Social Robotics in Education

A Survey on Recent Studies and Applications

https://doi.org/10.3991/ijet.v18i03.33529

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Abstract—Over the last years, social robots have been conceived to be used in various domains and for different purposes. This paper presents a survey on different applications and aspects of social robots in education. Different contexts are seen, ranging from children education, until higher education. A variety of applications and studies are reported, in areas like second language tutoring, teaching assistance, and storytelling. Robotic platforms used in these applications are observed, and means of evaluation of users' perception of robots are presented.

Keywords—robotics, social robotics, education, human-robot interaction

1 Introduction

The interaction of modern devices and technologies with education has been increasing in the last years as several concepts and applications were introduced. For example, digital educational and serious games [60,64], mobile devices and applications [59,63,67], and e-learning systems [61] have been involved in education to provide interactive and adaptive means of learning. In particular, social robots have been rising in popularity as a domain merging several areas of research, from robotics and artificial intelligence to human-machine interaction and social behavior. The applications of social robots have been envisioned in a diversity of fields [68], from medicine [1,2] to care and assistance [3,4,69], telepresence [5,6], children companionship [7,8], and education [9–14,65].

In education, robotics domains have been involved in different ways, from learning robotics and related disciplines, to learning in the presence and assistance of robots. More specifically, social robots can be seen in education to play different roles [15,16]: teacher, tutor, peer or learning companion, and novice being instructed by the student. This progress is being made, with challenges that are still to face, such as technical challenges related to the robot's intelligence and analysis of interaction scenes, and logistical challenges related to the introduction of social robots to educational practices [15]. The willingness of users, teachers and students, to accept and use a robot in an educational context is another challenge to take into account [17]. Most of the

social robots used in education are humanoid, and the attitudes toward them are not clearly positive [16]. However, a study made in [18] reported that stakeholders in this domain, like teachers and parents, saw social robots as potentially valuable and useful tools in education. The same study highlighted the importance of having guidelines for a responsible, safe introduction of social robots in primary education, taking into consideration the related practical and moral challenges.

As studies have been made with different aspects, approaches and methods, it becomes of importance to explore the wide array of possibilities where social robots can be used for education. Not only have robots been used for different tasks, but different studies have been made to accomplish the same task in certain cases. This paper aims to provide an image of the recent advances in educational social robotics, showing the different categories where they can be placed and the differences between the works done in the same category. Therefore, published studies and applications are examined, summarized and categorized according to different aspects. The review is not exhaustive, and while relevant work may have been missed, enough works from several domains were covered to provide a limited but clear view on the extent to which social robotics have been involved in education. The focus was to review work from the last five years, in social robotics specifically, with some less recent work being covered for relevance. However, some studies from other robotics domains have also been reported. The papers cited in this survey have been obtained by searching in relevant social robotics and education journals and conference proceedings with either general keywords like "social robot", "education" and "teaching assistance", or more specific keywords like "edutainment", "vocabulary enhancement" and "second language tutoring". The obtained search results were filtered based on their relevance and their dates of publication.

The paper is organized as follows: Section 2 shows previous work done to review and survey the usages of robots in education, from different points of view. Section 3 shows work done in different areas of application in different categories. Section 4 presents robotic platforms used in education contexts. Section 5 summarizes user attitudes and interaction evaluation of robots from different studies shown, followed by a discussion in Section 6 and Section 7 concludes the paper.

2 Previous reviews and surveys

With the diversity of works being done, robotics in education has been the topic of several reviews, either being general or specific to certain aspects and applications. In this section, previous reviews and surveys are shown, with a summary of the points they showed. This allows to see different aspects of tackling social robots in education and the variety of objectives of researchers working in this domain.

A review has been published in 2013 by Mubin et al [19], where prior works have been classified based on the following criteria:

- the domain or subject: technical, non-technical, second language teaching and assistance.
- the location: intra-curricular or extra-curricular.

- the role and behavior of the robot: passive as a tool or teaching aid, or active as co-learner or tutor.
- robot types: from low-cost kits to programmable kits to robots embodied as humans, pets or toys.
- pedagogical theories in educational robotics.

In 2016, a review on the applications of humanoid robots in education has been made, with a discussion on capabilities that the robots should possess, research challenges and ethical and social issues [20]. More recently, Belpaeme et al. made a review of social robotics for education in [15] where works were addressed if they showed physical robots used as teachers, rather than other usages they can have. Different points were addressed in the study, like learning effects in terms of cognitive and affective outcomes, robot appearance, capabilities and behavior, and robot role (tutor, peer or novice). The authors discussed challenges facing the usage of social robots in education, like the robot's ability to interpret its social environment which depends on artificial intelligence and signal processing tasks. Also, decision making and action selection were identified as challenging tasks, especially in pedagogical environments. Furthermore, the authors reported logistical challenges and risks related to introducing robots in the school curriculum.

A survey has been done in 2019 on robot-assisted language learning [21]. The following robot characteristics have been focused on in the survey among others and are reported from it.

- robot function: helping with pronunciation, writing clarity and listening skills for example.
- form: anthropomorphic, zoomorphic, mechanomorphic and cartoon-like.
- voice: synthetic or pre-recorded voices, or the user's voice in the case of telepresence robots.
- robot social role: teacher, assistant, peer/tutor or learner.
- verbal and non-verbal immediacy: using language, or other means of communication like smiling and gesturing.

Additionally, the same survey reported work showing good performances of robots in language learning and advantages of robots in certain aspects. It addressed the effect of robot assistance on learners' affect and reported results related to motivation, interest, engagement, confidence and anxiety.

In [22], a review has been made on the usage of robots in special education where studies have been analyzed, with different disability categories. The heterogeneity of learner profiles was reported as a challenge as it impedes standardizing performance measures. Also, contradictions among experts on the role of robots have been identified.

In the following three sections, the current survey shows previous work from different points of view, in a way that is similar to previous surveys but extended to cover an array of aspects that is enough to provide a wide view of the topic. While describing the designs and experiments presented in each publication, other points are shown. For example, the robotic platform used, the environment of interaction, the theoretical background and implementation, the users' feedback and evaluations are shown whenever it is possible.

3 Recent work and areas of application

As stated previously, social robots have been involved in education in different aspects. The work done in this context consists either of theoretical and conceptual studies, or of actual applications running in real interaction environments. Different areas of application have been identified, like storytelling, teaching assistance, language learning and others. And the reviewed publications were assigned to them in the following subsections, allowing to observe the differences and resemblance between the different approaches.

3.1 Storytelling

Social robots can be used in storytelling for educational or entertainment purposes, and while other media like audio books can be used to replace humans in this task, robots have the ability to convey social behaviors, facial expressions and gestures [23].

In [24], a robot was designed to play a storytelling game, where it introduces new vocabulary words to children, supporting their early language education. This design was made with the expectation that children will be comfortable in the presence of the robot, which will improve their learning. In [25], a storytelling robot that can converse about COVID-19 and adopt persuasive techniques and ethical stances was studied. Persuasion was based on theories from cognitive psychology, and ethical stances were based on models and theories in persuasion, virtue augmentation and virtue ethics. The work done in [23] addressed the usage of robots as storytellers and employed the Reeti robot with an expressive face to implement studies. Videos of human storytellers were analyzed, observing components of their behaviors like gestures, gazes, and words per minute. Outcomes of these analyses were used with manual annotations to model the robot storyteller. Different studies were conducted, aiming to:

- compare an emotional robot storyteller with a neutral robot storyteller and an audio book.
- evaluate the effect of contextual head movements used during the storytelling.
- investigate the effect of using multiple voices on the user's perception of the robot.

The results showed that using multiple voices brought a positive effect, while the first two studies did not show significant results.

In [26], experiments were conducted with school students in the purpose of identifying methodologies of implementing storytelling and drama activities using robots in science education. It was observed that these methodologies facilitate the teacher's development of scientific concepts with students and that the presence of robots improved the classroom's environment and the students' attention. Also, the expressiveness and customizability of robots were found to be important for the success of their tasks.

3.2 Teaching assistance

In the field of teaching assistance, different applications have been envisioned for social robots. The work shown in [27] proposed that a robot can improve the communication between lecturers and students. A humanoid robot was thus used to convey messages from students to lecturers and evaluated in a mock lecture experiment. It was shown that collaboratively controlling the robot by voting to utter student messages improved their participation in lectures. A Nao robotic platform was used in [28] in a class environment to support teaching through tasks like providing theoretical explanations. A usefulness of the robot was observed as it could enhance the students' social interactions. A Nao robot was also employed in [12] as a teaching assistant in a primary school, to revise mathematics topics. An evaluation and comparison with a human teaching assistant case showed that children were more engaged when interacting with the robot. Another teaching assistance application for robots was designed in [29] where robots were said to have the ability to help students in problem solving, using natural interactions. This design used the ARCS Motivation Model [30] that specifies attention, relevance, confidence and satisfaction as factors needed to improve students' learning motivation. To achieve each of these factors, the robot Zenbo was equipped and used in collaboration with teachers to interact with students.

3.3 Language learning

Social robots have also been used in language learning studies requiring interaction and repeated practice [31]. The study shown in [32] investigated the efficiency of a robot as a language tutor for children learning English as a foreign language. The Nao robot was used and in some experiments was producing iconic gestures representing the words being taught. However, no added value was seen in using the robot compared to using a tablet application uniquely. Also, the iconic gestures used were not demonstrated to bring an advantage.

In [14], an adaptive approach in robot language tutoring was presented. It employed a model of knowledge tracing allowing to adapt the tutoring actions to be in accordance with the knowledge of the learners. The Nao robot was used in second language learning for children, in conjunction with a tablet showing objects corresponding to words being taught. The robot was equipped with the ability to evaluate the learner's interactions and provide feedback. This approach was shown to be promising with refinements to be made.

Second language learning in primary education was addressed in [33] where experiments were conducted to compare a robot with a tablet in terms of effectiveness in children learning outcomes, engagement and enjoyment. The results showed an advantage for robots, despite the fact that the social behavior of the robot was not shown to be advantageous in comparison with its neutrality. Vocabulary enhancement and learning was addressed in [35]. The Pepper humanoid robot was designed to be used in a wordplay game aimed to teach new words to children. It was based on Portmanteau words

which are based on merging parts of at least two other words. No results of using the robot were reported but the authors claimed that the interaction experience of children with robots in a word-play game can improve their reading capability and vocabulary.

Differences between robots, their capabilities and interaction modalities have been seen to affect the outcomes of using them in language learning. But also these outcomes were affected by differences between the learners. The work presented in [34] observed how human language café moderators interact with their participants and used these observations as a basis for the interaction of a humanoid robot used in second language practice. Different robot interaction strategies were implemented on the Furhat robot: interviewer, narrator, facilitator and interlocutor. Human participants were asked to judge the sessions they had with the robot and did not show significant differences between the different robot strategies. However, differences between learner categories, like gender, cultural origin and second language level were found. In a related context, the study presented in [11] examined and demonstrated how differences between persons can affect the way they benefit from social robots. Factors like attitudes toward robots, anxiety in second language learning and personality traits were considered. Also, guidelines for designing robot tutors were suggested in [31], covering different aspects like interaction strategies with learners, adaptive personalization of tutoring and guidelines for evaluating the effectiveness of robots in this role.

3.4 Other areas and aspects of robots in education

Aside the previously shown areas of application for social robots in education, they can be seen in applications like the following where more limited work was done:

- sign tutoring for deaf or hard of hearing children [36].
- self-regulated learning [37,38].
- teaching and raising awareness about the importance of waste recycling [7].

Also, social robots have been used in the following areas with more studies made:

Edutainment. Edutainment, named by combining education and entertainment, has been an active field of usage of robots in the last years. In [39], research activities were conducted to investigate the learning process by edutainment using Lego robot kits. An analysis of the findings showed that students were stimulated in problem finding, problem solving and checking procedures. It was claimed in [40] that edutainment robots lacked flexibility with a limited set of games that could not be enlarged. Thus, a robot was presented in [40] and was called Maggie. It is a girl-like doll with different sensors, actuators and sensor modules allowing it to be interactive. Also, its software architecture allows it to obtain new skills by building on previously existing skills. More recently, the robot MIRO has been presented in [41] as a companion biomimetic robot encouraging users to explore its construction and operation and aiming to engage users in science and robotics. It was designed to have an animal morphology, to lower user expectation of behavior and performance.

Telepresence robots. Education has been proposed as an area of application for telepresence robots among others. The study published in [42] observed other papers and analyzed factors like the following, influencing the use intention of telepresence robots in education:

- perceived usefulness: telepresence robots allow students to attend school remotely in cases of medical conditions and disabilities and that allowed a good perception of usefulness. However, the narrow camera field of view, not allowing to see all students, led to a low perception of usefulness by teachers.
- perceived ease of use: associated with the robot's control and audiovisual interface and movement abilities.
- perceived risk, about factors like the performance of the robot and the judgement of others on its usage.

In the same study [42], a survey was conducted in an educational environment. It led to conclusions like the importance of prioritizing usefulness in robot design, and minimizing complexity and demands of cognitive load from users.

Learning by teaching. This is a paradigm of learning where a child acquires and enhances his knowledge by teaching another. Robots can be used in this area to play any of the two roles. In [43], a humanoid robot purposefully simulated handwriting mistakes and children taught it how to write. The interaction was performed in such a way that the child shows the robot a word to write, the robot writes it with letter deformation and asks the child for feedback. Then the child shows the robot how to write the letters that need to be corrected and the robot adapts its writing of the letters and this iterates until the child sees no more letters to correct. In the same context, a more recent study with several similarities was shown in [44] addressing learning by teaching and handwriting.

4 Robotic platforms used in education

Several platforms have been used in the various applications proposed for robots in education. Some of them have been designed for specific purposes while others were platforms made for a variety of usages, programmable, customizable and sometimes morphologically modifiable. Table 1 shows characteristics of some of these platforms. As it can be seen, they are in several cases humanoid, equipped with degrees of freedom allowing them to move and express like humans, although they are not always of the size of an adult or child. Other platforms were designed to look and move like animals and others did not have specific living beings' shapes.

The Softbank Robotics Nao and Pepper robots were the most widely used due to their usefulness and practicality. Figure 1 shows these two robots, displaying their degrees of freedom and expression abilities.

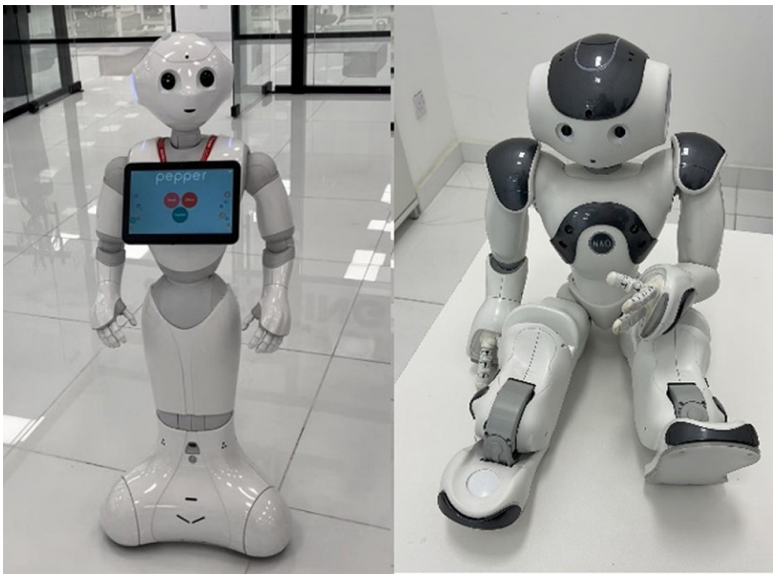

Fig. 1. Softbank Robotics Nao (left) and Pepper (right) robots at the American University of the Middle East

Table 1. Different robotic platforms seen in the surveyed papers, their shapes, some of their characteristics and usages

Robot	Shape	Capabilities	Usage
Nao [45]	Humanoid	Multiple degrees of freedom Touch, sound and image sensors Embedded speech recognition and dialogue, programmable, etc.	Teaching assistance [12, 28] Language learning [14, 32, 46]
Pepper [47]	Humanoid	Multiple degrees of freedom Touch, sound and image sensors Embedded speech recognition and dialogue, programmable, etc.	Language learning [35]
Furhat [48]	Human-like face	Onboard camera and microphones, speech recognition and synthesis, eye contact, etc.	Language learning [34]
Zenbo [49]	Unspecified	Platform movement Turning left-right Displaying facial expressions, etc.	Teaching assistance [29]
Maggie	Girl-like doll	Platform movement Moving head and eyelids Vocal utterances and mouth display, etc.	Edutainment [40]
MIRO	Pet-like	Platform movement, moving ears, tail, eyelids, vocal utterances, etc.	Edutainment [41]
Reeti	Cartoon-like	Expressive face	Storytelling [23]
CommU [50]	Humanoid	Human-like movement of the upper body Speaking, lip movement	Teaching assistance [27]

Despite the availability of several robotic platforms, usable for education, the work presented in [62] revealed the high cost of certain robotic platforms as a factor impeding the participation of students in educational robotics activities. A robotic platform was presented in the same paper, designed according to specifications based on stakeholders' needs and feedback. Other platforms were shown in [66] where robots and kits that can be used in primary education have been presented.

5 Attitudes toward robots, user evaluations and acceptance

Tools and metrics have been designed to evaluate the attitudes of humans toward robots they interact with, including their perceptions and acceptance degrees. In the context of education, it is important to seek opinions and identify concerns not only of students, but also of teachers and other stakeholders. Indeed, teachers can provide perspectives in designing robot functions and behaviors [51].

A survey was conducted in 2015 on the attitudes toward robots in Germany [52]. The authors elaborated hypotheses on factors affecting attitudes toward robots in education, like gender, age, level of education, social or non-social occupations, prior robot experience, need for cognition and technology commitment. Some of the findings obtained from this survey are as follows:

- females report higher negative attitudes than men.
- younger participants report more negative attitudes.
- educational level and field of study or occupation did not affect negative attitudes.
- prior robot experience does not help to predict the level of negative attitudes.

In this context, the Negative Attitudes Towards Robots Scale (NARS) was developed by Nomura et al. [53] and modified progressively. It has survey items addressing the interaction with robots, the influence of robots and emotional interactions with robots. Each item is scored on a five-point scale. The NARS has been widely used, with different categories of users like students in [54]. In this study, a robot was utilized as a teacher and the purpose was to explore the application of robotics in education, the perception towards robots and the educational implications. Results showed that mainly age affects students' attitudes toward robots. More recently, research on the use of NARS and on teacher attitudes toward social robots has been reviewed in [55] and a study was conducted in the aim of assessing how students would perceive a robot in a classroom. Following this study, items on the NARS scale were identified as needing clarification. Also, it was found that lack of prior experience with robots was the strongest predictor of negative attitudes toward robots. It is to note here that all the students were undergraduate and enrolled in the same introductory education course. Thus the effect of age on attitudes toward robots was not introduced.

In a more general perspective, the Unified Theory of Acceptance and Use of Technology (UTAUT) was formulated in [56], integrating elements from previous models of information technology acceptance. Performance expectancy, effort expectancy and facilitating conditions were theorized among the factors affecting user acceptance and behavior. The UTAUT was used in [57] to examine factors influencing the decision to

use a robot in the education of children, specific to the treatment of intellectual disabilities. A positive attitude was found, and it was noted that the university students becoming practitioners in the treatment of intellectual disabilities showed a higher willingness to use the robot than already practicing practitioners.

6 Interaction factors and challenges, a discussion

Research involving social robots in education has been rich in studies addressing various applications and tackling different challenges. Among the aspects related to the usage of social robots in education, the following notably emerge:

- the target users of the robot, as they can be of different ages, backgrounds and genders, which may have an effect on the interaction they have with the robot [11,34,54].
- the definition of the robot role: as it can be seen, a robot can be envisioned for learners as a teacher, companion, assistant, or even a peer [15,16].
- the environment of the human-robot interaction, as it can be a one-to-one interaction at home or school, or a one-to-many interaction in classrooms [12,27,28,32].
- the shape and capabilities of the robot, which affect different aspects of the way that humans interact with it, like believability, acceptance, trust, and enjoyment [42,62].

The diversity, activeness and interactions of the communities involved in social robotics, education, robot design and even psychology have allowed to reach specific studies and applications tackling the aspects shown above. However, diverse factors still need to be addressed to allow robots to be actively engaged in education in the future. Indeed, in the highly interactive environments of education, social robots still face challenges before reaching a state of maturity where they can be employed in everyday real environments. These challenges can be categorized in different ways as follows.

6.1 Technological challenges

Many of the challenges facing robotics in education are challenges to artificial intelligence in general, as cognition capabilities implementation on robots require efficient executions of tasks in signal processing, pattern recognition, decision making and response generation. For instance, improving capabilities of robots to understand speech and perform human-like behavior has been exposed in [19]. Moreover, responses can be of different forms like sound, visual as expressions or visual and tactile as gestures. Additionally, to implement all these capabilities, hardware considerations are to be made, from the platform design to the sensors and actuators equipping it, to the processing capabilities it has.

6.2 Usage challenges

In [19], challenges and open questions regarding robots in education have been listed. Notably, the need to design learning material and curriculum, and to define the

role of the human teacher. Also, adapting robot behaviors to the learner, taking into consideration factors like the age, and the knowledge of robotics and computer science. As stated in [58], designing socially assistive robots for education involves a combination of features that developers need to identify. Participatory design with stakeholders providing suggestions was said to be a promising solution [58].

7 Conclusion

Educational social robotics has been addressed in this paper, with the aim of showing the wide extent of work done in this field and the related aspects. Recent literature was surveyed and works were categorized according to their areas of application. The extent of the social robotics in education has been demonstrated in two aspects: the different domains of applications and the variety of the works done in each domain. Also, some of the robotic platforms used in educational contexts have been shown and a discussion has been made on considerations and challenges facing social educational robotics. These different points were shown in the parts of this paper with relevant sources cited. They allow to observe the possibilities of getting robots involved in education to provide positive impacts. Indeed, despite the fact that a large part of the presented work was done as studies and not actual implementations used regularly in education, it is possible to envision social robots as active role players in education. With challenges to overcome and advances to be made, robots may bring improvements to the student learning outcomes and be accepted and well-integrated in their contexts of usage.

8 Acknowledgment

The authors would like to thank the editor and the reviewers for their valuable comments that helped in improving the quality of the paper and the presented ideas.

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Article submitted 2022-06-22. Resubmitted 2022-10-10. Final acceptance 2022-10-14. Final version published as submitted by the authors.