Je-LKS
Journal of e-Learning and Knowledge Society
The Italian e-Learning Association Journal
PEER REVIEWED PAPERS
EDUCATIONAL ROBOTICS: RESEARCH AND PRACTICES OF ROBOTS IN EDUCATION
Vol. 15, n.2, 2019
ISSN: 1826-6223 | eISSN: 1971-8829

SOCIAL ROBOTS IN EDUCATIONAL CONTEXTS: DEVELOPING AN APPLICATION IN ENACTIVE DIDACTICS

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Keywords: Social robots, Enactive didactics, Pepper robot, Social feedback

Due to advancements in sensor and actuator technology robots are becoming more and more common in everyday life. Many of the areas in which they are introduced demand close physical and social contact. In the last ten years the use of robots has also increasingly spread to the field of didactics, starting with their use as tools in STEM education. With the advancement of social robotics, the use of robots in didactics has been extended also to tutoring situations in which these "socially aware" robots interact with mainly children in, for example, language learning classes. In this paper we will give a brief overview of how robots have been used in this kind of settings until now. As a result it will become transparent that the majority of applications are not grounded in didactic theory. Recognizing this shortcoming, we propose a theory driven approach to the use of educational robots, centred on the idea that the combination of enactive didactics and social robotics holds great promises for a variety of tutoring activities in

for citations:
Lehmann H., Rossi P.G. (2019), *Social Robots in Educational Contexts: Developing an Application in Enactive Didactics,* Journal of e-Learning and Knowledge Society, v.15, n.2, 27-41. ISSN: 1826-6223, e-ISSN:1971-8829
DOI: 10.20368/1971-8829/1633

educational contexts. After defining our "Enactive Robot Assisted Didactics" approach, we will give an outlook on how the use of humanoid robots can advance it. On this basis, at the end of the paper, we will describe a concrete, currently on-going implementation of this approach, which we are realizing with the use of Softbank Robotics' Pepper robot during university lectures.

1 Introduction

The progressive "technologization" of everyday life is changing rapidly the way we communicate and interact with, and learn from each other. These changes have a profound impact on how we organize our social life, ranging from daily work schedules, or the planning and structuring of meetings, to questions like how new knowledge is acquired. The acceleration of these transformations has been enforced by the now widespread use of advanced mobile technology, like smartphones, and the almost global availability of Internet access. This new level of interconnectivity in itself requires us not only to learn a variety of new social and technical skills, but also to question and redefine some of the seemingly most basic principles of human sociality. Furthermore, it asks us to re-discuss the nature of information, knowledge, truth and moral values.

While our societies are struggling with these new challenges, it is important to prepare the next generations for the issues ahead. In the same way that the increase of the influence of information technology - and the availability of information - is challenging our perspective on the acquisition of new knowledge and skills, the beginning of a widespread use of social robots is challenging our perspective on the ways in which humans are used to interact with each other.

For education these developments mean concretely that the structure of knowledge and the role of the teacher is in the process of changing fundamentally. We believe that this transformation should be primarily driven not by technological developments, but by didactic theory.

2 Related work

During the last ten years different applications and research approaches have demonstrated that the use of robots can be beneficial in didactic settings like kindergartens and primary schools. The application of robots in these contexts has been categorised in different ways. Mubin *et al.* (2013) and Tanaka *et al.* (2015) classify two different modes in which the robots were integrated into school curricula (a) as educational tools in themselves (e.g. to teach children the basic principles of programming), and (b) as educational agents.

One of the first robotic systems used in mode (a) was Lego Mindstorms NXT

(Lau *et al.*, 1999). It has been integrated in middle schools and high schools to teach students the basic principles of what robots are, how they work and how software applications can be developed for them (Hirst *et al.*, 2003; Powers *et al.*, 2006). Different other systems have been integrated since, not only to teach programming, but also physics and electronics (e.g. Balough, 2010; Mukai & McGregor, 2004). When these robotic systems are used as educational tools, the students construct with them specific applications or environments and, in this way, familiarise themselves with robotic technology and learn the underlying principles. This approach is typically based on a "constructionist" framework and the related "learning-by-making" methodology (Papert & Harel, 1991).

The second mode – robots as educational agents – has received increasing attention in recent years due to advances in "socially-aware" technology and social robotics. Different types of robots have been deployed in various teaching scenarios. 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 (Kozima *et al.*, 2009) has been widely used in education and therapy for children with Autism Spectrum Disorder (Kozima *et al.*, 2005). Besides these comic-like and zoomorphic looking robots, many studies have used humanoid and semi-humanoid robots to explore possible functions for social robots in education. The reasons lie in the possibility of endowing robots with non-verbal interaction behaviours, based on gestures and general body movements, intuitively understandable for their human interlocutors. Due to its relatively low cost, the most widely used humanoid robot is Softbank Robotics' NAO (Shamsuddin *et al.*, 2011). However other robots, like RoboVie (Ishiguro *et al.*, 2001) and Tiro (Han & Kim, 2009), have been successfully deployed and tested, and in the process provided valuable insights on the psychological dynamics characterizing social human-robot interactions in educational settings (Benitti, 2012).

Belpaeme *et al.* (2018) have examined the different roles social robots can assume in education. They found that they mainly fulfil the roles of novices, tutors, or peers. When fulfilling the role of novice, a robot allows the students to act as tutor and to teach the robot a determined topic. This helps the children to rehearse specific aspects of the syllabus and to gain confidence in their knowledge. The latter is specifically important when learning a second language (Tanaka & Matsuzoe, 2012). Consequently robots in this role have been used in countries like Singapore, Taiwan and Japan to teach English to children in primary schools (Tanaka & Kimura, 2009). When the robot is fulfilling the role of tutor its function is usually that of assistant for the teacher. Similar to robotic novices, robotic tutors have been used in classes for children learning English as second language. A tutor is defined as an educator of a single pupil or a very small group (Belpaeme *et al.*, 2018). 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).

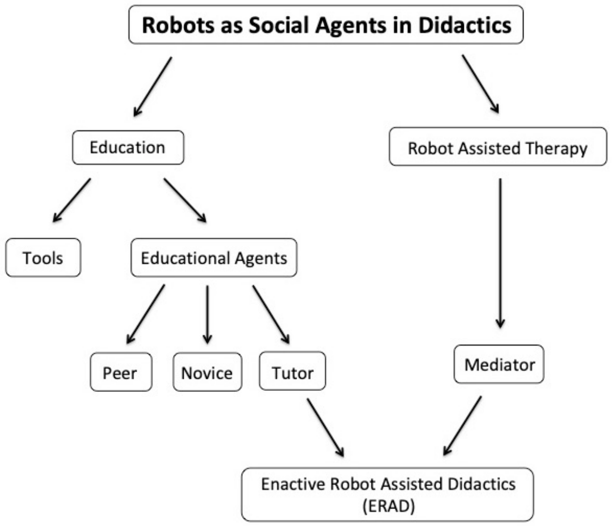


Fig. 1 - Different Functions or roles robots can assume in education

The idea behind having robots assume a peer role for children is that this would be less intimidating for them compared to a tutor or a teacher. In these cases the robot is presented as a more knowledgeable peer that guides the children along a learning trajectory (Belpaeme *et al.*, 2018), or an equal peer that needs the support and help of the children (Tanaka & Kimura, 2009). 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 & Matsuzoe, 2012).

Another very important field in which robots have been used to achieve educational goals is robot-assisted therapy (RAT) for children with Autism Spectrum Disorder (ASD) (Feil-Seifer & Mataric, 2008). Robots like KASPAR (Dautenhahn *et al.*, 2009) fulfil the role of social mediator to facilitate social interaction among the children and between them and the teachers (e.g. Iacono *et al.*, 2011). The social mediator role in therapeutic scenarios serves the function of teaching the children appropriate social behaviors via different play scenarios.

In the next sections we will examine how humanoid and semi-humanoid social robots have been used in education in the last 10 years, showing that the majority of applications are not grounded in didactic theory. Elaborating on this insufficiency, we will briefly introduce a theory driven approach – i.e., our Enactive Robotic Assisted Didactics approach – and give an outlook of how we envision the use of the semi-humanoid robot Pepper from Softbank Robotics based on this approach.

3 Social robots as educational agents

Only a few social robots have been used so far as educational agents. This is mainly due to the fact that social robotics (SR) is a relatively new field and educational robotics (ER) has in the past focused on STEM education in schools (Benitti, 2012), as well as on computer science and engineering classes in undergraduate courses at universities (Benitti & Spolaôr, 2017).

For example, after its release in 2014, the Pepper robot was officially introduced only in 2016 into schools. This happened in Singapore, one of the countries that strongly promote the concept of using social robots in education. Since then Pepper has been sporadically used as tutor in English language classes 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 (Financial Times, 2018).

ER has however produced a number of approaches (e.g. Castllano, 2013) and results that illustrate the advantage of using embodied and socially situated artificial agents in educational settings. Various studies have shown that the physical embodiment of social robots is more effective when compared to the presence of virtual agents, and that it is crucial for a successful and positive interaction between the artificial agent and the human on different dimensions (Kidd, 2003; Bartneck, 2002), mainly related to the robots' physical and social presence. It has been argued that this is due to the increased potentiality for social bonding with an embodied agent (Tanaka & Matsuzoe, 2012).

A lot of the research and applications in which robotic tutors have been used in education were conducted with pre-school and school children. Many of these studies have been conducted in Japan, South Korea, and Singapore in the context of English as second language 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 used as tools to teach programming skills to the students. They found that the main robots used where either virtual, or based on the LEGO Mindstorms system. It is therefore not surprising that the most widespread theory reported was project-based learning (Bell, 2010), because professors usually engage their students into activities in which they are building an artefact or product. The second most frequently used approach were "experiential" and "constructionist" learning theories. Benitti *et al.* (2012, 2017) are using "constructionist" as being synonymous with the "learning by making" approach (Papert & Harel, 1991). These and other reviews (e.g. Mubin *et al.*, 2013; Belpaeme et al., 2018) show that robots in the role of tutors are not yet widely used in universities, and that even when they are deployed in schools their application is confined to a few specific subjects. The underlying didactic theories used are usually limited to approaches that are defined by or closely linked to collaborative activities, which involve the use of technology as tool and object, and not as social mediator between the students and the teacher, or as tutor or motivational support for individual students.

In Table 1 we take a closer look at some of the robots that have been successfully applied in different teaching scenarios. We have chosen to focus on humanoid robots mainly because of their capability for expressing emotion states via body posture with their torsos, arms, head postures, and faces in an intuitive and comfortable way. We believe that this makes them a great candidate technology for becoming general educational aids, in particular as we envision it.

4 From social robots towards enactive mediators

When studying the relevant literature on educational social robots, it becomes evident that the vast majority of the robots are used with pre-school or school children, not with university students or in lecture hall contexts. We hypothesize that this is due to the less personal format of lecturing at universities. The large group size of university classes makes a one-to-one interaction impossible and would confine the use of robots to group works with small group sizes. This limitation seems to be more conceptual than due to technical issues. When combining the mediator functionalities of educational social robots with the ability to display relevant information on an integrated tablet in specific situations, it should be possible to create applications that could prove very useful for university level teaching in general.

The direction of our research trajectory points towards an extension of the concept of what robots can be in the didactic process, moving them away from mere tools and towards a central mediator position between teacher, student and new knowledge. Our approach, based on principles from enaction, enhances their relevant implications in the field of education (Shapiro & Stolz, 2018) by operationalizing the robots' the social mediator function during classroom teaching, lectures or group work. In the following part of the paper we will illustrate our approach with Pepper and discuss the theoretical underpinnings of our research.

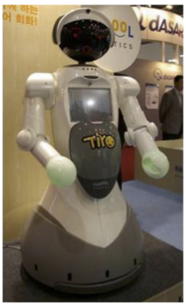
5 Developing Applications for an "Enactive Robot Assisted Didactics"

As previously mentioned, today the use of Pepper – as the use of all other robotic tutors currently deployed in educational settings – is driven mainly by technological feasibility rather than by didactic theory. In the last 4 years there have been a number of studies involving Pepper in educational settings (Belpaeme *et al.*, 2018). In most of them no general didactic framework has been mentioned, and in some cases even custom tailored theories have been chosen, according to the degree they would fit the technical limitations of the robotic platform that was used. At the opposite, our undertaking moved from our "Enactive Robot Assisted Didactics" approach, and, on this basis, focused on the Pepper robot. In other words, the starting points of our approach were research grounded theoretical considerations from didactics, on which we chose our robotic platform and addressed technical issues – not the other way around. We chose Pepper for its great potential for the development of new applications in didactics, and the fact it enables us to elaborate on the key points of the "Enactive Robot Assisted Didactics" approach we are structuring. 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 enhance naturalistic looking dynamics of the movements. Additionally Pepper has an inbuilt tablet that can be used to visualize Internet content or custom made applications.

Since Pepper was introduced 2014, being hailed as the new personal robot that will also be widely used in educational contexts (Benitti, 2012), it has not yet lived up to the expectations in this field. 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, 2018). We hypothesize that this limited use of Pepper in educational contexts has two main reasons.

The first is that classroom or lecture hall situations are much more complex compared to circumstances in which the robot is engaged in one to one interactions and has to provide answers to a limited set of specific questions. It can therefore be argued that one part of the problem relies in the technological limitations connected to social signal processing in noisy environments.

In our view the other part is due to the lack of development of dedicated didactic theories. Currently the application of educational robots in general is mainly based on technological feasibility rather then on sound didactic perspectives and plans of operationalization. This bears the danger of developing an ER detached, or even independent, from insights coming from educational science, instead of relying on the re-invention of didactic processes required by contemporary transformations and related challenges, and today increasingly allowed by the availability of new (social) robotic technology.

Name	Appearance	Communication Channels	Related Work
NAO		- speech recognition - speech generation - expressive whole body movement choreography	- Senft et al. (2017): found that, in order to improve its tutoring capabilities, the robot should be able to adapt to the learning specificities of each of their users - Vogt et al. (2017): 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 - DeWit et al. (2018): found that using co-speech gestures in combination with tailored learning task yield the best results
RoboVie R3		- verbally via speech generation - non-verbally via preprogrammed social interaction behavior scripts such as shaking hands, hugging and waving	- Kanda et al. (2004): showed that a robot can have beneficial effects on the language learning progress of elementary school children - Köse et al. (2015): successfully used a robot to help children with hearing disabilities sign-language; the study illustrated the beneficial effects of a physical robot on gesture recognition in this context
TIRO		- speech recognition - speech generation - emotional facial expressions	- Han and Kim (2009): used the robot as a physical aid and motivational support during music lessons; showed that the embodied presence of the robot and its coordinated movements were effective during class - Han (2010): showed the robot's usefullness for class management and timing of class activities

Maggie		- Automated Speech Recognition (ASR) - Emotional Text To Speech (eTTS) - Speaker Identification (SI) - dialogue management	- Gorostiza et al. (2006): proposed a multimodal interaction framework, which integrates and synchronizes tactile, visual and verbal inputs in order to enable natural peer-to-peer Human-Robot Interaction - Salichs et al. (2016): used Maggie successfully in different scenarios as assistive robot for patients with Alzheimer's Disease
Pepper		- speech recognition - speech generation - expressive whole body movement choreography	- Tanaka et al. (2015): guided by the *Total Physical Response* (*TPR*) Theory from Asher (1966); found that providing motivational haptic behaviors, like giving "high five" in combination with the use of the tablet created stress-free learning environment - Gao et al. (2018): found that people did not prefer robots that were giving encouraging feedback tailored to their person, but robots that were generally supportive

Table 1*. This table presents the* ***related work*** *on how social robots have been used in recent years in different educational contexts. This work also illustrates that the use of social robots in education is driven by technological development and lacks a general didactic theory of reference.*

6 Enactive Robot Assisted Didactics (ERAD)

These acknowledgments led us to attempt an approach to robotic applications in educational contexts by combining an enactive, participatory didactics approach with social robotic technology. The main underlying goal is to enhance this approach, described in *Table 2*, by strengthening its reticular interactional structure through social robotic technology. In other words, the main idea is to design for the Pepper robot a mediator function that strengthens the communication between teacher, students and the syllabus. As emphasized in *Table 2*, in this approach, for both the co-construction and the validation of new knowledge, feedback plays a central role as it allows the student to compare the knowledge gradually built, with other experiences or other findings that confirm or reject the results obtained. One of the limitations of many interactive processes is the lack of space for interaction and feedback. The absence of feedback produces self-referentiality, which is a characteristic of closed systems and diametrically opposed to the form of interaction between a subject and its environment as it is described in the enactive approach.

What are the key points of the Enactive Didactics Approach?

The Enactive Didactics Approach focuses on the interactions between teacher and student during the knowledge creation process. In this approach the teacher is seen as the focal point that raises the awareness of an issue in the students. Once this is done, it becomes possible for the teacher and the students together to build an answer. The trajectory along which the answer is constructed is sketched out by the teacher. She has the role of mediator between the world of the student and the new knowledge (Damiano, 2013), and the task of activating a cognitive conflict (Laurillard, 2012) that bridges the student's knowledge, the new problems to address and related new knowledge. After the new knowledge is established, it is crucial to validate it. In the enactive didactics approach it is the function of the teacher to verify the epistemological correctness of the constructed knowledge, ensuring that it doesn't contradict the existing knowledge. Such a contradiction could indicate either an error in the construction process, or the emergence of unexplored aspects of knowledge.

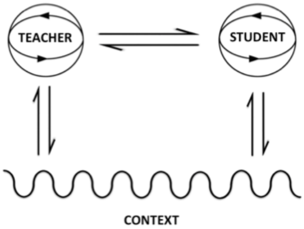


***Table 2.** The Enactive Didactics Approach*

As proposed thoroughly elsewhere (Lehmann & Rossi, 2018), one of the ways to ensure continues feedback during the didactic process is to introduce a robotic tutor, which functions as an embodied feedback channel. With the help of robotic tutors the regulation of the learning process can be focused not only on cognitive results, but also on methods, timing, attention and participation. The robot would become the mediator between the teacher, the students and the knowledge to be taught. This switch to a central role of "socially-aware" technology in the form of social mediator robot is illustrated in *Fig. 2*.

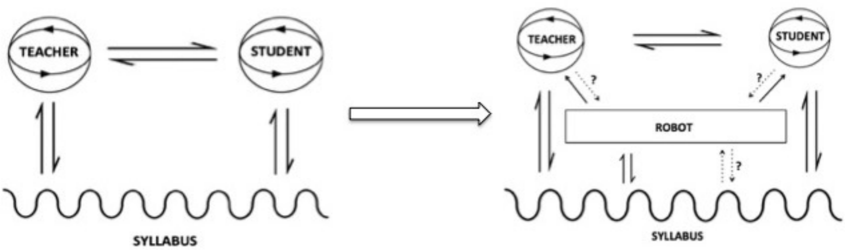


Fig. 2 - Extension of the Structural Coupling characterizing the Enactive Didactics approach by integrating a robotic tutor (taken from (Lehmann & Rossi, 2018))

7 Pepper as social feedback device

In order to develop and implement the ERAD approach sketched above we are in the process of using Pepper in combination with an audience response system (ARS). ARSs are mainly used as direct real-time feedback devices during conference or public presentations. They provide for example statistics about the perception of the presented material by the audience, enable real time polls to specific questions, or help to gather quickly information the composition of an audience. These data or statistics can be projected to a screen as source of information for the person giving the presentation, or it can be projected visibly for the audience and used as a source for discussion. In both cases it enables the listeners to actively participate or even intervene in the presentation process and increase their sense of agency.

The use of these ARSs and the presentation of their results are at the moment inherently "un-embodied", and the use the information depends strongly on the willingness of the presenter to allow the audience to interfere with the presentation. In order to "embody" the feedback provided by an audience we plan to use this technology in combination with the Pepper robot. Concretely for the application in university teaching we are implementing the scenario illustrated in *Fig. 3*.

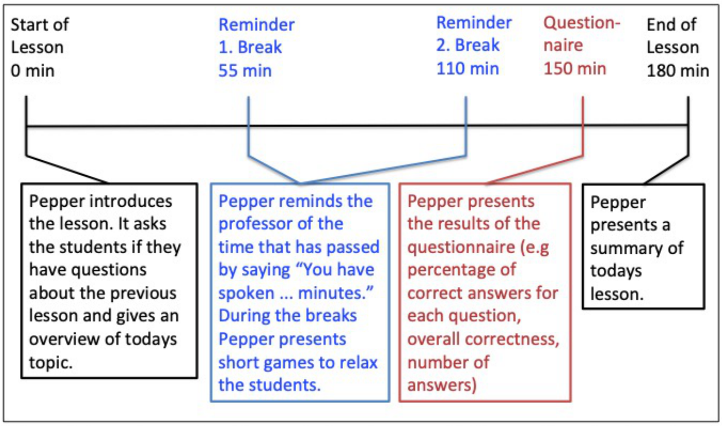


Fig. 3 - Exeplary order of evens during a lecture with Pepper. The robot introduces the course, keeps the time during the lecture, reminds the professor when to do breaks and gives a summary at the end. In the last part of the lecture, the students fill in a questionnaire in Google Forms. The robot analyses the answers and presents the results to the students.

Conclusion

The aim of this paper was to illustrate how humanoid and semi-humanoid robots have been used in the last two decades in educational contexts, and to propose a new "Enactive Robot Assisted Didactics" approach. We discussed recent attempts to classify the different roles robots are having in education at the moment, and identified some of the didactic theories that underlie the development of both the robotic embodiments and the design of the scenarios they are used in. We illustrated that most of these applications are driven by technological feasibilities, rather than by didactic frameworks. Recognizing the insufficiency of this widespread approach, we introduced an approach that follows the opposite path, from didactic theory towards appropriate robotic technology. In particular we discussed how to advantageously use the embodiment of socially aware robots to implement and enforce an enactive approach to didactics at universities, sketching an outlook on an upcoming series of applications that will see the deployment of the Pepper robot in combination with an audio response system in university lecture halls settings.

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