A REVIEW OF THE APPLICABILITY OF ROBOTS IN EDUCATION

Omar Mubin,* Catherine J. Stevens,** Suleman Shahid,*** Abdullah Al Mahmud,****
and Jian-Jie Dong*****

Abstract

Robots are becoming an integral component of our society and have great potential in being utilized as an educational technology. To promote a deeper understanding of the area, we present a review of the field of robots in education. Several prior ventures in the area are discussed (post-2000) with the help of classification criteria. The dissecting criteria include domain of the learning activity, location of the activity, the role of the robot, types of robots and types of robotic behaviour. Our overview shows that robots are primarily used to provide language, science or technology education and that a robot can take on the role of a tutor, tool or peer in the learning activity. We also present open questions and challenges in the field that emerged from the overview. The results from our overview are of interest to not only researchers in the field of human–robot interaction but also administration in educational institutes who wish to understand the wider implications of adopting robots in education.

Key Words

Social robotics, pedagogy, human–robot interaction, educational robotics, educational robots

1. Introduction

Robots are slowly being incorporated in our society and the number of service robots has in 2008 already outnumbered industrial robots [1]. Robots are slowly beginning a process of seamless integration in everyday lives both at home and at school. This impact of social robotics is even more crucial for children and teenagers, where robots can be used for their development and intellectual growth. As a consequence, greater attention must be levied onto how educational robots can be better integrated into the lives of young people. With the continuous advent of technology, it is worthwhile to understand the potential of robots as effective add-ons to learning. Robots can be an entertaining platform to learn about computers, electronics, mechanical engineering and languages. It has been shown [2] that young children performed better on post-learning examinations and generated more interest when language learning took place with the help of a robot as compared to audiotapes and books. Educational robots are a subset of educational technology, where they are used to facilitate learning and improve educational performance of students. Robots provide an embodiment and the ability to add social interaction to the learning context and hence an advancement on purely software-based learning. Not all educational robots require social interaction and this is discussed further in our review.

In this article, we present an analytical overview of the prevailing field of robots in education. The aim of this overview is fourfold: firstly, to provide an overview because a comprehensive overview of the field of robots in education does not exist in robotics literature. The only exceptions are [3] and [4]. The former was conducted in 1996 when the field of robotics was in its infancy. The latter, albeit recent, only considers 10 studies (hence is not meta level); looks at high school children only; does not mention the use of robots to impart non-technical education and only LEGO Mindstorms are discussed. Comprehensive reviews exist for robotics (in particular social robotics [5]), where educational robotics has been touched upon but not in great detail. Secondly, our overview will enable researchers in educational robotics to evaluate their research in an analytical manner and to place it in appropriate dimensions, for example, choosing an appropriate research question, choosing robotic behaviour for their learning activity or choosing the appropriate robotic kit. Thirdly, research in the area covers a vast space across cultures, student age groups, robot types and subject domain. Therefore, a meta-level approach would help in understanding the field better. Lastly, this overview will attempt to identify research opportunities for new research in educational robotics.

A systematic approach was followed to compile relevant articles. Research that was conducted within the last 10 years was considered (to ensure that we would

* School of Computing, Engineering and Mathematics and MARCS Institute, University of Western Sydney, Australia; e-mail: o.mubin@uws.edu.au
** MARCS Institute and School of Social Sciences and Psychology, University of Western Sydney, Australia; e-mail: kj.stevens@uws.edu.au
*** Tilburg University, The Netherlands; e-mail: s.shahid@uvt.nl
**** Delft University of Technology, The Netherlands; e-mail: a.almahmud@tudelft.nl
***** National Chia-Yi Girl's Senior High School, Taiwan; e-mail: djj6.tw@gmail.com
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only overview relatively recent research on the topic). In addition, an attempt was made to contemplate research across a variety of host countries such as Japan [6], [7], Korea [8], [9], Australia [10], Germany [10], USA [11], and Holland [12], [13]. This also gave us a mix of robots. Moreover, articles were short listed from not only Robotics conferences such as HRI [14], IROS[1], RO-MAN[2] but also educational technology sources such as the conference on educational robots[3] and on educational technology. The paper is structured as follows: initially we describe the results from a bottom up review of the literature. The analysis of prior literature resulted in emerging themes of the use of robots in education and then we consolidated our findings under those themes. We then discuss future avenues of research and, in conclusion, we present a "looking ahead" angle on the field.

2. The Major Dimensions that Classify Research on Robots in Education

Review of the literature yielded classification criteria that could act as thematic placeholders of current and future research in the area of robots in education. The criteria refer to questions of the type: what is studied, when is it studied, how is it studied. We now list the dimensions and give examples from the literature.

2.1 What Is the Domain or Subject of the Learning Activity?

The very first criterion that we present is the subject of learning. The two main yet quite broad categories are robotics and computer education (a general instilment of the awareness of technology that could be referred as technical education) and non-technical education (science and language). Technical education is the notion of giving students the knowledge of robots and technology. In most cases this is done with an aim to introduce computer science and programming and to familiarize undergraduate students with technology [11] and in [12] where Dutch high school students were gradually exposed to technical subjects using robots. A lesson plan usually involves first an initial introduction to programming the robot (introduction phase) and then the students apply their knowledge practically by making their robots work (intensive phase) [15]. The introduction phase usually helps when the students or even the educational setup is unfamiliar with the use of robots in education. As the students also build the robot such activities are usually quite hands on. The activity of building one's own robot has been shown to provide a strong sense of ownership and enhanced interest in students [12] as students can take their robots home, tinker with them during free time, *etc.*

The second observed domain in the area of robots in education are non-technical subjects (such as the sciences), where we witness the employment of robots as an intermediate tool to impart some form of education to students, such as mathematics [10] and geometry [16]. In such scenarios, the movement of the robot is typically the main principle upon which the learning is based. For example, in [10] (project executed in Macquarie University Australia) children discuss the concept of rotations and transformations based on the movement of the robot. In [16], the path trajectory of the iRobot is used to interpret angles and geometry. Other examples of non-technical applications of robots education are areas such as kinematics [17] and music orchestration using the Tiro robot [8] for Korean children.

The third common domain in current literature is the use of robots to teach a second language. For example English was taught to Japanese children by the Robovie robot in [6] by researchers from the robotics laboratory ATR, Kyoto and in [9] English was taught to Korean children using the Tiro robot. The implications of using robots to teach a second language have been well documented [18] by computer science researchers in Taiwan, where it is stated that children are not as hesitant to speak to robots in a foreign language as they are when talking to a human instructor. In addition, robots can easily behave in a repetitive manner while students are talking to them allowing the students to practice without the problem of a human instructor getting tired. Moreover, in [18] the embodiment of a robot and its social capabilities is discussed as an important aspect of teaching language. The analysis in [18] is well presented but lacks empirical evidence. For example, to verify their claims a study would need to be run to compare language instruction by a human, a robot and a computer. Another critical issue is that language instruction requires accurate speech recognition and that is one of the hurdles in acknowledging the use of robots for language instruction [12]. This is precisely why some researchers use wizard-of-oz techniques (a human wizard controls the robot behind the scene) to run their experiments [7]. For some of the aforementioned studies of using robots to teach language, one finds it hard to reach confident validation. The studies were conducted over a few weeks and therefore a large component of the language was not learnt.

A fourth domain is the field of assistive robotics, where robots are used for the cognitive development of children or teenagers. We will not elaborate further on this, as it is outside the scope of this paper and extensive survey articles already exist in the area [19].

2.2 Where Does the Learning Take Place?

The second dimension is the location of the learning activity. The use of robots in education is either intra-curricular or extra-curricular. Intra-curricular activities are those that are part of the school curriculum and a formal part of the syllabus. One could even include some robot competitions as part of formal learning, as they take place towards the end of the learning activity and are a form of assessment-based learning [20]. Extra-curricular learning takes place after school hours at the school itself as workshops under the guidance of instructors, at home under the guidance of parents or at other designated locations, such as public places and events. Extra-curricular activities are

[1] http://www.iros2013.org/
[2] http://www.kros.org/ro-man2013/
[3] http://www.rie2013.eu/

Table 1
Example Case Studies Across Different Roles of an Educational Robot

	Tutor	Peer	Tool
Language	The robot helps students in remembering vocabulary [13]	When a student pronounces a word correctly, the robot says well done [9]	A student learns certain phrases in a non-native language by playing a game with a robot [12]
Science	The robot adapts the arithmetic exercises based on the performance of the student [29]	The robot and the student collaboratively solve exercises in a science class [30]	Sensors and actuators in the robot enable the students to learn about physics [31]
Technology	The robot discusses the difficulty of the programming task with the students	The robot plays a happy animation sound when the students successfully program the robot [10]	The students use LEGO Mindstorms NXT to learn about programming [32]

generally more relaxed, allow for deviations and therefore easier to setup and organize. There are several examples of educational robotics curriculum in formal settings [11]. One of the most well-documented example of informal robotics education are the Thymio robot workshops conducted in EPFL, Switzerland [21]. One of the main advantages of running informal sessions with educational robots over formal curriculum advancements is that they are short term, require minimum curriculum design and because the robot experts can be there "onsite" minimum training is required for the teaching staff. However, informal sessions are usually one-off and hence one can question their longitudinal impact.

2.3 What Role and Behaviour Does the Robot Have During Learning?

The robot can take on a number of different roles in the learning process, with varying levels of involvement of the robot in the learning task. The choice depends on the content, the instructor, type of student and the nature of the learning activity. Firstly, on the one hand the robot can take a passive role and be used as a learning tool/teaching aid. This would especially apply to robotics education, where students would be building, creating and programming robots. On the other hand, the robot can take the role of co-learner, peer or companion and have active spontaneous participation [7] (where the focus was on cooperative learning with the Asimo robot) or even care receiver [22] (where children learnt English along the way as they taught the Nao robot). The role of a robot as a mentor has also been discussed in [23]. However, it is apparent that before the robot can take on the role of an autonomous mentor, technological advancements are necessary in the perceptive abilities of social robots.

In summary, we can define three main categories of the role of a robot during the learning activity: tool, peer or tutor (see Table 1 for examples). A similar dissection (albeit named differently as learning about, with and from robots) has also been discussed in [24]. Upon analysis of prior literature, it is evident that a clear mapping needs to be drawn out linking the learning activity to the interaction style of the robot. For example, for basic learning tasks a cooperative robot was preferred compared to an instructional robot [7] but for language learning a tutoring style was preferred [13]. This decision is also governed by the perception of the students. It has been shown that younger children were content with robots behaving as peers in the learning process while older children thought of robots more as teaching tools/aids [24]. The degree of social behaviour of the robot is more or less linked to what role the robot plays during the learning activity, to the subject domain and to the age of the students. In [7], it was ascertained that the children preferred a human-like behaviour and voice for the Asimo robot. Other attributes such as maintaining eye contact have also been discussed [25] to engage students. For language learning and cognitive development, social interaction is imperative as suggested by [26] (it may not be essential for technical education), where a survey of two robots was conducted regarding 4 weeks of usage at home and school. The two robots were an emotionless humanoid and an animated robotic dog. The conclusion was that both children and their parents preferred the robotic dog. Similar results have been obtained in [27], where a social agent was found to generate much more interest as compared to a less social agent and in [13], where a more social robot led to higher post-test scores while teaching a foreign language to primary school children in a study conducted by HRI researchers in Holland with the iCat robot. The constraint of the way a robot "looks" physically is more flexible; for example, a humanoid robot could potentially be used to teach any subject. Nevertheless, prior research has looked into physical attributes of a robotic teacher. In [28], a quantitative analysis of the preferred dimensions of the physical features of educational humanoid robots is presented.

2.4 What Types of Robots Are Used in Education?

The embodiment of the robot is also a critical factor in the learning activity. There exist numerous robotic kits, ranging from low-cost single function kits to LEGO Mindstorms to humanoid robots costing thousands of dollars. To explore the various options, we may consider a hypothetical progressive scale of embodiment. On one end of the scale

Table 2
Choice of Robots Across Subject Domains and Across Background Knowledge Required in Computing (Darker the Colour the more Computing Knowledge Is Required to Use/Interact with the Robot in that Cell)

Subject Type	Electronic Robotic Kit	Mechanical Robotic Kit	Humanoid Robot
Language		LEGO Mindstorms robots teach ROILA by playing games with children [12]	Robovie the humanoid robot teaches English [6]
Science	Students learn the principles of electronics by creating robots using the Boebot multi function kit [35]	Students use the accelerometer of the Thymio robot to understand gravity [21]	Students learn physics by understanding the processes involved in humanoid kicking a ball [43]
Technology	Students learn programming while creating robots using Arduino [44]	Students enjoy a tangible method to learn programming using the Mindstorm robots [37]	University students learn about computer vision while implementing the Nao robot [45]

there could be the low-cost single function mechanical kits that are typically used to illustrate only one function, such as following a line or reacting to the source of sound, *e.g.*, OWI-9910 Weasel [33]. Further down the scale, we have kits which provide the option of educating about not only robotics but also electronics, *e.g.*, Arduino [34], Parallex BoeBot [35]. Such kits are fully programmable and students can also build robots and upload scripts onto them. If the kits allow more mechanical freedom and flexibility with the robot design we step into the category of robots such as used LEGO Mindstorms [36]. Mindstorm robots have been shown to teach a wide array of subjects ranging from language [12], computer science/programming [37], physics [31], engineering design [38] and robotics [32].

Further, we move to fully embodied robots/agents used in both formal and informal education such as the Nao humanoid robot [22], robots embodied as pet animals or toy characters (Pleo the dinosaur [39]). These robots have the ability to engage in social interaction, by virtue of being able to talk and exhibit facial expressions. In most situations, such robots are used to teach non-technical subjects such as language, music, which require the robot to engage in some form of social interaction with the student. Not all robotic kits will appeal to all kinds of students. For example, we cannot expect young children to build complex robots or even use them. On the contrary, to attract young children, the robot must have animated features [40], one example being the BeeBot robot [40]. The BeeBot is a colourful bug like robot that can move but does not have the ability to display expressions or verbally express itself. The BeeBot is neither physically manipulative as for example the Mindstorms robot. It is therefore suitable to teach subjects such as mathematics [10] and programming [41] to young children.

In general, educational robots should be designed to take into account the age and the requirements of the students or they must be adaptable in real time. For example, as shown in [42], robotic technology was developed that enabled a robot "Asobo" to adapt its behaviour based on the prevalent mood of young children. However, real time and subjective evaluations are yet to be conducted for such state of the art technology. Ultimately, the choice of which robot to utilize in the learning activity depends on various factors: cost, subject domain, age of the students. We provide certain examples on the type of robots employed for each subject domain in Table 2. The background colour of each cell indicates the computing skills required by the students to use the robot.

2.5 Which Pedagogical Theories Underpin Research on Robots in Education?

In this section, we discuss a few pedagogical theories that are the most prevalent within the domain of educational robotics. The work of Papert [46] on the programming language Logo to introduce turtle geometry has been well grounded in robotics literature under the *theory of constructionism*. Initially within the field of robots in education there was a gradual shift from the *theory of constructivism* as suggested by Piaget [47] to the modern educational method of Papert. This shift has been well explained in [48], including why the paradigm of Papert best fits the field. The theory of constructivism states that learnt knowledge is shaped by what the learners know and experience. Papert adds to this by introducing the notion of constructionism, which states that learning occurs when a student constructs a physical artefact and reflects on his/her problem solving experience based on the motivation to build the artefact. Research in robots in education lends itself well to the constructionism theory and is by far the most adopted in robotics curricula [49], [50]. Most robotics curricula are hands-on, encourage students to think and be creative and are based on problem solving.

Robots also act as a bridge in enabling students to understand humans. For example, students can learn how speech is processed by humans by considering how robots recognize speech [12]. This fits with the aspect of constructionism where learning is a function of what students know in the real world and what they infer in the virtual world. The connection to biology *via* the linking of human sensors to robotic sensors has also been discussed in [50]. Analogous to the theory of constructionism lie the principles of *active learning* [51] and *learning by design* [52] that advocate a hands-on approach to increase the motivation of students. Such paradigms are well suited to the field because by their very nature "most" robots are tangible and require to be physically manipulated as part of the learning activity. Interacting with tools and artefacts also accords with the concept of the extended mind [53]. Lastly, we would like to mention the notion of *social constructivism* as proposed by Vygotsky [54] which generally applies to most peer or tutor-based methodologies of robotics education. The theory of Vygotsky gave rise to the principle of scaffolding, *i.e.*, breaking up of complex tasks into smaller tasks, a common occurrence in robotics education [55].

3. Discussion: Challenges and Open Questions in the Area of Robots in Education

One of the primary goals of our overview has been to identify relatively unaddressed avenues and challenges in the area of robots in education, which we now enlist briefly.

3.1 Exploring the Impact of Robots in Collaborative Learning

It has been established in pedagogy that collaborative learning is more beneficial than individual learning [56]. It would be interesting to see if the trend replicates while evaluating and comparing the learning processes of a child learning alone against learning with a robot and against learning with another child. If the results prove that collaborative learning with a robot is as efficient or not significantly worse than learning with a human peer then this will be the first step in wider acknowledgement of the integration of robots in education. Similar research has been conducted in measuring the game experience of children while playing alone, with a friend or with a robot [57].

3.2 Understanding the Role of Teachers in Robots for Education

One of the major shortcomings in the area is the absence of well-defined curriculum and learning material for teachers. Robotics education is still seen as an extra-curricular activity and a part of informal education. As we discussed earlier, informal education does not require well-defined curricula *per se*. Efforts must be devoted not only to the development of robotic hardware and software for education but also to the design of learning material and appropriate curriculum and to the role of the teacher. In theory, the role of a teacher is directly linked to the role the robot plays in the learning activity. If the robot acts as the main focal entity in the learning activity (*i.e.*, as a teaching tool, *e.g.*, in the case of teaching about robots), the teacher takes on the role of a facilitator [58]. If the robot takes on a passive role then the onus is on the teacher to transfer base knowledge (*e.g.*, using the robot to teach language). In such situations, training of teaching staff on robotics and how to conduct robotics curricula is imperative. Looking ahead it is clear that work needs to be done before robots can be fully integrated into our schools and support must be gained from the teachers. In a survey [59], teachers were more critical of robots in schools than parents and students were. Teachers need to be reassured that the intention is not to replace them with robots but rather provide them with a teaching tool/aid that can complement the learning experience and motivate of the students.

3.3 Adapting Robotic Behaviour and Curricula to the Learner

Another important aspect to consider in research on educational robots is the character of learners and typically not much work has been undertaken on it. This would include various attributes of the learner such as the age, gender, background knowledge of robotics and computer science, and social and cultural profile. This is where adaptable tools such as the LEGO Mindstorms are useful as they cater for learners from diverse technical backgrounds by providing various programming options (script based or more advanced languages such as Java/C++). We can also see examples on considering the gender of students as in the Roberta project, where an effort is made to engage girls in technical subjects [60].

3.4 Designing a Socially Acceptable Educational Robot

Moreover, improvements are also required in the design of robots. For students to have a satisfying user experience with robots, efforts must be devoted to improving the speech understanding capabilities of robots and reproducing human-like behaviour (in light of the uncanny valley [61]).

4. Conclusions

This review paper has presented a summary of important and recent works in the area of robots in education. We believe that not only are robots built on advanced technology but they also provide a tangible and physical representation of learning outcomes: a valuable aspect of employing them in education. An outcome of the review is to encourage pedagogical experts to further understand the practical aspects of the utilization of robots in education. We have tried not to delve too much into pedagogical theoretical aspects and have attempted to focus more on issues related to Student–Robot Interaction, unlike prior reviews in the field [4]. Moreover, since there is a large volume of research in the area we may have neglected certain works, such as reports from educational institutions, which are not readily and widely available. To conclude, our message is that we do not intend that robots replace human teachers but highlight the added value that robots can bring to the classroom in the form of a stimulating, engaging and instructive teaching aid.

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Biographies

Omar Mubin is currently a lecturer in human–computer interaction at the School of Computing, Engineering and Mathematics at the University of Western Sydney, Australia. He obtained his Ph.D. qualification in human–robot interaction from the Eindhoven University of Technology, The Netherlands. His research interests include educational robots, user centred design and empirical research in the human perception of social robotics.

Catherine J. Stevens investigates the psychological processes in creating, perceiving and performing music and dance, and applies experimental methods to evaluate complex systems and human–computer interaction. She holds B.A. (Hons) and Ph.D. degrees from the University of Sydney. She is professor in Psychology and leads the Music Cognition and Action research program in the MARCS Institute at the University of Western Sydney (http://marcs.uws.edu.au/).

Suleman Shahid is currently an assistant professor at the Tilburg centre for Cognition and Communication, Department of Communication and Information Sciences, Tilburg University. He obtained his Ph.D. in communication sciences in 2011. Before joining Tilburg University in 2007, he finished his Professional Doctorate in Engineering (P.D.Eng.) degree from the Eindhoven University of Technology and during his stay in Eindhoven he also spent almost a year at the Philips Research, Eindhoven. He has a background in Media Computing, but in the last few years he has been involved in interaction design and social aspects of affective computing, particularly in a cross-cultural setting.

Abdullah Al Mahmud is a postdoctoral research fellow at the faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands. He obtained his Ph.D. degree in human–computer interaction design from the Department of Industrial Design, Eindhoven University of Technology (TU/e), The Netherlands. He also earned a Professional Doctorate in Engineering (P.D.Eng.) degree from the same university and worked as a visiting researcher at the Philips Research, The Netherlands. His research interests are method adaptation (*i.e.*, design and evaluation) for different purposes/user groups, socially responsible interaction design, *etc.* Moreover, he is very much interested in all sorts of field trials including reliable data gathering techniques.

Jian-Jie Dong is a part time lecturer of National Formosa University and a technology teacher of National Feng-Yuan Senior High School in Taiwan. His research interest is about educational technology application.