7 Social Robots as Educators

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Robots in education largely fall into two categories: robots that are used to teach and enthuse children about STEM subjects, and the more recent application of robots as teachers. While the pedagogical potential of robots for STEM education has been extensively explored since the 1970s, robot teachers form a new technology, driven by new developments in artificial intelligence and robotics, which is currently the subject of research and proof-of-concept trials. These robots assist teachers in their pedagogical task by offering specific tutoring experiences to students. Their potential stems mainly from their ability to provide one-to-one tutoring and a physical presence, with the latter missing in traditional computer-based learning. While there are no commercial solutions yet aimed at formal education, research suggests that social robots do offer benefits which computer-based solutions do not. Their physical nature lends them to real-world interactions with learners, and they have an increased social presence, which enhances learning outcomes. There are, however, considerable technical, economical and logistical challenges to rolling out social robots in classrooms.

Introduction

Robots in education are typically used as a means to teach STEM subjects. Originally seen as a way to introduce students to programming and computational thinking, robots are now also used as a tool in the teaching of electronics, mechanical design, computational thinking, and even arts, and to also practice soft skills such as collaborative work and negotiation skills (Alnajjar et al., 2021[1]). The use of robots for STEM education has been well explored for over 50 years and is known to be particularly effective as a catalyst to teach a range of subjects (Benitti, 2012[2]). As a result, robots as learning tools are adopted with varying success in primary, secondary and tertiary education.

In recent years a new application has emerged of robots in education. Fuelled by advances in robotics and artificial intelligence, social robots are now being explored as teaching assistants (Belpaeme et al., 2018[3]). Social robots are robots that interact with people using the same interaction channels used in human-to-human communication. They use speech, facial expressions or body language to communicate. They are often designed to have visual appeal and their software is tailored to keep social interaction flowing. While these robots are still fairly limited in terms of their interaction abilities, they do well in restricted and contained interactions (Bartneck et al., 2020[4]; Breazeal, 2004[5]; VanLehn, 2011[6]). In recent years the potential of social robots has been explored in education, with a body of research showing that robots have significant potential in formal and home education.

In this chapter, we will present the promise of robots as educators and also the current limitations in this area. We will mainly focus on two types of robots: social robots that are designed to operate autonomously and aid teachers to carry out some tasks; and telepresence robots based on a more hybrid model that are operated remotely by teachers and embody the teacher in the classroom. After presenting some of the current learning domains of application and giving some explanations on their technology, we will highlight some difficulties for their wide adoption and stress that, while they can be useful supplements to teachers, they are unlikely to replace teachers in the near future. Their cost may also remain too high for a massive presence in education systems.

Why robots as educators?

Social robots are attractive in a number of ways. Their lifelike behaviour and their social responsiveness speaks to us, and this has not gone unnoticed by educators. In the most basic sense, robots appeal to a large audience and can be used to make teaching more engaging. But beyond this short-term attraction, perhaps the largest appeal of robots is that they offer the potential for taking over some of the tasks of the teacher. While financial resources put a limit on the amount of time teachers can spend on pupils, robots are relatively cheap and could potentially be used to teach and tutor small groups, with, in the ideal case, each learner being assigned their own robot tutor. Tutoring, that is, the teaching of only one learner or a small group of learners, is known to be one of the most effective forms of teaching. VanLehn (2011[6]) found that human tutoring has a mean effect size of $d = 0.79$ when compared to class-based teaching. Computer-based teaching, and specifically step-based Intelligent Tutoring Systems (ITS) which provide fine-grained customised instruction and feedback to the learner, can achieve a similar outcome of $d = 0.76$ for certain subjects (VanLehn, 2011[6]). The expectation is that robot as educators will achieve similar outcomes, with a recent review showing that early robot prototypes achieved learning gains of $d = 0.70$ when instructing subjects varying from language tutoring to teaching about the dynamics of energy use in a city (Belpaeme et al., 2018[3]).

Key to assigning an educational role to robots is the social interaction that these robots can support. Through their appearance and software, social robots are optimised to engage humans in a manner that comes naturally. Most often these robots will have a friendly design, with face-like features such as a head, eyes and a mouth evoking the ability of the robot to see, hear and speak. Through their artificial intelligence they are able to interact with people: they use face detection and recognition to detect and identify people, use speech recognition to extract words from spoken interaction, and will use dialogue models and speech synthesis to converse (Bartneck et al., 2020[4]). The natural interface makes them suitable for a large range of tutoring activities, from tutoring pre-literate children to tutoring languages using natural interaction.

While software-based solutions for learning, such as Intelligent Tutoring Systems, can offer individual and personalised teaching, a robot adds social and physical presence which is missing from a typical Intelligent Tutoring System. It has been shown that the physical and social presence of a robot induces behaviours which are conducive to learning (Bainbridge et al., 2011[7]; Li, 2015[8]). Attention is higher, compliance increases, and motivation is more persistent when social robots are used. This is likely due to the human brain responding strongly to social stimuli, and while on-screen avatars to some extent also offer a social presence, the tangible nature of a robot amplifies this and any associated effects. This may sound paradoxical as a criticism of computer-based learning assumes the inability of humans to engage emotionally with machines: while interactions with robots are of course different than with other humans, they still trigger social responses and create some form of connection (Belpaeme et al., 2012[9]).

The different teaching roles of robots

Social robots can play different roles to teach or support students during their learning journey. In education, social robots are typically designed and programmed to play one (or more) of the following roles: tutor, teacher (or teaching assistant), and peer learner.

The most promising and pragmatic role for social robots in education is as a *tutor* (e.g. Kennedy, Baxter and Belpaeme, 2015[10]; Leyzberg et al., 2012[11]; Saerbeck et al., 2010[12]). In this role the robot provides support to a single learner or to a small group of learners. The robot can offer individual attention in a manner that can augment the capabilities of a teacher in a typical classroom setup. It can offer help to children who fall behind, or can challenge children who are ahead, without disrupting the usual classroom activities. It has infinite patience and can rehearse subjects as long as the teacher allows. Furthermore, the robot is often seen as non-judgemental by the learner (Bhakta, Savin-Baden and Tombs, 2014[13]; Catlin, 2014[14]), thereby removing the anxiety often associated with answering questions with a human tutor or teacher. Box 7.1 presents an example in language learning.

Box 7.1 Language learning with a robot tutor in the Netherlands

Language learning, and specifically second language tutoring, has been identified as a particularly promising application of robot tutoring. A child's first language is acquired through interacting with parents, siblings and peers, but quite often a second language is learned in a formal education setting and the process of learning is radically different from that of acquiring a mother tongue. No longer is the language learnt through interaction, but instead through the rote learning of vocabulary lists and grammatical rules. This stark contrast in mode of learning is to a large extent due to resource limitations. The teacher is not in a position to interact in the target language with individual children in the classroom, and instead is forced to resort to class-based teaching. In addition, the teacher himself might not be confident enough to speak the target language, or does not master all aspects of the target language. For example, native English speaking teachers will often struggle with French pronunciation – and vice versa.

This is where a robot tutor can make a valuable contribution (van den Berghe et al., 2019[15]). The robot can support the child in learning a second language through not just tutoring, but through genuine interaction in the target language. Not only can the robot offer language lessons, but the robot is likely to have a better accent in the target language than the teacher, as modern computer voices are now almost indistinguishable from human voices. Moreover, while speaking a new language many people suffer from foreign language anxiety, something which is alleviated when speaking to a robot as learners do not feel judged by the robot.

In a recent study Dutch children aged 5 were taught English as a second language with the help of a social robot. The young learner and the robot sat around a tablet computer, on which short stories were displayed. The robot described the stories in both Dutch and English and taught the children a range of words, from nouns to mathematical concepts, but also introduced grammar through play rather than through formal instruction (Vogt et al., 2019[16]). The study wished to see how effective robots were for early second-language learning and also tested if gestures by the robot, such as the robot mimicking a little jog when teaching the verb "running", would speed up learning. The children were able to acquire and retain English taught by the robot tutor to a similar extent as when they are taught by a tablet application. However, learning overall was slow. When learning with the robot in which they met the robot for seven 20-minute sessions, the children's score on a comprehension test of English only increased from 3.47 to 7.69 out of a maximum of 34.

Figure 7.1 English-as-a-second-language teaching with the help of a social robot

Source: Vogt et al. (2019[17])

The robot can also be used as a *teacher* or a *teaching assistant*: here the robot will substitute for the teacher by, for example, delivering a lecture or by providing assistance during teaching. In this case the robot addresses the class, rather than a single learner. The robot can assist with administrative tasks, such as registering students, and can take over narrow teaching tasks, such as announcing today's topic, checking prerequisite knowledge, setting a learning task, asking multiple-choice questions, summarising responses and providing feedback. In doing so, the robot frees up time of the teacher. The value of the robot not only lies in freeing up the teacher from class-based interaction, instead allowing the teacher to provide individual attention to learners, but providing experiences which the teacher might find difficult to do, such as native pronunciation of foreign languages. However, more often than not, robots are just used to spice up a lecture or classroom experience; for example, by acting as a sidekick to the teacher (see Box 7.2).

A novel and particularly promising role for a robot is as a *peer learner* (Tanaka and Kimura, 2009[18]; Tanaka and Matsuzoe, 2012[19]; Hood, Lemaignan and Dillenbourg, 2015[20]). In this the robot is presented as a learner and children are invited to learn together with the robot or are asked to instruct the robot. This relies on the protégé or learning-by-teaching effect, the idea that explaining study material to others reinforces a student's understanding: the robot plays the role of a "teachable agent". In this model, children have been shown to spend more time and effort on learning activities and to learn more (Chase et al., 2009[21]). This has been shown to be effective in learning subjects as diverse as handwriting (Lemaignan et al., 2016[22]) and second-language learning (Tanaka and Matsuzoe, 2012[19]). This effect is more pronounced for weaker students, and is probably linked to the robot inducing more confidence in the student. With the peer-like robot in the classroom, the weakest learners are no longer the weakest students, the robot instead is weaker and its reliance on being taught elevates the status of the children.

Box 7.2 Robots used as a sidekick during language class in Iran

Iranian secondary school students have been using a small humanoid robot, nicknamed Nima, to support them during their English classes. The robot acts as a sidekick to the teacher, with both the teacher and the robot standing at the front of the classroom. The robot helps the all-female class of 12- to 13-year olds to practice their English (Alemi, Meghdari and Ghazisaedy, 2014[25]) through for example giving feedback on exercises or demonstrating the correct pronunciation of English words and phrases. Over a period of five weeks, the teacher taught the official curriculum to a group of 30 students together with a robot assistant. When compared to a balanced group of 16 students who were taught only by a teacher, the group with the robot assistant showed greater vocabulary gain and retention (the students' mean score on a pre-test was 13.45, after five weeks the robot group had a mean score of 39.76, the control group a mean score of 30.50). At the same time, the group with the robot assistant enjoyed the subject more, offering a possible explanation for their performance.

Figure 7.2 A class with a robot assistant

Source: Alemi, Meghdari and Ghazisaedy (2014[25])

Besides teaching, robots can also be used to provide *socio-emotional support*. As robots are generally considered to be non-judgemental and neutral, people will often share information with a robot which they would be reluctant to share with others. This can be used to discuss personal aspects and offer advice on how to address problems. The robot can, if given permission by the learner, share selected information with teaching professionals or support staff. This has for example been effectively in education to address bullying, the study showed that children disclosed more about the occurrence of bullying at school than they when reporting bullying using an anonymised form (Bethel, Stevenson and Scassellati, 2011[23]; Bethel et al., 2016[24]).

Robots as telepresence devices for teaching and learning

Social robots in education are usually designed to perform certain learning tasks by themselves. While most of the time they are still meant for a learning environment controlled by teachers, they are often autonomous to perform specific teaching (or learning) tasks. Robots can also be used in a different way, as a telepresence device, with varying functionalities. The telepresence robot becomes the teachers' avatar in the classroom.

In this scenario, a remote teacher controls the robot and engages the learners. As the artificial intelligence required to run fully fledged teaching is still unavailable, telepresence robots can fill this technological gap. As the robot is controlled by a human teacher, it can respond to the sometimes wide-ranging responses and needs of the children, something which an AI-controlled robot, for the time being, cannot do. It also allows learners to have access to expertise and skills which their local teacher cannot offer, or draws in expertise from people who are not locally present or who wish to contribute to teaching on an occasional basis.

Telepresence robots are robots that are remotely operated by a human operator and are capable of embodying the operator's presence as a robot avatar. These robots can provide several benefits by leveraging the embodied properties of the avatar in the field of education. This topic has been gaining particular attention under the risk of infectious diseases such as COVID-19.

One instance of use of telepresence robots in education is when a human teacher employs a robot to conduct lessons remotely, providing the teacher with a richer perception of the classroom than with the traditional video-conferencing. This is because the teacher can arbitrarily control the locations of the robots and of the sensors (cameras, microphones, etc.) that are installed on the avatar robot, whereas the sensor locations are mostly fixed in the traditional video-conferencing.

In addition, students in the classroom can experience the presence of the remote teacher better when a robot avatar is present in the classroom. Typically, the teacher's face is projected on the head of the robot. A field trial conducted in a public elementary school in Japan revealed that students felt some sort of tension (i.e. the classroom atmosphere under control) in the presence of an avatar robot in the classroom (Okamura and Tanaka, 2020[26]). The students were mostly in favour of this tension because it prevented distractions in the classroom in the absence of the human teacher.

Another instance of the benefit of telepresence robots is the situation in which a student operates the avatar robot. For example, a student can participate in the classroom activity of a remote school (even in a different country), which offers good opportunities for both learning various languages and experiencing different cultures. In a field trial (Tanaka et al., 2013[27]), two elementary school classrooms, one in Australia and the other in Japan, were connected by a telepresence robot, and students of one school participated in the classroom activities of the other school (Figure 7.3). The classroom teachers and school managers who observed the trial greatly appreciated the use of this technology for learning languages and cultures. This functionality is also often used to allow students who have a long-term illness to maintain the contact with their school (Box 7.4).

Furthermore, a study reported that a telepresence robot can be used to facilitate second-language learning in a face-to-face manner (Tanaka et al., 2014[32]). Here, learners participated in a private lesson conducted remotely by a native speaker of a language via traditional video-conferencing. This situation posed a challenge for some learners; in fact, learners often froze owing to their non-fluency in using the second language. However, when they participated in the lesson by using a telepresence robot, they could communicate with the remote teacher not only verbally but also physically (i.e. by utilising the body of the avatar robot), which facilitated the second-language learning (Figure 7.4). With gesturing and hand-to-hand interactions, both learners and teachers can relax, resulting in responsive learning between them (Tanaka et al., 2014[32]). In Korea, the Engkey robot developed by the Korea

Institute of Science and Technology was designed to support English learning in primary schools: a remote teacher, whose face appears on the robot screen, controls the robot using a computer. Results from a field study in the city of Daegu involving 29 classrooms suggest that the telepresence robot controlled by a native English speaker improved students' achievement, especially in speaking (Yun et al., 2011[33]).

Box 7.3 Attending class via a telepresence robot in Norway and France

Many telepresence robots were developed with the objective of allowing students with long-term illness to maintain a connection with their school.

For example, the AV1 robot developed by the Norwegian start-up No Isolation is a student-operated telepresence robot. When a student cannot attend class due to illness, AV1 can take the student's place in the classroom. The robot is equipped with a camera, speaker, microphone, and Internet connection, enabling remote students to listen, see and speak in class (by using an app on a smartphone or tablet). They can look around the room, raise their hand to speak in class, change the robot's eye expression to convey their emotions (e.g. confusion) and even whisper to a neighbouring classmate. The use of the robot can of course also allow them to stay in touch with friends by attending birthdays and other gatherings remotely.

In France, "my connected schoolbag" is a telepresence robot also designed to take the place of a student in the classroom when ill. It is equipped with the same hardware devices as the Norwegian AV1 robot (rotating camera, speaker, microphone, Internet connection, plus a tablet app). Developed as part of a non-profit initiative, this telepresence robot takes the form of a traditional schoolbag, with the objectives of allowing students to attend class and be present among their classmates, while avoiding substitution mechanisms that anthropomorphic robots might generate.

Many similar robots were developed for similar uses in other countries, such as Inbot Technology Ltd.'s PadBot in China; Axyn Robotique's Ubbo in France; FuutureRobot's FURo-i in Korea; Wicron Robotics' Webot and R.bot's Swan Synergy in the Russian Federation; Giraff Technologies' Giraff in Sweden; Xandex's Kubi, Blue Ocean Robotics' Beam, Orbis Robotics' Carl and Teleporter, Double Robotics' Double 3 in the United States.

Source: AV1: Belton (2018[28]); and Anthony (2017[29]); Mon cartable connecté (n.d.[30]); Telepresencerobots (n.d.[31])

Figure 7.3 Classrooms in Australia and Japan were connected by a telepresence robot in real time

Source: Tanaka et al. (2013[27]).

As a supplement to remote and virtual laboratories in science, telepresence robots are being tested to carry out science experiments in a real lab. Researchers in Canada studied the use of a specifically-designed telepresence robot in a mock-up smart laboratory as a way to enable students to conduct lab or field work remotely. They built an affordable prototype (about USD 350) with a two-degree of freedom arm; online users could easily operate it and results of the small pilot suggested increased engagement of online students (Tan et al., 2019[34]).

Considering the benefits explained so far, one may imagine students participating in a classroom by using a telepresence robot from his/her home, enabling them to safely attend classes in dangerous situations involving the spread of infectious diseases, for example. Currently, because of the high cost this would represent, this idea is not feasible in education. However, a single robot avatar can be controlled by multiple operators (shared-control), and therefore, fewer robot avatars than the number of students is required. It will be interesting to test whether a few (e.g. 2-3) robot avatars and a teacher can conduct a meaningful class for more (e.g. 4-6 or more) students.

Figure 7.4 A telepresence robot facilitated the second-language learning of students

Source: Tanaka et al. (2014[32])

With the help of technologies supporting remote education, we may be able to secure new teachers. For example, retired senior people who have the necessary skill and knowledge can teach school children from their homes (Figure 7.5) (Okamura and Tanaka, 2016[35]). By introducing AI features such as keyword-spotting and dialogue generation to facilitate intergenerational conversation between school children and these senior teachers, a telepresence robot can act as an intelligent interface that assists the senior teachers in grasping the status of the remote students and giving a lecture effectively.

Figure 7.5 Senior people can give a lecture from their homes by making use of a telepresence robot

Source: Okamura and Tanaka (2016[35]).

Robot effectiveness: age and learning domains

Robots seem to be effective for a wide range of ages. While most research focuses on children between 6 and 12, robots have been shown to be effective for other ages as well. They have been used for language tutoring in pre-school classrooms (Gordon et al., 2016[36]; Vogt et al., 2019[16]), but have equally been shown to be effective in higher education (Weber and Zeaiter, 2018[37]). While it was believed that robots would be most effective at the age where children still show "suspension of disbelief" it is now increasingly clear that social robots are convincing at any age. An appropriate design of the robot and an appropriate interaction experience for the age of the learner suffices. However, building robots for older students has proven to be more technically challenging, as older learners put higher demands on the robot's abilities (Beran et al., 2011[38]). Younger children will accept that the robot leads the interaction and keeps the interaction on track, and will still believe the robot to be social. Older children are more likely to want a more diverse and unscripted interaction, which in turn is technically challenging to deliver.

Robots as educators work best for topics that are relatively restricted and where the input to the robot is well-described. One reason for this is that social signal processing, a sub-branch of artificial intelligence which attempts to interpret the social environment (Vinciarelli, Pantic and Bourlard, 2009[39]), can for now only handle rather explicit social signals, such as strong facial expressions or gestures. The technology to transcribe and understand spoken language and non-verbal social signals, to understand the intents and beliefs of people, and come up with appropriate responses, while impressive, often struggles to interpret social interaction in context. But well-functioning social signal processing is necessary to offer a full interactive experience similar to that offered by a human teacher. This means, for example, that robots for now are not able to engage in unconstrained dialogue: while they can transcribe spoken language into written language, the artificial intelligence struggles to access the meaning of what is being said and without it cannot formulate an appropriate response. This is the reason why voice-operated technology still requires us to use short, structured commands and for now struggles with long and unconstrained spoken language. However, when appropriate constraints on the learning context are in place, robots can provide support in a wide range of subjects. Often, the robot is presented together with a screen, which is not only used to display educational content, but which also serves as an input device where the learner can enter responses or select exercises shortcutting the need for the robot to understand verbal input.

Content-based subjects, where rote learning is important, such as geography, vocabulary, or low-level science, lend themselves well to robot tutoring. The repetitive nature of this type of learning and the relative ease with which topics can be taught and tested make them suitable for computer-based and robot-based instruction. As these topics are well-structured, the level of the learner is easily assessed through formative assessment or quizzes, upon which the robot can adapt its tutoring.

Skill-based subjects such as reading or mathematics also lend themselves relatively well to tutoring by robots. Here, often the skills are displayed on a computer screen, as they often have a strong visual component, and the robot offers encouragement and support during learning. The robot adapts to the learner's profile and progress and will offer hints, encouragement and help at just the right time. As with Intelligent Tutoring Systems, it is important to dose support in an appropriate manner. Too much support often leads to learners' overreliance on the system's help function (Aleven et al., 2003[40]), but robots can actively shape help-seeking behaviours of the learner (Ramachandran, Litoiu and Scassellati, 2016[41]).

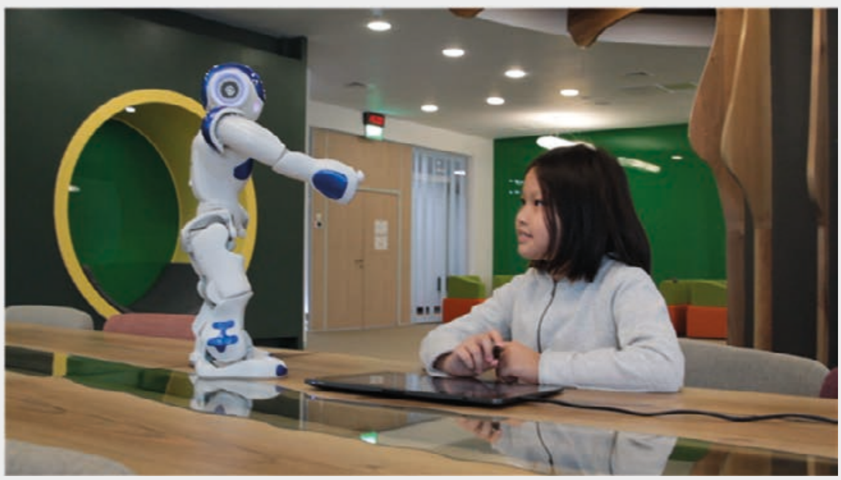
Robots have also shown promise in tutoring in the affective domain. This can be directly applied to education itself, for example when the robot encourages learners to complete more exercises or to practice at home (Kennedy et al., 2016[42]). But, robots can also be used to teach and promote soft skills and social skills. For example, robots are known to be effective at practicing social skills for children with Autism Spectrum Disorders (Robins et al., 2004[43]; Scassellati, 2007[44]). Here, the robot implements Applied Behaviour Analysis, a therapeutic approach in which social skills are internalised through repeated practice.

Robot tutoring comes into its own with the tutoring of physical skills, such as motor skills or physical rehabilitation. Here, the robot demonstrates and supports the learning process. A social robot has been used to teach handwriting skills to children aged between 6 and 8. For this peer learning was used: the robot was presented to children as having poor handwriting and the children were asked to demonstrate proper handwriting to the robot. As the robot improved, the poorest hand-writers were shown to improve as well (Hood, Lemaignan and Dillenbourg, 2015[20]; Zhexenova et al., 2020[45]) (Box 7.4).

Box 7.4 Robots supporting handwriting skills in Kazakhstan

The Kazakh government decided in 2017 on a transition from Cyrillic to Latin script for government communication and education. The transition will be phased over a seven-year period, and the role of formal education is essential in this process. A team of researchers studied how robots can be used to support children with learning the newly-adopted script and its handwriting system. They use a "learning by teaching" paradigm, in which the children taught the robot. While the robot approach achieved similar results as learning with a tablet computer or a teacher, the robot has significant benefits when it comes to lifting children's motivation and the robot was found to be the preferred method of learning (Zhexenova et al., 2020[45]).

Figure 7.6 Experimental setup



Source: Zhexenova et al. (2020[45])

The most challenging learning domain, but also the one where robot tutoring is likely to have the largest return on investment, is that where the robot relies on unconstrained social interaction for teaching. Language learning is a prime example, as it benefits from spoken interaction in the target language, something which could be practised with a robot. These robots would also be able to offer support going beyond formal teaching, and could for example offer psychosocial support. However, the technical challenges involved in unconstrained human-machine interaction mean that this application will probably take decades to mature. As mentioned above, in the meantime telepresence robots operated by humans can fill the gap.

Technical aspects of robots in education

Tutoring robots come in a variety of shapes and sizes, from 10cm-tall simple robots to tall, humanoid robots. The application and target audience often dictates which robots are more appropriate: for young children a small robot might be more appropriate, but a robot addressing a lecture theatre with adult students might need to have more authority and therefore be taller and human-like. The actual appearance of the robot seems to have little influence on the learning outcomes: research shows that more human-like robots do not necessarily achieve better learning outcomes, but rather that it is the presentation and social presence of the robot which matters for the learning outcomes. A meta-analysis (Belpaeme et al., 2018[3]) for example showed that small toy – like robots, such as the Keep On robot, which is a 15cm – tall robot, can achieve learning outcomes comparable to more expensive humanoid robots (such as the robot in Box 7.4).

In its simplest form, a social robot has very limited interactive abilities. It runs through simple scripts in response to minimal input, such as button presses or input on a tablet computer. Moving on from there, the robot can shape the interaction based on the learner's performance. It can monitor answers to quizzes and build a model of the learning trajectory of the student. This model is then used to shape the interaction, as already happens in Intelligent Tutoring Systems. In recent years, machine-learning techniques have been used to build more detailed models of the learner's performance and predict which responses by the robot will have the highest chance of increasing learning (Schodde, Bergmann and Kopp, 2017[46]; Spaulding, Gordon and Breazeal, 2016[47]). As such, robots can offer exercises and material that sufficiently challenges the student without being off-putting. Social robots can also provide encouragement or commiserate with wrong answers, for which they require a modest amount of information such as the answers given and the timing of the responses. While these approaches have for some time been available in educational software, they are only now becoming available in commercial social robots.

However, beyond adapting the teaching to the learner, the assumption is that social robots also complement their educational functionality with a range of social responses. One element of an increased social responsivity is the use of personalisation (Molenaar, 2021[48]). This not only means that the robot tailors its teaching or quizzing to the individual learner, but that it also stores and recalls personal information. This can range from using the learner's name, to storing facts about their family and hobbies and adapting its behaviour to the personality of the learner. Studies have shown that students bond with robots which appropriately use personal information (Belpaeme et al., 2012[9]), and that this has a positive impact on learning outcomes and motivation. Baxter et al. (2017[49]) embedded a social robot in two primary school classrooms in the United Kingdom for a period of two months. The robots acted as learning companions for familiar and novel subjects. One robot personalised its responses, by using the children's name when speaking and by adapting its personality to match that of the child, while the other robot did not. Results showed that there was increased learning of novel subjects when interacting with a robot that personalised its behaviours, with indications that this benefit extended to other class-based performance in which the robot did not take part. The study also showed increased acceptance of the personalised robot peer over a non-personalised version.

Finally, full social interaction requires the robot to be able to interpret verbal and non-verbal social signals and respond appropriately. Some elements are technically straightforward: a robot can use its camera to detect people and respond to their presence, it can make eye contact and read simple emotions. Speech recognition, the transcription of speech into written language, is fairly mature and, while it does not work well yet for younger users, the technology is sufficiently advanced to allow spoken responses to the robot. This can be used for simple, turn-based spoken interaction, for example the robot asks a multiple-choice question and listens for a spoken response.

However, unconstrained dialogue is still technically impossible. For this the robot not only needs to transcribe speech, but needs to understand what is being said and formulate an appropriate response. This is only possible in limited interaction settings, but the current state-of-the-art cannot yet handle open dialogue between a user and a robot. Still, this and other social skills, would make for a very persuasive and effective social robot in general, which would have large implications for the application of social robots, including in the educational landscape.

Attitudes of teachers

As teacher attitudes are a strong predictor of technology use in the classroom, a positive attitude towards robots will be a prime driver for adoption of social robots in education. Studies show that teaching professionals hold a range of attitudes towards the use of social robots in education, but that many have reservations about the introduction of robots in the classroom (Kennedy, Lemaignan and Belpaeme, 2016[50]; Kim and Lee, 2015[51]; Reich-Stiebert and Eyssel, 2016[52]; Serholt et al., 2014[53]).

Teachers with a more positive attitude towards technology in general, have perhaps unsurprisingly also a more positive outlook on robots in education. They also believe robots to be good at supporting teaching activities in science, technology, engineering, and mathematics (STEM), but do not consider other subjects, such as social skills or languages, to be appropriate for the use of robots. A survey of UK primary school teachers by Kennedy, Lemaignan and Belpaeme (2016[50]) showed that 57% of teachers believed robots could assist with STEM subjects, but only 13% believed the robot to be suitable for teaching humanities and arts. This may reflect the teachers' familiarity of robots as learning devices and tools rather than robots taking up an educational role.

Studies also surveyed teachers' concerns about the use of robots, the main ones are:

- Potential disruption to classroom activities, where the robot distracts from teaching rather than supports teaching.
- Fairness of access, especially if robots will be few and far between, access should be given to learners who will benefit most, not to privileged learners. Cost is indeed an issue, and if robots are expensive, they will be only available to learners and schools with sufficient financial means.
- The robot might add to the workload of the teaching staff. If a robot would act as a teaching aid in the classroom, it should be easy to use and require a minimum of effort to set up, operate or put away.
- Finally, an often heard concern was that social robots might have a negative impact on interpersonal relations and exacerbate social isolation. They could also introduce a "robotic" style of interacting to the classroom environment, as robots have simplistic interactions, exhibit a lack of empathy and a lack of flexibility, which would have negative consequences for young learners.

We need to stress however that these results are based on surveys completed by teachers who have never had access to social robots, or to robots used as teaching assistants. As such, responses will be coloured by preconceptions formed by popular media and science fiction, and might not reflect future attitudes. Anecdotal evidence suggests that teachers who have worked with social robots in the classroom are generally very positive about the potential applications of robot teachers.

One interesting element in all surveys is that job loss is less of a concern or no concern at all: teachers do not consider robots to be a replacement for human labour, but see robots as a technological aid for their profession.

Some of those concerns appear as legitimate, while others are less so. For example, while the concern about robot-like interactions, in which the interaction lacks depth and warmth, is currently valid, the idea that children (and adults) cannot engage in emotional interactions with robots is actually not true. Studies show that children and adults readily form emotional bonds with robots, and that these can be used to support people in a positive manner (Belpaeme et al., 2012[9]). As mentioned above, robots can help solve socio-emotional issues, and research has shown that, while understanding their limitations and the fact that they are just machines, children can "like" a well-designed robot (van Straten, Peter and Kühne, 2020[54]).

The questions around workload, disruption, technical maintenance and distraction are fair concerns that researchers and developers in education robotics have to factor in when designing their robots. The best and most effective uses of social and telepresence robots in education still have to be researched and experimented.

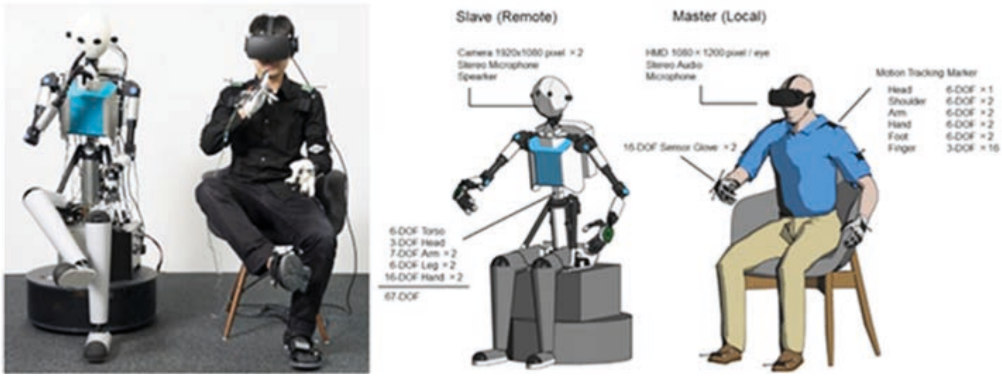
Commercial offerings

Cost and affordability are very legitimate concerns for the education community.

At the moment there is a very limited commercial availability of social robots for education. Some products are aimed at the edutainment market. Cody The Smart Cub by Vtech Playtime, an interactive bear toy, is advertised as a cuddly learning companion for children aged 6 to 36 months, but is limited to playing canned utterances and songs which can be adapted to the learner. The WEDRAW Educational Robot is a talking pen plotter aimed at children between 3 and 8 years old which can draw on paper and comes preloaded with content about shapes, figures and numbers. More advanced solutions exist as well, such as the Softbank Robotics Nao and Pepper robots, which are being presented as "educational robots" by the manufacturer. For example, an educational application for English learning was commercialised with Pepper robot (Tanaka et al., 2015[55]).

As for commercial telepresence robots, they are available at prices below USD 1 000. However, these affordable telepresence robots have limited capabilities in terms of sensors, actuators, and controlling interfaces. The latest remote avatar systems are equipped with higher-functioning sensors, actuators, and virtual reality interfaces (for robot operators), making them more expensive. Educational telepresence robots will thus probably be more expensive than those that are currently available. The TELESAR series is one of the most advanced "telexistence" system with a long history of research and development since the 1980s led by Susumu Tachi and his colleagues (Tachi, 2015[56]). The TELESAR VI (Figure 7.7) system comprises a remote avatar with 67 degrees of freedom to perform human-like movements. In principle, the system can also be equipped with rich sensing capabilities, including vision, audio, and haptics. Although these systems represent cutting-edge research and are highly expensive at present, the research lets us envision the future direction of remote education, with telepresence robots being able to behave with increasing complexity in a classroom.

Figure 7.7 TELESAR VI. (2019)



Source: Courtesy of Prof. Tachi.

A main limitation to the commercial success of these robots is twofold. On the one hand, there needs to be a substantial supply and demand for these robots. Often this forms a chicken and egg problem. When there is no demand for robot tutors, there is no commercial interest in developing these systems, and vice versa. Software and content need to be written (supply) that make these robots attractive to buyers, both families and educational institutions (demand). There currently is a lack of public and private investment here, as most content providers are reluctant to make content for educational robots. The other limitation is that social robots for education need appropriate processes and ecosystems before their introduction can be a success and they have a viable demand. At the moment there is a vacuum in teaching practice and teacher training programmes, which sits in the way of using social robots for education – even for those that are already available.

These limitations form a chicken and egg problem: content developers and robot manufacturers will withhold investment in these new technologies as long as the market is not developing, and market uptake is very low because of limited availability of affordable hardware and content. Still, there are early adopters. Some schools have been investing in the purchase of one or a few social robots and these are used for limited aspects of the curriculum, such as teaching English to Japanese school children.

Future prospects

There is limited commercial availability of robots used as teachers or tutors, and this is unlikely to change soon. The technology has to compete with other classroom educational technology tools and while research has shown that robots do offer a marked benefit in educational outcomes over screen-based technology, it is unclear if this is enough to convince technology companies and schools to invest in robots to assist teachers. As such, we need to take a long-horizon perspective and it is as yet unclear how the technology will mature and how it will find its way into mainstream education.

While research focuses on robots that have a very clear robotic appearance, with a head, eyes and a mouth, it is equally likely that aspects of the technology will be first introduced on other devices, such as digital voice assistants, which distinctly lack visual social features. Technical components, such as emotion perception or adaptive modelling of the learner, are likely to be found in other educational technology, and are not unique to robots.

A concern exists that robots in education will exacerbate the digital divide. There remain reservations about unequal access to educational technology, from access to high-speed Internet connections, access to computers and EdTech software, to differences in uptake of digital technologies across ethnicities, gender, socio-economic background, and geographic regions. As robots for education will in the foreseeable future be an exclusive technology, early adoption will likely be by affluent educational institutions and families. While this is typical for the innovation lifecycle and is typically followed by wider adoption, it is likely that the digital divide in education will persist and this will have an impact on the use of robots in education.

It is unclear if and when robots will support education, but it is very likely that insights from research into social robots for education will inspire future educational technology. The social aspects of these robots are important to motivation and learning, and the technology that powers social interaction – such as emotion recognition, the robot's ability to empathise, or the building of personalised interactions – is likely to find its way into future educational technology. It is also clear that robots will not be substitutes for human teachers; instead they will, in the best case, complement the teaching profession where human time and resources are scarce. It is unlikely that these robots will be seen in formal education in the next decade, instead, the first use of robots as tutors is expected to be in the home as educational toys. Still, the potential of robots for education is considerable, and it will only be a matter of time before we have robot assistants in the classroom.

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