behavioral psychology, robot design and HRI research. It deals with the hardware and software aspects of the robot chosen for the implementation in the didactic process. The hardware aspect is concerned with the physical appearance and characteristics of the robot. It is important to choose a robot that fits well the specifics of the teaching situation. On one hand to avoid overly high expectations, on the side of the students, about the social interaction capabilities of the robot. On the other hand to fit well the physical restrictions of the classroom/lecture hall setting. We will discuss this second aspect later in the course of explaining why we chose a Pepper robot for our implementation.

On the software side it is important to keep the intra- and inter-individual aspects of behavior in mind when developing the behaviors of the robot. We need both an individual coordination controller (i.e. a library of naturalistic movements for the different body parts of the robots (e.g. arm and head) including timing properties of these movements, to allow for their synchronization and control, and in this sense for the creation of a controlled complex set of naturalistic movements), and an inter-individual coordination controller (i.e., a correlation matrix dynamically linking a library of gestures or movements that the robots can detect in their human partners and the library of movements that they can execute).

The **third procedural level** of the synthetic method involves psychological and HRI research. It refers to the evaluation of the implemented robot applications. It is based on the idea that, to effectively assess their capability of creating useful human-robot didactic applications, tests have to be performed in the context of real human-robot didactic settings. Accordingly, this procedural level is dedicated to experiments involving students and teachers in real life educational situations in classroom settings.

Not all of these levels can be translated into concrete steps in educational settings, but in the rest of this chapter it will become apparent which part of our implementation corresponded to which part of the synthetic method.

3.2. The Pepper robot

Most of the educational social robots in use today are implemented in settings with pre-school or school children, and not with university students or in lecture hall contexts. One reason for this might be the less personal format of lecturing at universities. The large group size of university classes makes a one-to-one interaction almost impossible and limits the use of robots to group works with more or less small group sizes. This limitation is more conceptual than due to technical issues. When combining the mediator and feedback functionalities of educational social robots with the ability to display relevant information on an integrated tablet in specific situations, it is possible to create applications that prove effective also for university level teaching. The direction of this research trajectory brings us back to the theoretical underpinnings of what role a social robot can play in the process of didactic mediation and where its position in this process is.

We decided to use the Pepper Robot from Softbank Robotics for our applications. The robot stands 120 cm tall, has a weight of circa 30 kg, an integrated 10.1 inch touch display, a lithium-ion battery that gives it an approximate operating time of 12hrs, and a variety of sensors and actuators that enable it to interact with potential social interlocutors on a verbal and non-verbal level. As can be seen in Figure 1, the sensors include tactile sensors on its head and on the back of its hands, two RGB cameras, one 3D-sensor, microphones, bumper sensors, laser sensors, and infrared and sonar sensors. The touch sensors, the cameras and the microphones are mainly used for social interaction, whereas the laser, bumper, infrared and sonar sensors are used mainly for navigation. Additionally the robot is, for communication purposes, equipped with a series of LEDs, which are positioned on the side of its head, around its eyes, and on its shoulders.

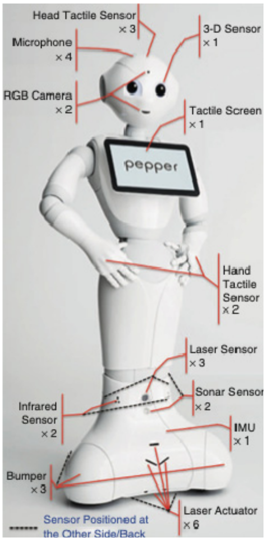

Fig. 1 - Pepper robot

In order to move the Pepper robot has motors in the neck, in its shoulders, elbows wrists and hands, as well as in its hip and its knee. On its bottom Pepper has three multidirectional wheels that allow it to move in every direction and to turn on the spot. The multiplicity of these actuators allow for smooth and naturalistic looking movements.

The robot can communicate with its human users in four different ways. It can generate speech, use body posture and gestures, display content on the tablet and change the color of its LEDs. The LED's on its shoulders indicate changes in the robots system status, e.g. the robot is booting up, an error occurred, or the robot is in sleep mode. The LED's around its eyes have the very important function of indicating, when the robot is listening. This can only happen, when the robot can "see" its social interlocutor.

When the robot has detected a person in front of it, its “eye color” changes from green to blue, indicating that it is ready to process speech from a person. If a person speaks to the robot when its “eye color” is not blue, the robot doesn’t register that it is the target of a social interaction attempt.

In general the semi-humanoid structure of the robot combines two advantages. Its expressive head, arms and hands allow for intuitive and naturalistic human-robot interaction, and its compact torso and multidirectional wheelbase gives it the stability to navigate in complex environments with moving objects or humans.

Why Pepper?

As discussed in chapter two, we can ascribe to social robots a central role in the feedback process between teacher and students in order reinforce the reticular character of the structural coupling during the learning process. It can be argued that this central role requires from the robots embodied non-verbal communication competencies with a character similar that of humans in order to be easily understood and non-disruptive. This need for similarity to humans means that robots should be equipped with culturally sensitive social gesture and posture libraries, which can be expressed best with a humanoid or semi-humanoid embodiment. Despite the differences between existing robot embodiments used in social interaction scenarios, they usually have a general humanoid structure (i.e. head, torso, arms, hands).

Pepper as a social robotic platform that incorporates these features. When Pepper was introduced 2014, is had been hailed as the new personal robot that would also be widely used in educational contexts (Benitti, 2012). However, it has not yet lived up to the expectations in the field of didactics. Pepper is at the moment mainly used as information guide in banks, shopping malls and public spaces like airports and museums (e.g. HMS Host, 2019).

We chose Pepper for our project because of its great potential for the easy development of new applications, and the fact that it allows us to focus on the key points of the “Enactive Robot Assisted Didactics” approach, which we are proposing. This is mainly due to the philosophy behind the design and construction of Pepper, which was conceptualized as a personal robot capable to express emotions and communicate with humans via gestures, body posture and speech (e.g. Softbank Robotics, 2018; CNN, 2018). Pepper's smooth motion-generation technology makes it specifically adapt for non-verbal communication, and enhances naturalistic looking dynamics of its movements. It can for example execute dances with motions that are fluent and "big enough" to draw attention in noisy environments. Overall the movement capabilities of Pepper allow for the quick proto-typing of complex movement scripts that also involve head gaze and gestures. As we have shown in detail in chapter two both head gaze and gestures are crucial for non-verbal human-human interactions due to their importance in human social evolution.

Other factors that need to be taken into consideration are the robots visibility and audibility in the classroom. A typical school class consist of approximately 30 students, but at university a lecture can be attended by around 150 people. Since we wanted to test the robot during first and second year pedagogy and didactics lectures we were looking at a group size of 150+ students. For this a robot is needed that can be seen in the lecture hall also from the backrows. This means the robot needs to be at least as tall as a sitting student. Further it is advantageous for the robot to be capable to draw attention to itself by speaking sufficiently loud. Since Pepper was designed to be used also for entertainment purposes in public spaces, it matches these two requirements.

Finally Pepper has an inbuilt tablet that can be used to visualize custom made applications or internet content. For a robot that is supposed to fulfil the function of didactic mediator this is very important, since it gives it the additional functionality of iconic representation. It is possible to use the tablet to visualize maps, pictures and slides. In our application we use this functionality to visualize timings during the lesson and support what is said by the robot. The details of this and the other parts of our application will be described in detail in the next section.

3.3. An application with Pepper

We use Pepper in different modalities during first and second year university lectures in pedagogy and didactics at the University of Macerata. These lectures are typically attended by approximately 150 students. In our application Pepper has three main functionalities:

- The robot's most important function is the strengthening of the feedback about the progress of the learning cycle between the professor and students concerning the content of the lesson.
- The robot provides structural feedback during the ongoing lesson, helping the professor improve the structuring of the lesson's content and the students to identify subsections and key concepts.
- The robot helps to increase the motivation of the students by providing relaxing entertainment during breaks.

In Figure 2 shows an overview of a typical lesson with the robot. It illustrates the different activities and interventions done by the Pepper robot during in chronological order.

Structuring the lesson

In its structure providing functionality Pepper not only helps the Professor to structure the lesson by keeping time and giving reminders of when a break is needed, a behavior specifically important during lectures lasting multiple hours, it also helps the students to recall the content of the previous lecture by giving a summary at the beginning of the lesson, and helps them to structure the content of the ongoing lesson, by giving an outlook of the central points at the beginning, and another summary at the end.

The robot starts a new lesson by welcoming the students to draw in their attention. After the students have settled down, the robot recapitulates the content of the previous lesson. The robot then asks if any of the students would like to ask questions about the previous lesson, or the robot itself asks questions to the Professor. After the potential questions are answered by the Professor, the robot provides an outlook for the ongoing lesson, describes the key concepts of the lesson and points out the learning objectives. The robot does all this in such a way that it enables the students to put the lesson's content in the bigger context of the lecture.

At the end of the lesson the robot summarizes what has been discussed in the previous three rs and asks different questions concerning specific key concepts, which the students are asked to answer. After having re-elaborated the lesson in this way, the robot provides an outlook for the next lesson and says goodbye to the students and the professor.

Additional to the recapitulation in the beginning lesson and the summary at the end, the Pepper robot reminds the professor how much time has passed at predefined intervals during the lesson. It does so by waving its right hand and saying that it would be beneficial for the students' attention to have a small break.

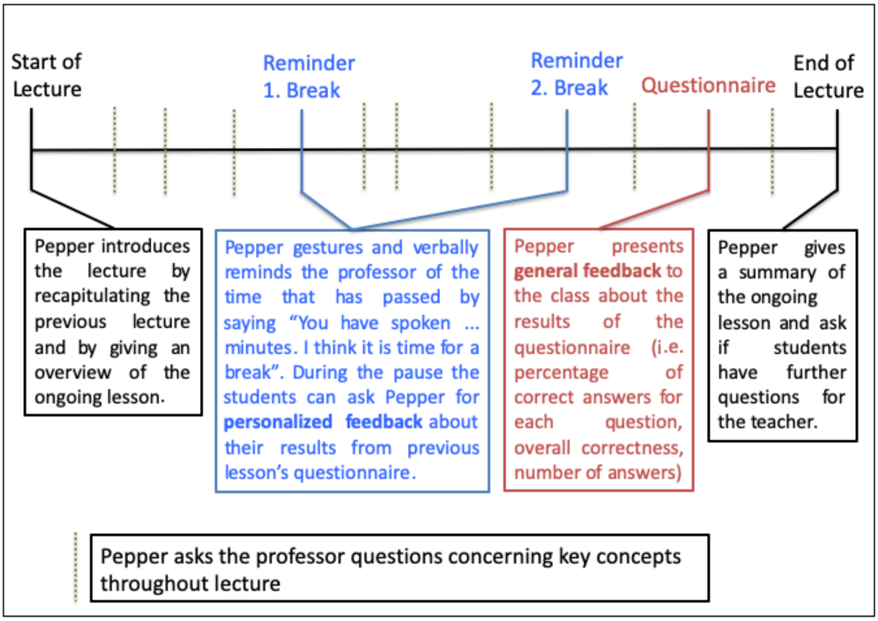

Fig. 2 - Exemplary order of events during a lecture with Pepper. The robot introduces the lecture, keeps the time during the lecture, reminds the professor when to do breaks, asks questions about key concepts during the lecture, and gives a summary at the end. In the towards the end of every lecture, the students fill in a questionnaire in "Google Forms". The robot analyses the answers and presents the results to the students during the lecture in form of general feedback, or after during the breaks of the next lecture in form of personalized feedback

At specific predefined moments during the lesson the robot raises its arm to indicate that it would like to ask a question about a specifically difficult point made by the professor. The question the robot would like to ask appears on its tablet. When the professor is ready to answer the question she/he can touch the tablet of the robot. The robot then lowers it arm and asks the question. The moment of activation of this application, called "The doubts of Pepper", depends on the professors progress during the lecture and serves to model the reflective process of the students. We will discuss this in more detail in the next section of this chapter.

During all the interventions the robot is executing, while speaking, it uses currently gestures that are generated by the "animated say" function of the "Choregraphe" desktop application provided by Softbank robotics. These gestures are designed to be synchronized with the intonation, tone and rhythm of what is said by the robot. They involve however also a random and potentially repetitive element. We therefore plan in a next step, to equip Pepper with clear context specific gestures to illustrate and emphasize the content of what it is saying. The only exceptions to the "Choregraphe" generated gestures we are using, are for the moment counting gestures and the iconic hand raising gesture. The counting gesture is used by the robot when it presents a list of concepts to the students that involves more then two elements and that need to be in a specific order. The raised hand gesture is used by the robot in the mode similar to this of students around the world, whenever it would like to ask a question to the professor.

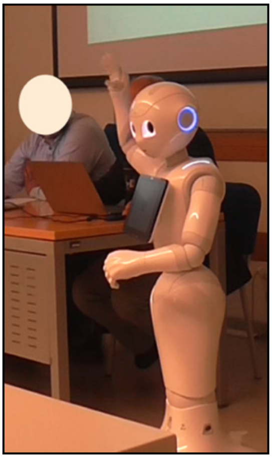

Fig. 3 - Pepper signals the necessity of a break

Modeling the reflective processes of the students

As briefly mentioned in the previous section, we use Pepper also to model the reflective processes in the student with an application called "The doubts of Pepper". As the lesson progresses, the professor explains different key concepts. Some of these concepts are difficult to understand in the context of the lecture. When these points of potential difficulty for the students are reached, the robots expresses this in place of the students, by raising its hand to indicate that it hasn't understood something completely and would like to ask a question. The professor knows from experience when these problems in understanding arise and what the questions of the students are. The questions of the Pepper robot are defined by the professor before the lecture accordingly and activated at an approximate

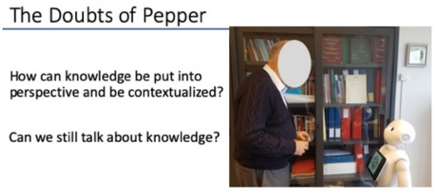

Fig. 4 - Example for question displayed on Pepper's tablet

moment during the lesson. In order for the robot not to be too interruptive it raises its hand and displays the question on its tablet. This gives the professor the possibility to exactly determine when she/he would like to interrupt her/his flow in teaching and to answer Peppers question by touching its tablet.

This does not only provide additional structure to the lesson, but also gives the professor the possibility to reflect together with the students about the potential conflicts arising in the knowledge construction process.

Providing feedback

In its feedback functionality we are using Pepper in combination with an Audience Response System (ARS), in our case Google Forms. Although the intrinsic usefulness of ARS's for direct real-time feedback is undeniable, the feedback they provide, is inherently un-embodied and depends strongly on the willingness of the presenter to let the audience interfere with the presentation.

We are using Pepper as a conduit in order to add an embodied component and to enforce the integration and the social characteristics of the feedback. In our application the robot provides feedback to the students in three different ways. Its feedback is always based on the use of questionnaires given to the students via *Google Forms*. One of these questionnaires is provided to the students towards the end of each lesson and consists either of closed multiple choice questions, or open questions. For the multiple choice questions, based on the performance of the students, the robot has two different feedback modes:

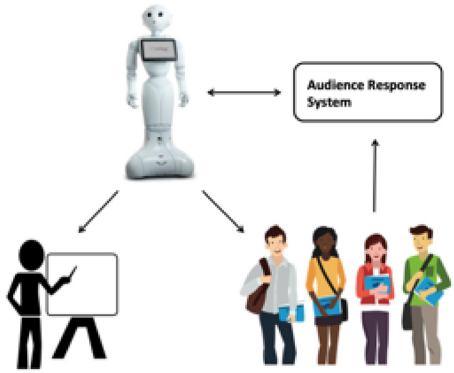

Fig. 5 - Pepper as conduit for the presentation of ARS results

(A) *Immediate general feedback:* This type of feedback is presented to the entire class directly after the questionnaire is finished during the lesson

(B) *Personalized feedback:* Based on her\his student ID number the student can ask the robot about her/his performance in the questionnaire during the breaks or directly after the lecture.

The answers for the open questions are evaluated by the professor after the lesson.

(C) *Detailed personalized feedback with vote and evaluation of the teacher*: For these open questions the robot gives feedback, consisting of a vote and an assessment by the professor, to an individual student based on her/his student ID number, either directly before, or after the next lesson

The general workflow of the feedback application is the following:

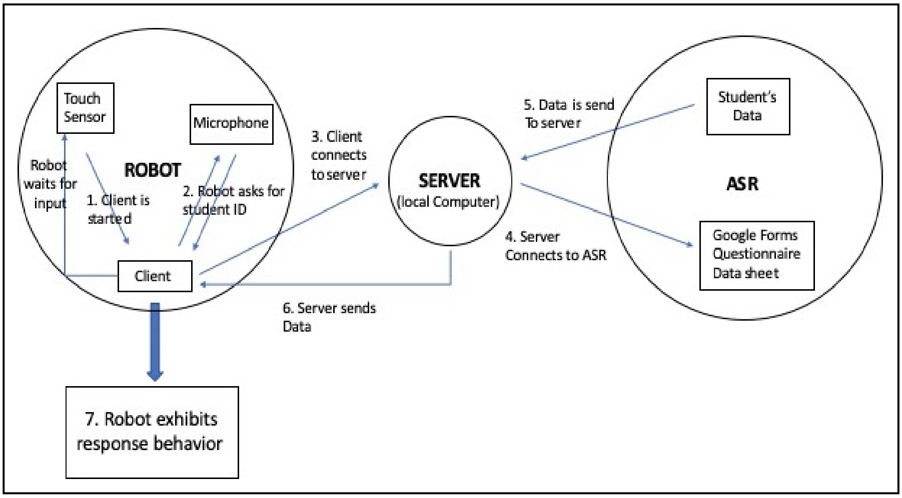

Fig. 6 - Example of the workflow during the personalized feedback application

After a specific time, determined by the professor, but usually towards the end of the lesson, the students will be given the login information to an online questionnaire and will be asked to complete the questionnaire. The questionnaire typically consists of five to seven multiple choice questions and one or two open questions about key concepts of the ongoing lecture. After around ten minutes the teacher will ask the students to stop. The data is analysed automatically on an excel sheet linked to the *Google Forms* questionnaire, on the google drive of a specifically generated google account. A local computer dedicated to the robot is connected via an API to the google drive and when the application is activated the results are sent to this computer. At the same time the robot is connected to this computer via a client-server connection and the data from the excel sheet is transmitted to the robot. How the robot presents this information depends on the feedback mode in question.

(A) Immediate general feedback:

The robots receives for each question the percentage of how many students answered correctly and how many wrongly. The robot will start directly after the students completed the questionnaire to say for example: "I received '….' answers. *Question one was '…………………..'? The correct answer to question was '……………'. '...' percent of you answered this questions correctly. Question two was '………'?"* and so on. After the percentage of correct answers for each question, the robot will give the overall percentage of the correct answers for the entire class. This type of feedback provides a quick overview of how well the class has understood the key concepts of the lesson. This is useful for both the teacher and the students. It gives the students a general impression of the importance and difficulty of the different parts of the lesson, and provides the teacher with information where she/he has not been understood by the majority of the class. Since the feedback is given towards the end of the lecture, it leaves enough space to the teacher to re-discuss and explain particularly difficult topics, which have not been understood correctly by the majority of the students.

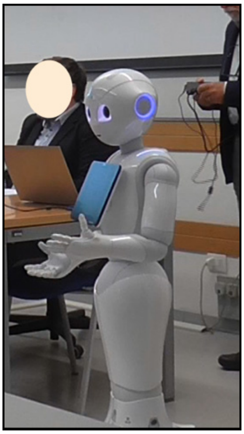

Fig. 7 - Pepper gives general feedback to the class

(B) Personalized feedback:

In the case of personalized feedback, the students have the possibility to approach the robot directly after the class and ask it for their specific results in the questionnaire. Typically the robot will be standing in front of the class, executing small movements with its hands and head. These movements indicate that it is listening. In this specific application the robot's tablet will read "If you want to know how well you did in last week's questionnaire, please touch my head.". When touching the robots head, the student is asked by the robots what her/his student ID numbers is. Based on the students response, the robot displays the number on the tablet and re-asks if the number is correct? If this is the case the robot will connect to the server and give the student her/his results in percent, based on the data retrieved in the way illustrated in Figure 6. This gives the student the possibility to compare her/his performance again with the general performance of the class, and to understand were her/his personal deficits are.

(C) Detailed personalized feedback with vote and evaluation of the teacher:

The third type of feedback provided by the robot differs from the other. The analysis of the data is not immediate. Since open questions cannot be automatically analysed by an artificial system yet, because the content of the answer needs to be understood and interpreted, the professor evaluates after the lesson the content of the answers and, depending on what the student wrote, gives a vote and writes an assessment in a data sheet on the google drive dedicated to the robot applications. The next time the robot is used in the class room, the students can access their evaluations in the same way they receive their personalized feedback. This form of feedback enables on one hand the professor to understand the students' comprehension of specific topics more deeply, and on the other hand it gives the students a more detailed assessment of their potential shortcomings.

Providing motivational entertainment during the breaks

During these breaks, which are usually ten to fifteen minutes long, the robot can engage the students in two different types of activities. It provides either personal feedback based on the answers to a questionnaire done in the previous lecture, or it does relaxing activities with the students. In order to activate the personal feedback feature the students need to touch the robots head, this is indicated on the robot's tablet, and to tell it its student ID number. We will discuss process in detail later in this section. If no student approaches the robot to check her/his questionnaire results, the robot starts different gaming activities. These activities include guessing games, dances and its in-built Tai Chi movements.

The type of activity which is initiated is selected at random. If the robot executes a dance, it chooses one at random from its dance libraries. The robot has a couple of example dances in its library a priory, but due to the Choregraphe desktop application, it is very easy to create new complex movements and dancing animations. These dances involve the playing of a well-known song and movements of the robot that are synchronized with the music.

The in-built Tai Chi animation follows the same principle. When activated the robot execute a serious of predefined Tai Chi movements and plays rhythmic drum music that is in synchrony with the movements. Similar to the dances, due to the easy usability of Choregraphe's timeline function, it is possible to expand the existing Tai Chi movements or add an entire new choreography for the Tai Chi application. This can be used to animate the students to move from their seats, and given there is sufficient space, to follow the exercises demonstrated by the robot in order to increasing their concentration ability for the next part of the lecture.

The guessing games the robot plays with the students follow a different principle. They including a film and a song guessing game. When the playing one of these games the does not move around, like in the dancing or Tai Chi applications, but uses its speech function and its tablet to interact with the students. Both the movie and the song guessing game have the same structure. When started, the robot displays an context depending animation on its tablet, for example in the movie guessing game a movie theatre curtain, and describes the instructions and rules of the game. When the students are ready, the robot plays a sequence of a well – or not so well – known movie. In the case of the song guessing game it plays a part of a song. After the replay is finished the students have a moment to discuss what the correct answer could be, and then tell it to the robot. If the answer is correct the robot congratulates the students and gives them the choice to play another game or to finish the activity. The content of the games, in terms of which movies or songs are chosen, can be varied between each lecture in order to keep the games interesting for the students. The games can either be played with an individual student or a small group of students standing directly in front of the robot, or with the entire lecture hall, depending on the number of students present, and on the physical setup of the lecture hall.

As we will see in the results of our first evaluation, which we will report and discuss in the next section of this chapter, the feedback from the students concerning these break activities is very positive. Additionally the students provided in their feedback a variety of new and interesting possible games for the break, that are more linked to the content of the lesson, indicating that pure relaxation might not be the optimal break entertainment.

3.4. Evaluation

At the end of the final lecture of the semester in which we first used the pepper robot during class we made an exploratory evaluation of the impression it made on the students. In order to collect the data we did an online questionnaire consisting of the following 8 questions:

Q1. Did you appreciate the fact that the lesson was introduced by the robot?
Q2. Did you appreciate the fact that the robot measured the time of the lesson and reminded the professor to take breaks?
Q3. Did you like the interactive activities performed by the robot during the breaks?
Q4. What other interactive activities do you imagine for the breaks with the robot?
Q5. Did you appreciate the fact the robot provide general feedback concerning the results of the lesson questionnaire?
Q6. Did you appreciate that the robot gave a summary of the key concepts of the lesson at its end?
Q7. What other activities would you like the robot to do during a lesson?
Q8. In general how much did you appreciate the presence of the robot during the lesson?

Quantitative results

For questions 1, 2, 3, 5, 6 and 8 we used a 5 point Likert-scale ranging from 1 = Not at all to 5 = very much. For questions 4 and 7 the students were free to answer however they liked. The questionnaire was present to the students via a link to a google form. We collected 59 anonymous answers in total.

Tab. 1 - Descriptive statistics of questionnaire results

	Q1	*Q2*	*Q3*	*Q5*	*Q6*	*Q8*
Mean	4.05	4.86	4.47	4.03	4.31	4.34
StDev	0.97	0.35	0.70	0.93	0.84	0.73

As Table 1 shows, the students answered all closed questions positive or very positive. The best received aspect of the robot behavior was the structuring of the lesson, which received the highest mean score with the lowest standard deviation. Interestingly the lowest scores, still above the positive score of 4, were given to questions 1 and 5. Question 1 dealt with the introduction to the lesson and question 5 with the general feedback from the questionnaire. The high standard deviation of just below 1 for both of these questions indicates that the students opinion varied for these questions from 3 = indifferent to 5 = very much. For question 1 a possible explanation could be that the robot introduces the lesson on its exact starting moment. Being an open university lecture, usually at that point not all students have arrived and the class has not entirely settled in yet. This results in an elevated noise level and less concentration on the side of the students. However, another contributing factor might be that the robot is not interactive at this point. It starts by welcoming the class, then recapitulates the key concepts of the last lecture and gives a brief outlook on the current lecture. The interactivity of the robot at this point could be improved by it asking the students questions about the previous lecture, or asking if the students have questions concerning the content of last lecture. These questions then could be answered by the professor, in this way reinforcing the feedback mechanism between teacher and students. For question 5, the presentation of the general feedback concerning the lesson questionnaire, the comparatively low average mean score could have different reasons. First, the feedback consists of the correct answers to the questions and the percentage of the students that gave the correct answer. This means it is a feedback to the entire class and in order for each student to solve know whether she answered correctly, she would need to remember her answer. The more questions there are, and the more complicated the answers are (i.e. the more similar they are in a multiple choice form), the harder it is for the student to remember. This results potentially in responsibility diffusion, which in turn leaves the student with decreased interest levels. From a practicability perspective we found that 7 questions seem to be the right amount for a questionnaire during a lesson. The length of the questionnaire represents a tradeoff between too short = ineffective and too long = disruptive for the flow of the lecture. In order to improve the feedback experience of the students we introduced the above described two types of personalized feedback from the robot, in which each student can go after the lesson to the robot and by providing her student ID number obtaining her personal results. However giving general feedback to the entire class should be an important mechanism during lectures and given the still positive mean score of 4.03 will maintain to use it. The second issue that might have effected to provision of the feedback is a general problem of the pepper robot. Since it was designed to mainly interact with individuals and small groups of people, it is hard to understand from far away, even with its audio output volume on the highest level. This might have negatively impacted specifically the general feedback functionality since the robot provides quite few simple statistics. The meaningfulness of these numbers relies more on the understandability of the robot, then general information concerning the content of the lecture, which can also be inferred by the context of what is said. Nevertheless, the understandability issue was the major criticism that was pointed out by the students in the open questions 4 and 7. The size of the class – 150 to 160 students – results in a necessity of a fairly large lecture hall, which might be semi-optimal for the application of the Pepper-robot. Students specifically pointed out that the robot was difficult to be heard from the middle to the back of the lecture hall. Unfortunately there is very little that can be done, besides choosing smaller lecture halls, reducing the size of the class or using lecture hall with improved audio infrastructure.

Qualitative results

Activities during the break - In question 4 we asked the students to let us know what activities they would like to do with the robot during the ten minute breaks between the different parts of the lesson. We defined five different categories into which we could classify the answers of the students.

Category 1 - Interactive Games
Category 2 - Repeat or discuss content of lecture
Category 3 - Didactic Games
Category 4 - Various
Category 5 - Nothing different in Particular

Tab. 2 - Number of replies for each break activity category

	Category 1	Category 2	Category 3	Category 4	Category 5
Number of replies	29	15	4	7	6

Most students suggested to play different interactive games with the robot, followed by an interactive way of repeating the content of the lecture and the playing of didactic games. Category 4 included suggestions which were not possible to be categorized and the last category 5 includes the answers of the students that were happy with the activities the robot was already performing during the breaks in the current application. Even though we classified the answers into categories the fact that we let the student answers freely implies that their replies were quite diverse, specifically when looking at what kind of games and activities were suggested by the students. Let us have a closer look at each category and discuss the most distinct answers exemplary.

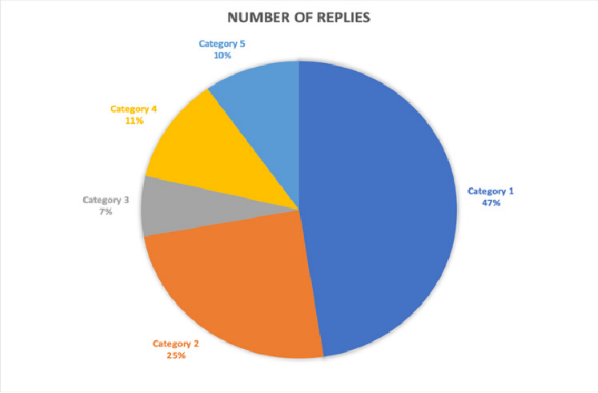

Fig. 8 - Percentage of replies for each break activity category

Most students answered that they would like to play, additionally to the above described film and music guessing games, other types of interactive games with the robot during the break. This is from a didactic perspective less interesting then the other categories, specifically because the conventional games serve "only" the purpose of relaxation and revitalization for the next part of the lesson, it is however relevant to have a closer look at the ideas of the students and seems them as a form of brainstorming activity for the implementation of future robot applications not only in the context of educational settings. After combining similar answers and excluding vague answers like “game activity” or “some sort of quiz” the following ideas emerge:

- *Taboo-like games*: The robot has to guess the object, the animal or the person a student (or group of students) has thought of by asking questions to get clues. The game could also be done in reverse, so it is the robot that "thinks" about something, and the students must guess what it is.
- *General culture or art quizzes* : The robot could formulate general culture quizzes for the person in front of it and give a final report; all with the aim of testing the level of knowledge learned and known by the subject. The quiz could also refer to the things just faced in class, to a specific topic of a discipline, to a current topic (show, gossip or curiosity) or to some practical notions (inherent to the context of the lecture or related to everyday experiences).
- *Different types games*: board games with the help of the tablet, team games to promote socialization, karaoke, logic games, games to train languages
- *riddles or jokes*: The robot could tell riddles or jokes during the pauses

The second category of answers to question 4 is much more relevant from an educational perspective. Many students suggested that the robot should discuss or repeat content of the lecture during the pause. Similar to the answers in the games category most ideas could be combined into a couple of points referring to the repetition of the lecture content in different ways. The main difference is that some answers referred to group and some to individual activities:

- Group activities:
- The robot collects anonymously student questions concerning the difficult topics of the lecture in order to discuss them with the professor during the lesson
- The robot explains all its possible functions and how they can be used during class, simulating some examples and giving the students an outlook about robot assisted didactics
- The robot repeats topics that can be used for a review, like simple definitions for the concepts addressed during the lecture that can be listened to again during the pauses

- The robot gives a brief overview of the topics of the lecture covered until the break, specifically for those students who arrived late to the lesson, so that they can understand them better
- Individual activities:
    - The robot provides clarifications about key concepts of the lesson to those students who want them
    - The robot deepens topics requested by students through multimedia presentations
    - The robot does small quizzes or mini tests on the topics presented during the lesson, so that the student can see if she/he has understood the issues discussed and if not, the robot gives an explanation of what the correct answer is

The third category includes also responses concerning games, but this time specific didactic games. Since there were 4 distinctly different responses we will report all of them here:

- Collaborative games like "friends and enemies" or "improvisation games"
- Activities in which the robot simulates and pretends to be a student and the students are the professor
- The robot proposes and carries out didactic activities, which are useful to the students as examples for the introduction of new technologies in didactics and in the daily work practice of teachers.
- The robot instructs the students to do interactive exercises of logic

The fourth category includes all answers that are that were not possible to classify into a another category due to them being very diverse and somewhat vague:

- The robot could propose group activities
- Discussions on various topics
- Conversations
- Say some interesting curiosities; tell some story/anecdote
- Group dances
- Listening to music
- For example listening to music

Activities during the lesson - In question 7 we asked the students to let us know what additional activities the robot do during the class. The answers to this question were more specific and diverse than the answers to question

4. We therefore needed to define 7 different categories into which the we could classify the answers of the students.

Category 1 - Structuring the lesson
Category 2 - Collect questions of students
Category 3 - Give examples during the lesson
Category 4 - Use multimedia tools
Category 5 - Interactive activities
Category 6 - Various
Category 7 - Nothing different in Particular

Tab. 3 - Number of replies for each activity during lesson category

	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7
Number of replies	21	8	5	4	4	5	10

Despite the fact that one of the main interventions the robot did in our application was the structuring of the lesson, most of the students wanted the robot to do even more structuring activities. The second most request was for the robot to collect questions of the students during the lesson, followed by the robot supporting the teacher via examples and the use of multimedia presentations. Additionally 7 percent of the students suggested that the robot should do interactive activities during the lesson. Similar to question 4 we also created a various activities category in which we included all singular replies. The last category 7 included the replies from students that

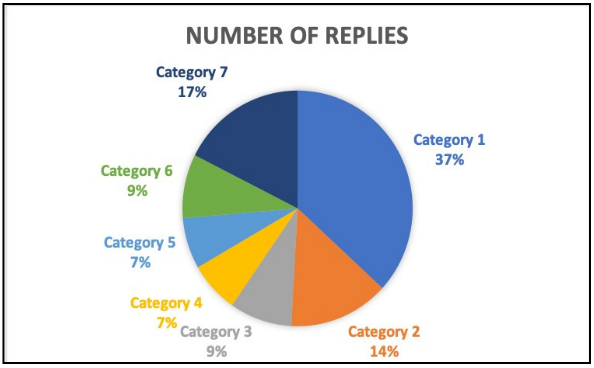

Fig. 9 - Percentage of replies for class activity category

were content with what the robot was doing in our current application and did not want it to do something more or different. The replies of the student for most of categories were more diverse and explicit than for questions 4. It is consequently necessary to look at them in detail and single out the suggestions that are most interesting and practical. As for question 4 we summarized the answers that were very similar.

Specifically the replies concerning a further structuring of the lesson by the robot included multiple interesting new potential activities for the robot. In the first of the categories for the answers to question 7 we grouped the replies that asked for further structuring of the lesson in different ways. Most of the students would like to see the robot in the future to focus on key concepts during the lecture. Ideas how to implement this involve the stopping of the lesson at certain points and asking the teacher to repeat already addressed concepts, periodically ask the students questions about a different key concepts of the lesson, and summarizing key concepts by giving examples.

- Emphasize key concepts
    - The robot should stop the lesson more frequently and ask more often to repeat the key concepts of the lesson
    - The robot could periodically intervene by asking questions, in addition to those posed by the professor, perhaps taking up concepts already addressed to create a bridge.
    - The robot could reiterate, through keywords, the main topics of the lesson and propose possible links to the topics addressed.
    - The robot could intervene more often during the professors explanation, and summarize concepts in simple sentences, with the addition of some examples
    - The robot could fix the keywords of the different topics during the explanation, and write them on the tablet
- Introduce subsections of the lecture
    - The robot should focus on the main concept of the topic explained in the first part, then in the second, then in the third and so on. I think it is useful to do it during the lesson to always have in evidence the red thread of the topic. Then at the end it will be even more useful to take stock of all the red threads encountered.

    - The robot should introduce more topics and not only the beginning or the summary of the lesson and propose questions in order to develop discussions.
    - I would like the robot to interact more on the content of the lesson itself by also making an introduction to the topics to be covered and not just a summary.
- Provide feedback during class
    - The robot could give feedback during the lesson. Feedback that may be useful to the teacher, but also to the students. Or if a student has a doubt about a topic, the robot can explain it in the teacher's place.
    - The robot, during the lesson, could ask some questions to the class. On the basis of these, the teacher will continue the lesson and, in this way, the students could be stimulated to participation and attention (students could be more attracted by the voice of the robot, compared to the usual persistent voice of the teacher).
- Bridge between lessons
    - At the beginning resume the previous lesson highlighting and introducing what are the logical threads with the next lesson
- The robot could generate a ritual at beginning and end of each lesson.
- The robot should recall the class when there is too much confusion and noise.

Another addition which the students suggested was that the robot should collect their questions during the lesson. We classified this type of answers into category 2. The suggestions of the students were quite diverse ranging from directly collecting questions asked to using external software to which the students could send their questions and which the robot could access. The idea behind these suggestions appears to be twofold. On one hand the robot could report the questions to the professor after the lesson (helping her/him to better prepare the next lesson based on the questions) and in this way improve the feedback between the professor and the students, and on the other hand the robot could provide answers to the students directly after the lesson.

- Directly collect answers
    - The robot could collect questions asked directly by students
    - The robot could move between students (if space permits) and collect questions/requests for clarification

    - The students could send any questions about the course directly to the robot and the robot could report these questions to the professor.
    - The students could send questions related to the topics covered during the lesson to the robot and the robot, at the end of the lesson, could provide the answers to these questions directly after the lesson.
    - The robot could collect the questions that emerge during the lesson and at the end it could repeat the questions to the students checking their understanding, so that the teacher can use this as a feedback channel about the lesson (if it was clear enough, if it managed to involve the students' interest, if it went too fast, if it is necessary to further clarify the concepts-linkages).
- Using external software
    - Create a dedicated account on an external platform, for example *menti.com,* where questions could be entered by the students during the lesson. From time to time the robot could access this account and interrupt the lesson to post some of the questions that have been posted on the account until that moment.

The third category includes answers in which the students asked for the robot to give examples for specific topics during the lecture. The students thought that the robot could intervene at certain points during the lesson and support what the professor was explaining by illustrating the keypoints. The answers of the students were very similar had prototypically one of the following structures: “The robot could provide other examples in addition to those proposed by the teacher to help the students to better understand the concepts presented in the lesson.” or “The robot could search for sources and give examples in support of what the Professor is explaining.”. Therefore there is no need to list the replies in more detail.

The students also suggested to use the robots’ multimedia capacities more frequently during the lecture, mainly referring to its tablet. They proposed different ways in which the robot could present the content of the lesson including:
- The robot could show some diagrams
- The robot could show slides
- The robot could be used to make multimedia examples

- The could present short videos about the lessons context

Category 5 includes answers that refer to an increased amount of interactive activities initiated by the robot.

- Group work in which the students can interact with the robot as if it were a student itself.
- Problem solving and investigation activities in which the robot can intervene applying the action - feedback - revision cycle
- Questionnaires on the topics of the day
- Making quizzes about topics that are covered in class or previous lessons

The category that includes various suggestions by the students is comprised of to some degree vague answers or answers that would fit any of the other categories. The most informative suggestions were the following:

- The robot could ask general questions about the context of the lesson at its end
- The robot could ask questions at the end of the lecture in such a way that students can start to think about the content of the next lecture
- The robot should do more questionnaires, collecting students' answers and organizing them in various statistical modes
- The robot should interact more with the students on topics that are taught in the classroom

Discussion of results

The qualitative results show that the overwhelming majority of the students had in general a very positive impression of presence of the robot during the course of the class. Specifically the fact that the robot structured the lecture by reminding the professor to take breaks was appreciated by most. Since all the answers had an average score of above 4 (liked) with an average standard deviation below one, it is safe to say that almost all students had a favorable conception of the activities the robot performed. As pointed out above, the main problem seems to have been a difficulty in understanding what was said by the robot. This is however more an organizational and technical issue than a conceptual. Besides the aforementioned reduction of students, it is also imaginable for the robot to be connected to the general audio infrastructure of the lecture hall via a wireless microphone. The problems that occurred in our implementation however illustrate the importance of the audio channel for the acceptance of the robot in situations in which it needs to interact with large groups.

The games the robot performed during the breaks in order to help the students to relax for some minutes were perceived very positively. They consisted mainly of guessing games in which the robot would show a video sequence of a movie or play a short part of a song and the students had to guess the name of the film or of the song. Even though these activities were well perceived the answers to question 4 provide a large number of ideas and potential other activities. Mainly focused on games for relaxation, many students also asked for the robot to repeat and exercise the new knowledge discussed during the lecture. Since we listed a detailed account of the ideas above, here we will discuss some of the more practical suggestions that are potentially realizable in a 10 – 15 minute timeframe. Following the structure of the answers we need to focus our attention on two questions:

1. "Should the robot play games with the sole purpose of entertainment, or should it play games that are linked to the knowledge that is discussed during the lecture?"
2. "Should the robot play games that are directed towards an individual, or should it play games that are directed at a group of people?"

The answer to the first question depends on the solutions that are possible for incorporating the content of the lecture into a game that is fun. Since the activities during the break should help the students to relax and "recharge their batteries" a complicated game that merely repeats what the teacher said during the class is probably a semi-optimal solution. Many students suggested on one hand general knowledge or art quizzes, and on the other that the robot should repeat key concepts of the lesson. For future applications it is imaginable to combine these two concepts into one game in which the robot does a quiz with the students which contains the key concepts of the lesson.

The answer to the second question depends on the setup of the teaching environment. Small class rooms with very few students and longer breaks warrant the use of individual focused games. In large lecture hall settings with many students it is more practical to play games that are directed towards the entire group. For this it seems to be essential to use external software in combination with the robot. It is imaginable that to develop an App that can be used by the students though their phones. Such an App could consist of various types of interactive games. The robot could show the app on its tablet, and could explain how to use it and moderate while the students are playing the game the App consists of. The replies of the students could be selected and the robot could present them to the students. In this way it would be possible to play both entertaining and educative games with larger numbers of students.

The replies of the students concerning additional activities during class provided an multitude of new ideas. The most prominent of which concerned further structuring the lesson and increasing the interactivity of the robot. It is interesting to see that the student intuitively ask for an increase of feedback when considering the structuring of the lesson. Almost all the requests by the students involved in one way or the other the collection of their questions by the robot, and the transfer of their questions to the teacher. Even though we are currently attempting to model the reflective processes of the students in the "The Doubts of Pepper" application, it seems that the students would like to be more directly involved in this process. This is promising since this kind of reinforced direct feedback processes are at the center of the enactive robot assisted didactics approach we are proposing. At the moment the teacher is anticipating the questions of the students based on her/his experience, and the robot is interrupting the lecture based on the anticipation of the teacher. In the future this modeling of the students reflective processes could be handed over more directly to the students, moving it from a model to a direct representation of the doubts of the students via the robot. This could be done like an App in which the students could enter their questions concerning a specific part of the lecture. The problem that arises from this is the need for a further clarification of the structure of a lesson by the teacher. This would imply a further limitation of the freedom of the teacher during the presentation of the lesson and potentially more interruptions by the robot. However it seems to be an application of the robot which the students would like to see the most. In order for this to work, a predefined structure of a lesson is imaginable, which gives more space to discussions between the teacher and the students and focuses more on the interactive component of the knowledge construction process. This again makes it apparent that the use of a social robot during lessons in the way we imagine it seems to almost naturally force the didactic mediation process towards an enactive approach.

Other suggestions by the students concerning the activities of the robot during the lesson, are for the moment, not realizable because they involve the robots movement around the classroom. Although Pepper is capable to move around, it needs a relatively large space to manoeuvre and a flat surface to do so safely. Both is in our current lecture hall setting not given. However, this raises again the question of a potentially needed co-evolution of teaching spaces and the embodied socially evocative technology used in them. As we have pointed out in the first chapter the introduction of social robots in mixed human-robot ecology will most likely not only change the evolution of the robotic embodiments, but also of the spaces they will occupy together with us. Despite these future prospects at the moment the robot is, in lecture halls, mainly confined to the front of the calls.

In summary it can be said that the students are very positive towards the use of a social robot during their lessons and that they would like the robot to do even more activities than it is already doing. From the replies and the suggestions of the students, which are focused on feedback processes between them and teacher mediated by the robot, it appears to be natural to view the robot as a part of the teaching process that reinforces a reticular structure and enactive characteristics.

Conclusions

The aim of the book is to introduce a potential theoretical grounding for social robots in enactive didactic theory. We gave an overview of the field social robots in education and showed the different ways in which social robots are used in educational settings at the moment. By discussing the principles of enactivism and constructivism we showed their influence on enactive didactics and the implication the principles of these theories have on the teaching process. Specifically from the perspective embodied socially evocative technology the ideas of enactivism play a crucial role for the use of social robots in schools and universities. Structural coupling between the different parts of complex systems as defining principle of the enactive approach, has been translated into didactic theory in form of different types feedback. Applying these principles to the enactive didactics changes transforms the teaching process from an undertaking in which knowledge is transmitted into complex dynamic system of interactions between the teacher and the students in which new knowledge is constructed. The complexity or reticularity of the interactions depends on the strength of the feedback mechanisms and channels between the different parts that constitute the system. Our application of the Pepper robot as reinforcing feedback device show a first glimpse at the central role this kind of socially evocative technology can play in education.

Finding collectively a solution for the cognitive conflict that is created in the students during the teaching process, is central for sustainable learning. To permanently dissolve the cognitive conflict it is crucial to validate the newly constructed knowledge, which can only have via feedback processes. This is where social robots can play a decisive role. As we have shown in our applications they can not only provide feedback for the students, helping them to access their level of understanding and progress by analyzing, in combination with for example audience response systems or intelligent tutoring systems, but they can also provide feedback to the teacher about her/his teaching progress. Social robots can be used to model the students reflective processes, and in this way help the teacher to anticipate issues of understanding and encourage the students to reflect and discuss their conflicts with material of the ongoing teaching process. All these functionalities are facilitated by the physical presence and social characteristics of this type of robots.

Social robots' ability to enforce feedback mechanisms and to facilitate the necessary inherently reticular structure of the enactive didactic approach is already a partial answer to the first two questions we posed at the end of the first chapter: "*What can the role of social robots be in the didactic process?"and "Where can social robot be situated in the process of didactic mediation?"*. Beyond their role as feedback devices, they can be and indeed are used as different forms of didactic mediators, as we how shown in the first chapter. Classified by Damiano (2013), there are different types of didactic mediators involved in the process of didactic mediation. These mediators range from active to symbolic, and from concrete to abstract. The function of this mediators in the didactic mediation process is to assist the construction of new knowledge. The embodied and animated characteristics of social robots ascribe to them a hybrid function in the classification of mediators. They can be used to display and illustrate learning materials (if equipped with a tablet) such as periodic tables, maps and diagrams and this sense become iconic mediators. They can also be used as models and during simulations for specific social processes and hence become analogous mediators. Due to their ability to speak they can also be classified as symbolic mediators. In this more conventional view their most distinctive characteristic however is their ability to provide social and emotional support on a motivational level, encouraging students to work independently. They can provide guidance by assuming different social roles, which is only possible due to their socially evocative characteristics. As mentioned above by assuming these roles, they provide different types of feedback not only for students, but also for teachers, and in this way they reinforce the reticular structure of the learning process and support an essentially enactive quality of teaching. This justifies for social robots the definition of a role that goes beyond that of a didactic mediator. Since social robots incorporate, to various degrees of abstraction, all characteristics of the didactic mediation process, and provide additionally the ability to facilitate social interactions between the component of the didactic system, the definition of their role in education should be that of an embodied artificial agent that ensures the reticular structure in education processes by providing wholistic feedback for all the elements involved in these processes.

The question about the position of social robots in the didactic mediation process,is closely linked to their role they need to assume. According to their potential to reinforce and provide between teacher and students in a specific social space, the robot is being connected with everything, the teacher who develops its application, the interaction in the form of feedback which is reinforced by the robot, and the students who use the robot to mirror themselves during the learning process. The resulting central position characterizes the main purposes of social robots during didactic mediation. They allow on one hand the teacher to monitor the progress of the student and to understand her/his own performance during the teaching. On the other hand they allow the students, through the robot, to understand their progress in the learning process in form of a subconsciously reinforced critical self-reflection.

Concerning our last question: *"Can the integration of social robotics in education be a sustainable progressive development?"*, it is safe to say that the commercial success of social robots in education has increased in the last 10 years, leading to more platforms and cheaper prices for these platforms. These developments are similar to the ones of the cell phone and computer market, which makes it possible to project that social robots will most likely be more and more distributed in education environments. Their success in education will depend strongly on the place they are given by the stakeholders. In order to achieve an increased distribution social robots will need to be given a stable position in school curricula. This presupposes a firm grounding in didactic theory, and a diverse methodology for the evaluation of their effects and potentiality. Much of this methodology still needs to be developed, since classrooms or lecture hall settings have a very different nature compared to the usual controlled experimental settings used for impact evaluation. Despite these issues there is a good chance, specifically taken the drop in costs that are associated with this type of robots into consideration, that social robots will be used more and more in schools for various applications. This use will go beyond the current use of providing an additional support for language classes or using them a novelty items to catch and draw in the attention of students, and to stimulate and inspire their imagination. Most likely the next applications we will see for social robots will be as personalized tutors for learning at home. It is safe to say that social robots for education are going to be an integrative part of our learning and teaching culture. Overall we believe that the presence of an enforced embodied feedback channel, in form of embodied social evocative technology like social robots, could become a fundamental support for teaching and learning processes. This technology can help to avoid a lack of feedback between the different elements involved in education, and with this the dangers of self-referentiality and a closed learning cycle.

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The use of robotic technology in education over the past 25 years has primarily focused on STEM education in schools, and on computer science and engineering classes in undergraduate courses at universities. The increasing technological developments in socially evocative robotics has started to change this, and in recent years has led to an increasing number of social robotic platforms is being integrated into classroom settings. Due to the relative short time in which the social robotic revolution has happened, there is a lack of theoretical grounding for the use of social robots in education into contemporary didactics theory, specifically when taking ideas from didactic mediation and Enactive Didactics into consideration. The consequence of this limited theoretical grounding is that despite the availability of social robots like Pepper, their firm integration into school curricula around the world is still limited to only a number of cases, many of which still use the robots as experimental additions during the usual proceedings of the lessons.

In this book we will illustrate how current social robotic technology can be used to shape future learning from the perspective of an enactive approach to didactics. Our approach is based on the enactive approach to cognition, and is interwoven with ideas from didactic mediation theory. We will discuss the roles social robots can play for reinforcing different types feedback mechanisms between teacher and students and answer some of the, from our perspective, central questions about the grounding of social robots in didactic theory: what can the role of social robots be in the didactic process? Where are social robots situated in the in the process of didactic mediation? Can the integration of social robotics in education be a sustainable progressive development?

Hagen Lehmann is a research fellow at the University of Macerata, where he works on the development of a enactive robot assisted didactics approach. His main research interests are: Social robots for education, Enactive robot assisted didactics, Human-Robot Interaction, and developmental psychology.

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