A Review on the Use of Robots in Education and Young Children

Article *in* Educational Technology & Society · January 2016

5 authors, including:

Albert Causo
Nanyang Technological University

I-Ming Chen
Nanyang Technological University

Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A Review on the Use of Robots in Education and Young Children. *Educational Technology & Society, 19* (2), 148–163.

A Review on the Use of Robots in Education and Young Children

Lai Poh Emily Toh[1], Albert Causo[1*], Pei-Wen Tzuo[2], I-Ming Chen[1] and Song Huat Yeo[1]
[1]Robotics Research Centre, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore // [2]National Institute of Education, Singapore // emilytohlp@ntu.edu.sg // acauso@ntu.edu.sg // peiwen.tzuo@nie.edu.sg // michen@ntu.edu.sg // myeosh@ntu.edu.sg
[*]Corresponding author

(Submitted August 13, 2014; Revised February 24, 2015; Accepted August 27, 2015)

ABSTRACT

A systematic review was carried out to examine the use of robots in early childhood and lower level education. The paper synthesizes the findings of research studies carried out in the last ten years and looks at the influence of robots on children and education. Four major factors are examined – the type of studies conducted, the influence of robots on children's behaviour and development, the perception of stakeholders (parents, children and educators) on educational robots, and finally, the reaction of children on robot design or appearance. This review presents the approach taken by researchers in validating their use of robots including non-experimental (mixed-method, anecdotal, cross-sectional, longitudinal, correlational, and case studies) and quasi-experimental (pre- and post-test). The paper also shows that robot's influence on children's skills development could be grouped into four major categories: cognitive, conceptual, language and social (collaborative) skills. Mixed results are shown when it comes to parents' perception of the use of robots in their children's education while design was shown to influence children's perception of the robot's character or capabilities. A total of 27 out of 369 articles were reviewed based on several criteria.

Keywords

Early childhood education, Lower education, Educational robots, Review

Introduction

With the rapid development of technology in the 21st century, the use of multi-media tool in education has become increasingly popular. Notwithstanding their usual engineering applications, robots are being used more in schools. According to Beran et al. (2011), children are also playing more with technologically advanced devices during their playtime. Subsequently, studies were conducted to investigate robot use's influence on children's cognition, language, interaction, social and moral development (Wei et al., 2011; Kozima & Nakagawa, 2007; Shimada, Kanda & Koizumi, 2012; Kahn et al., 2012). Recent studies (Wei, Hung, Lee & Chen, 2011; Highfield, 2010; Chen, Quadir & Teng, 2011) reported that robot use encourages interactive learning, making children more engaged in their learning activities. This increase research on robot application to education needs systematic look at the direction taken this past decade in order to elucidate a roadmap for future studies.

Recent reviews on the use of robots in education show the challenges faced by researchers in this field. Benitti (2012) points out that more than 70 papers could have qualified in his review work but only 10 provided quantitative measurement on the use of robots in education. From these ten papers, only those that discuss the potential of using robots in all level of education and highlight the non-engineering benefits were selected.

Mubin et al. (2013) analysed research works from through the actual robots used. The major factors identified were robot's role, type (physical form), behaviour (capabilities and interaction capacity), learning activity type, and venue (inside or outside of classroom) where learning takes place. Mubin et al. (2013) and Benitti (2012) find similarity on the topics where robots were being used in education – learning language, science, and technology. Although Mubin et al. (2013) differs by pointing out the various roles played by the robot in education – as tutor, tool, or peer.

The reviews provide good starting points for researchers, the criteria (Benitti, 2012) and perspective (Mubin et al., 2013) taken by these two papers could potentially miss those that could be relevant to researchers in the field. Moreover, other factors critical in the use of robot in education may have been overlooked, like the effect of design on interaction or the importance of parent's perception in the success of implementing a robot-in-education project.

The aim of this paper is to assess the effectiveness of using robots in studies published within the last decade. We look at effectiveness as having four sub-factors – the study type done by the researcher, the influence of the robots on the behaviour and development of students, the perception of stakeholders (parents, educators and children) about the robots, and the importance of design or robot appearance. To achieve this aim, we would focus on articles on the application of robots in early childhood and lower level education and evidence for the factors would be analysed.

The rest of the paper is organized as follows. The review approach, especially the search and selection strategies, is discussed in details in the next section. The discussions on the four factors above are described in the succeeding sections. The conclusion provides a summary and presents the remaining challenges in this research field.

Review approach

To limit the papers to be reviewed, we implemented a search and selection strategy using specific keywords in electronic databases. We started with 369 articles and narrowed it down to 27.

Search strategy

Articles reviewed were limited to those published in English from 2003-2013. To gather as many papers as possible, five major databases were searched: IEEE Xplore, Academic Search Premier, ERIC (Educational Resources Information Center, ScienceDirect, and SpringerLink. Only articles published in journals have been included for review, with some exceptions.

Initially, search terms like “robots” and “education” was keyed in but in order to narrow down the result, we used a similar approach to what Benitti (2012) employed. Table 1 shows the five databases and the keywords used for each one.

Table 1. Summary of search protocol

Database	Search protocol
IEEE Explore	(((((“robots”) AND “education”) AND “learning”) AND “ teaching”) AND “robotic”) under advanced search options < Journal & Magazines>, < Publication Year : 2003-2013>, < Full Text and Metadata>
Academic Search Premier	“Robots” AND “Education” AND “Learning” Search <Full Text>, <Date Published: 2003 to 2013>, <Peer Reviewed Scholarly Journal>
ERIC	“Robots” AND “Education” AND “ Learning” Search < Full Text> <Peer reviewed> <Journal>, <Date Published: from 2003 to 2013>
Science Direct	Search Terms: ‘Robots’ AND ‘Education’ AND ‘child’ and ‘learning’ AND LIMIT-To (topics, “child, robot”) AND LIMIT-To (Topics, “child, robot”), <Date Published: Year: 2003 to 2013>
Springer Link	Search Terms: “education” AND “robots”, Search under: <Education and Language>, <Learning and Instruction>

Selection strategy

This review focuses on articles that reported the use of robot in early childhood education. Selected studies were relevant from early to secondary education context and focused on robot or robotics influence on learning, pedagogical and developmental domains. The studies selected should report the use of robots as an educational tool.

Given the broad inclusion criteria, we managed to find 369 articles in all (see Table 2). To further narrow down the scope of the review, the following exclusion criteria have been implemented:

- Exclusion Critera E1: Article reported the technical use of robots, designs or innovations.
- Exclusion Critera E2: Article reported robotics as a teaching subject.
- Exclusion Critera E3: Article reported studies conducted in higher or university education.
- Exclusion Critera E4: Article reported the use of robots as assistive technologies.
- Exclusion Critera E5: Article did not mention on the use of robots in education.

As shown in Table 2, with the above exclusion parameters, only 27 papers were left. A large number of papers were excluded due to the focus on robots or robotics as the teaching subject (a total of 132 articles based on E2). Most of the engineering articles excluded mentioned the use of robot in education in passing or as a justfication for its design; 115 articles were removed based on E1. Moreover, around 12% of articles were excluded because robots were reported as an educational tool for higher education.

Table 2. Summary of selection

Database	Selected articles	Total reviewed	Excluded criteria articles				
			E1	E2	E3	E4	E5
IEEE Explore	11*	59	16	15	10	3	4
Academic Search Premier	5	188	79	70	25	9	0
ERIC	4*	10	0	3	0	0	3
Science Direct	3	46	14	0	0	8	21
Springer Link	4*	66	6	44	11	1	0
TOTAL	27	369	115	132	46	21	28

Note. *One paper in Academic Search Premier and one in ERIC, are repeated in SpringerLink.

From the selected paper, the following details were examined: the purpose of the study, the sample size of the students involved in the experiments, the description of the setting, data collection and analysis methods, presented results and the implication of the studies.

Discussion

Four major factors are focused on in this paper: the type of studies conducted, the robot use's influence on child behaviour and development, stakeholder perception, and children's reaction to robot design or appearance.

Types of studies conducted

Majority of the reviewed papers employed non-experimental studies. There were three studies involving the use of survey, where video was used to record children's behaviour and interaction with the robots. Four quasi-experimental studies involved pre-test and post-test, which were conducted with control group. There were ten anecdotal case studies, five mixed-method studies and one correlational study. There were three experimental studies and one short review paper. The detail of each study approach is listed in Table 3.

Table 3. Types of study reported in the reviewed papers

Type of study	Papers
Non-experimental (Mixed-method Study)	Williams et al., 2007; Levy & Mioduser, 2008; Liu, 2010; Young et al., 2010; Sugimoto, 2011
Non-experimental (Anecdotal case studies)	Barker & Ansorge, 2007; Rusk et al., 2008; Highfield, 2010; Hong et al., 2011; Chang et al., 2010; Chen, Quadir & Teng, 2011; Slangen et al., 2011; Varney et al., 2012
Non-experimental (Cross-sectional survey)	Woods, 2006; Lin et al., 2012
Non-experimental (Longitudinal survey study)	Ruiz-del-Solar & Avilés, 2004
Non-experimental (Case studies)	Bers, 2010; Bers & Portsmore, 2005
Non-experimental (Correlational study)	Bers, 2010
Quasi experimental (Pre-test & Post-test)	Barker & Ansorge, 2007; Whittier & Robinson, 2007; Chambers et al., 2008; Kazakoff et al., 2013
Experiment study	Beran et al., 2011; Salter et al., 2004; Michaud et al., 2005
Short review paper	Cangelosi et al., 2010

Robot's influence on children's behaviour and development

The reviewed articles revealed four major themes where robot was able to aid in child's behaviour or development.

Theme 1: Problem-solving abilities, team skills and collaboration

Studies by Barak (2009) and Varney et al. (2012) were conducted to investigate how the introduction of robots could change education, especially to help prepare children with 21st century skills and to increase student interest in robotics. The study conducted by Barak (2009) showed that high school students were able to come up with inventive solutions to problems and could benefit from working on project-based programmes. Robotic kits such as LEGO Mindstorm allowed students to work in teams as they carried out their projects in small groups.

Robotics was further viewed as an effective tool to develop "team skills" in students (Varney et al., 2012). The use of robots in various activities with young children supports constructivism as a learning method. Students discuss, solve problems, work with their peers, and combine their knowledge in order to construct their robots. In Chang et al. (2010), the results from the study further supported that robots could create an interactive and engaging learning experience.

Robots in elementary school helped promote collaboration and problem-solving skills in children as they became involved in the process and construction of their artefacts for their robotic projects. This was further highlighted by Hong et al. (2011) study where robots allowed children to engage in deep reflection as they solve problems and collaborate with their peers, both of which enhanced their learning experience.

Theme 2: Achievement scores, science concepts and sequencing skills

The study conducted by Baker and Ansorge (2007) examined students' achievement scores with the use of robots in their science curriculum. Robots were found to be effective at teaching 9-11 year old students science, engineering and technical concepts. Results from another experiment study conducted by Kazakoff et al. (2013) supported the use of the robotic programming such as CHERP, a tangible programme which helped increase sequencing skills in pre-kindergarten and kindergarten children.

Table 4. Articles that reported on skills development

Papers	Skills
Barker & Ansorge, 2007	Results showed increase mean scores from pre- to post-test, indicating that robotics was effective at teaching youth about science, engineering, & technology concepts.
Williams et al., 2007	Study shows a significant difference on acquiring physics knowledge but not for science inquiry skills
Barak, 2009	Study reveals that students often come up with inventive solutions to problem when learning with robots.
Highfield, 2010	The result significantly showed that children engaged in multiple mathematical processes; they demonstrated perseverance, motivation & responsiveness.
Whittier & Robinson, 2007	The results showed that all students obtained significant gains in their conceptual understanding. There is an increase of mean pre-test from 26.9% to post-test 42.3%.
Kazakoff et al., 2013	Results indicated that the sequencing ability of pre-kindergarten and kindergarten students increases when participating in an intensive robotics and programming curriculum.
Bers, 2010	The result showed that boys had a higher mean score than girls on more than half of the tasks. Boys scored significantly higher than girls in properly attaching robotic components and programming using 'Ifs'.
Slangen et al., 2011	Robots helped challenge pupils to manipulate, reason, predict, hypothesize, analyze and test.

The use of robot to assist non-English speaking students to improve in their understanding of science concepts was carried out by the Whittier and Robinson (2007) study. Results showed that all students obtained sufficient gains in their science conceptual knowledge with an increase from 26.9% in pre-test to 42.3% in post-test. The middle school students developed problem-solving skills, inquiry and engineering design skills. Robots were also used to develop and improve learning of science concepts, technology and problem-solving, which was further supported by Barak's (2009) qualitative analysis of observations, interviews and reflections of students working on their projects. Similarly, anecdotal records in the Highfield (2010) study showed that robotic toys could be catalyst for mathematical problem solving through participation in multi-faceted approach by integrating and inter-relating concepts and skills through dynamic tasks. The use of robotic to develop of physics content knowledge showed a significant difference but not for the science inquiry skills, according to the Williams et al. (2007) study. Table 4 shows a summary of the skills where robot has a positive effect.

Theme 3: Language skills development

In the study by Chang et al. (2010), a humanoid robot was used to teach a second language in a primary school. Results showed that robots could create interactive and engaging learning experiences as the children responded with high motivation. The use of robots for language development was found to be advantageous as it also allowed for demonstration of highly mobile behaviour and extensive repetition. Sugimoto (2011) used robot for storytelling, where the robot was used in students' learning and provided opportunity for children to learn in a mixed-reality environment. The children engaged strongly in story expression and acted in a coordinated manner while also being involved in their story creation with their robots.

Table 5. Articles with focus on language skills development

Papers	Overview of paper on language skills development
Chang et al., 2010	Results indicate that robots could create interactive and engaging learning experience for students.
Young et al., 2010	Quantitative results showed that 95% have positive attitude towards tangible learning companions/robots. They become more active in practicing conversation.
Hong et al., 2011	Students were highly involved and reflective during the construction of their artefacts.
Varney et al., 2012	Results showed that robot could be used as an effective tool in children to develop 'team skills'; 75% of students actively raised questions.
Sugimoto, 2011	In the study, the children engage strongly in story expression and acted in a coordinated manner.
Chambers et al., 2008	Results suggested that providing children with physical experiences were not sufficient to understand mechanical concepts. Timely & appropriate intervention is important.
Bers, 2010	TangibleK robotics could be implemented in the early childhood setting in a developmentally appropriate way by integrating other disciplines.
Rusk et al., 2008	Results suggested multiple paths for engagement of children, teens, families and educators.
Levy & Mioduser, 2008	The role of adult's interaction enables children to shift into more complex technological rules.
Varney et al., 2012	The study presented results on the efficacy of the LEGO robotic programme in fostering student's interest.
Ruiz-del-Solar & Avilés, 2004	Social robots were effective in fostering students' interest in engineering.
Michaud, et al., 2005	Roball, a robot capable of autonomous motion, was used in child-development studies.
Cangelosi et al., 2010	Studied embodied cognitive agent-humanoid robot. Discussed areas such as complex sensorimotor, linguistic & social learning skills.
Chen, Quadir & Teng, 2011	The use of robot with computer and book enhanced students' concentration in their learning of English, interest and motivation.

According to Slangen et al. (2011), students working on projects using LEGO and Mindstorms were found to be involved in frequent process of comparing their test results with their objectives, expectations, and in refining their conceptual knowledge and skills. Table 5 summarizes the articles that reported on the use of robots for language skills development.

Theme 4: Participation

Rusk et al. (2008) introduced Picocricket invention kit program to increase participation from children, teens, families and educators in robotics-related endeavors via workshops, after-school programs and professional development programs. The workshops allowed students to work on broad themes based on their own interests. As these students were given the opportunity to combine art and engineering, encouraged to use storytelling and exhibition and introduced to new technologies, their interest in robotics increased.

Parents', educators', and children's perception of educational robots

Liu (2012) and Ruiz-del-Solar and Avilés (2004) investigated perception of parents, children and teachers on the use of educational robots. The results from Lin et al. (2012) revealed that most parents' would consider educational robots as beneficial for their children. However, parents felt that they were less confident when playing and teaching their children on using robots.

Ruiz-del-Solar and Avilés (2004) studied the children's degree of satisfaction on robot use, their inquired level of competence and their eventual interest to pursue an engineering career. 700 children and teachers were surveyed in that study and 86% of the participants would consider studying in an engineering or science university in the future.

In the Bers (2010) study, educators developed computational thinking and learning about the engineering design process in young children by introducing the TangibleK programme. It integrated other disciplinary learning in a developmentally appropriate way for young children. Table 6 provides the list of articles and their reports on stakeholder perception on using robots in education.

Table 6. Perception of different stakeholders

Papers	Perception
Beran et al., 2011	Results from frequency and content analysis suggested that a significant proportion of children ascribe cognitive, behavioural, and affective characteristics to robots.
Salter et al., 2004	Findings suggested that touch could have an important role to play when developing natural human-robot interfaces. It further suggested that robot interaction levels could vary to suit different children.
Woods, 2006	Results showed that although the robots are very human-like, children were still capable of distinguishing them from humans. However, the robots evoke a feeling of discomfort or repulsion.
Liu, 2010	Results showed children regard • Educational robot as a plaything; • Studying robotics as a source of employment; • Learning of robotics as a way to high tech. Male and female perceptions differ.
Lin et al., 2012	Results indicated that parents considered educational robots as beneficial for their children. But they were less confidence in playing and teaching with educational robots with their children themselves.
Bers & Portsmore, 2005	Engineering students gained insight into the educational system and issues involved in incorporating ICT into the classroom. Pre-service teachers saw the potential offered by technology and what they would need to know to continue using it.

Children's reaction to robot's design or appearance

Levy and Mioduser (2008) presented rich anecdotal data on children's descriptions and explanations of robots' behaviour. Their study involved children in two strands of tasks (description and construction). It also showed that when adult facilitate and interact with the children, they were capable of shifting into more complex technological rules. In addition, a study conducted with 184 (Beran et al., 2011) showed that a significant proportion of the children ascribe cognitive, behavioural, and affective characteristics to robots.

159 children were asked to evaluate 40 images of robot through questionnaires in order to investigate how children perceive robot's appearance (Woods, 2006). The study showed that children perceive robots' intentions and capabilities based on robot appearance. Children judged human-like robots as aggressive and machine-like ones as friendly. Sullivan and Bers (2012) showed using the TangibleK programme that the boys scored significantly higher than girls in properly attaching robot components and programming using "Ifs." However, as reported for the rest of the tasks gender differences were statistically insignificant.

Conclusion

The effectiveness of robots in education programme could be analyzed from different aspects: Study design in order to report meaningful and statistically significant results, robot's effects on child's behaviour and development, relevance of stakeholders' perception on using robots in and outside of classroom setting, and users' reaction (especially the children) to the robot's design.

Researchers, majority of whom relied on non-experimental methods, implemented various approach to validate their studies. However this just shows that experimental methods are sorely lacking; quantitative analysis is needed, as pointed by Benitti (2012).

In education, the use of robots has the potential to help children develop various academic skills like science process understanding, mathematical concept development and improvement of achievement scores (Barker & Ansorge, 2007; Williams et al., 2007; Highfield, 2010). In addition, the introduction of robotics in curriculum also increases children's interest in engineering. As reported in Chang et al., 2010, the use of robots in education allows children to engage in interactive and engaging learning experiences. Robots seem appropriate to use in language skill development because it allow for a richer interaction (Sugimoto, 2011; Chambers et al., 2008; Bers, 2010; Chang et al., 2010; Young et al., 2010).

Two new factors have emerged in this review paper: the stakeholder's perception and the value of robot design. Aside from the main users (children), parents and educators have to be on-board as well in order to increase the chances of success of this kind of programmes. Lack of parental support would confine educational robots to applications only inside the classroom.

Lastly, design is usually the last consideration when incorporating robots into an application. However, as Woods (2006) and Sullivan & Bers (2013) studies showed, design could make a difference on robot perception and hence, how the children would interact with it. Unfortunately, not a lot of work has been done yet on this question.

Past studies are like beacons on where research have been and indicates various milestones (e.g., Cangelosi et al., 2010). This paper shows a possible roadmap and highlights research gaps in this field.

Acknowledgements

The authors would like to thank the Singapore Millennium Foundation for supporting this work.

References

Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal Research on Technology in Education*, *39*(3), 229-243.

Barak, M., & Zadok, Y. (2009). Robotics projects and learning concepts in science, technology and problem solving. *International Journal Technology & Design Education*, *19*(3), 289-307.

Beran, T. N., Ramirez-Serrano, A., Kuzyk, R., Fior, M., & Nugent, S. (2011). Understanding how children understand robots: Perceived animism in child–robot interaction. *International Journal Human-Computer Studies*, *69*(7–8), 539-550.

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A Systematic review. *Computers & Education*, *58*(3), 978–988.

Bers, M. U. (2010). The TangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice*, *12*(2), n2.

Bers, M. U., & Portsmore, M. (2005). Teaching partnerships: Early childhood and engineering students teaching math and science through robotics. *Journal Science Education and Technology*, *14*(1), 59-73.

Cangelosi, A., Metta, G., Sagerer, G., Nolfi, S., Nehaniv, C., Fischer, K., Jun Tani, Belpaeme, T., Sandini, G., Nori, F., Fadiga, L., Wrede, B., Rohlfing, K., Tuci, E., Dautenhahn, K., Saunders, J., & Zeschel, A. (2010). Integration of action and language knowledge: A Roadmap for developmental robotics. *IEEE Transactions on Autonomous Mental Development*, *2*(3), 167-195.

Chambers, J. M., Carbonaro, M., & Murray, H. (2008). Developing conceptual understanding of mechanical advantage through the use of Lego robotic technology. *Australasian Journal Educational Technology*, *24*(4), 384-401.

Chang, C. W., Lee, J. H., Chao, P. Y., Wang, C. Y., & Chen, G. D. (2010). Exploring the possibility of using humanoid robots as instructional tools for teaching a second language in primary school. *Educational Technology & Society*, *13*(2), 13–24.

Chen, N. S., Quadir, B., & Teng, D. C. (2011). A Novel approach of learning English with robot for elementary school students. In M. Chang et al. (Eds.), *Edutainment 2011, LNCS 6872* (pp. 309–316). Heidelberg, Germany: Springer-Verlag Berlin Heidelberg.

Highfield, K. (2010). Robotic toys as a catalyst for mathematical problem solving. *Australian Primary Mathematics Classroom*, *15*(2), 22-27.

Hong, J. C., Yu, K. C., & Chen, M. Y. (2011). Collaborative learning in technological project design. *International Journal Technology & Design Education*, *21*(3), 335-347.

Kahn Jr, P. H., Kanda, T., Ishiguro, H., Freier, N. G., Severson, R. L., Gill, B. T., Ruckert, J. H., & Shen, S. (2012). "Robovie, you'll have to go into the closet now": Children's social and moral relationships with a humanoid robot. *Developmental Psychology*, *48*(2), 303-314.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The Effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Educational Journal*, *41*, 245–255.

Kozima, H., & Nakagawa, C. (2007). A Robot in a playroom with preschool children: Longitudinal field practice. In *Proceedings of 16th IEEE International Conference Robot & Human Interactive Communication (ROMAN 2007)* (pp. 1058-1059). doi:10.1109/ROMAN.2007.4415238

Levy, S.T., & Mioduser, D. (2008). Does it "Want" or "Was it programmed to..."? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal Technology and Design Education*, *18*(4), 337-359.

Lin, C. H., Liu, E. Z. F., & Huang, Y. Y. (2012). Exploring parents' perceptions towards educational robots: Gender and socio-economic differences. *British Journal of Educational Technology*, *43*(1), E31-E34.

Liu, E. Z. F. (2010). Early adolescents' perceptions of educational robots and learning of robotics." *British Journal of Educational Technology*, *41*(3), E44-E47. doi:10.1111/j.1467-8535.2009.00944.x

Michaud, F., Laplante, J. F., Larouche, H., Duquette, A., Caron, S., Létourneau, D., & Masson, P. (2005). Autonomous spherical mobile robot for child-development studies. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*, *35*(4), 471-480.

Mubin, O., Stevens, C. J., Shahid, S., Al Mahmud, A., & Dong, J. J. (2013). A Review of the applicability of robots in education. *Technology for Education and Learning*, *1*, 1-7.

Ruiz-del-Solar, J., & Avilés, R. (2004). Robotics courses for children as a motivation tool: The Chilean experience. *IEEE Transactions on Education*, *47*(4), 474-480.

Rusk, N., Resnick, M., Berg, R., & Pezalla-Granlund, M. (2008). New pathways into robotics: Strategies for broadening participation. *Journal Science Education & Technology*, *17*(1), 59-69.

Salter, T., Te Boekhorst, R., & Dautenhahn, K. (2004, March). Detecting and analysing children's play styles with autonomous mobile robots: A Case study comparing observational data with sensor readings. In *Proceedings of the 8th Conference on Intelligent Autonomous Systems (IAS-8)* (pp. 10-13). Amsterdam, The Netherlands: IOS Press.

Shimada, M., Kanda, T., & Koizumi, S. (2012). How can a social robot facilitate children's collaboration? *Social Robotics*, 98–107.

Slangen, L., Keulen, H. V., & Gravemeijer, K. (2011). What pupils can learn from working with robotic direct manipulation environments. *International Journal of Technology and Design Education*, *21*, 449–469.

Sugimoto, M. (2011). A Mobile mixed-reality environment for children's storytelling using a handheld projector and a robot. *IEEE Trans Learning Technologies*, *4*(3), 249-260.

Sullivan, A., & Bers, M. U. (2013). Gender differences in kindergarteners' robotics and programming achievement. *International Journal of Technology and Design Education*, *23*(3), 691-702.

Varney, M. W., Janoudi, A., Aslam, D. M., & Graham, D. (2012). Building young engineers: TASEM for third graders in Woodcreek Magnet Elementary School. *IEEE Trans Education*, *55*(1), 78-82.

Wei, C. W., Hung, I. C., Lee, L., & Chen, N. S. (2011). A Joyful classroom learning system with robot learning companion for children to learn mathematics multiplication. *The Turkish Online Journal of Educational Technology*, *10*(2), 11-23.

Whittier, L. E., & Robinson, M. (2007). Teaching evolution to non-English proficient students by using LEGO robotics. *American Secondary Education*, *35*(3), 19-28.

Williams, D. C., Ma, Y., Prejean, L., Ford, M. J., & Lai, G. (2007). Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *Journal Research on Technology in Education*, *40*(2), 201-216.

Woods, S. (2006). Exploring the design space of robots: Children's perspectives. *Interacting with Computers*, *18*(6), 1390-1418.

Young, S. S. C., Wang, Y. H., & Jang, J. S. R. (2010). Exploring perceptions of integrating tangible learning companions in learning English conversation. *British Journal of Educational Technology, 41*(5), E78-E83.

Appendix

Appendix Table. Details of the selected studies

Paper	Level (age)	Area explored	Robot used	Study detail	Results	Implications	Type of study
Barker & Ansorge, 2007	32 (9-11 years old)	Achievement Scores	LEGO Mindstorms	28 lessons conducted using experiential learning modes to teach Science Engineering Technical concepts	No significant results between Pre-test & Post-test for control group. Robotic group showed a significant increase from (M = 7.93, SD = 3.71) to (M = 17.00, SD = 0.88)	Increase of mean scores from pre-test to post-test indicated that Robot was effective at teaching youth about SET concepts.	Quasi experimental study
Williams et al., 2007	K-12 (21 middle school students)	Acquisition of Physics Content Knowledge and Scientific Inquiry Skills	LEGO Mindstorms and ROBOLAB	2 weeks robotic camp as students work in small groups to examine whether they increase their Physics Content Knowledge & Science Inquiry Skills	There is a significant difference on the Physics Content Knowledge but not for the Science inquiry skills.		Mixed methods
Rusk et al., 2008	Robotic activities were arranged for • museum workshop for families • after-school program for girls • professional-development workshop for educators.	Broadening of participation in robotic	Picocricket	Robotic workshop for students to work on themes to foster their interest and a sense of shared experiences. Combining art and engineering encourage story-telling, exhibition & new technologies.	The results suggested multiple paths for engagement for children, teens, families, and educators.	Robotic is introduced in areas of students' interest e.g., music, art and story-telling, providing new learning experiences to wider audience.	Non-experimental (Anecdotal Case Studies)
Levy & Mioduser, 2008	Kindergarten 3 boys, 3 girls, randomly selected, (5yrs - 6yrs old)	Children's perspectives	LEGO mobile robots Two sets of instruments have been developed for the study: a computerized control environment and a sequence of tasks	To investigate children's perspectives. Children took part in a sequence braided of two strands of tasks: Description and Construction. Five 30-45 minute session. Data collected on children's description and explanations of robots' behaviour.	The role of adult during facilitation: with adult's interaction, children shift into more complex technological rules.	Learning is viewed as enculturation and knowledge is socially constructed. Differentiate between technological and psychological points of view.	Mixed-method
Barak, 2009	Junior High School, 80 students	To improve learning concepts in Science, Technology and problem-	LEGO Mindstorms	Data are collected through qualitative analysis of observations, interviews &	Students often come up with inventive solutions to problems. They are likely to		Non-experimental (Anecdotal Records, Case studies)

		solving		reflections as students work on the projects.	benefit from implementing informal instructions in project based programme		
Liu, 2010	Elementary: Grades 4-6 Survey: 318 Students. Interview: 48 (24 boys, 24 girls)	Early adolescents' perspectives of educational robots and learning of robotics. To develop a scale to collect students' perception.	Experiences in using LEGO Mindstorms & in using robots	The study was conducted with the use of questionnaire. The tool was developed with high validity & reliability.	Results showed (1) children regards educational robot as a plaything, (2) learning about robot as source of employment, (3) Learning of robotics as a way to high technology; Differences between male and female perception.		Mixed-method
Highfield, 2010	33 (3-4years old) 22 (Year 1)	Robotic toys as a catalyst for mathematical problem-solving	Bee-bots & Pro-bots	2 hrs/week over 12 weeks of study. Children were required to complete 3 tasks (1) Structural tasks (2) Exploratory tasks (3) Extended tasks Study to examine tasks as sequenced as possible; learning framework to support the development of mathematical processes.	The result showed significant children engagement in multiple mathematical processes; they demonstrated perseverance, motivation & responsiveness.	A multi-faceted approach, integrating and inter-relating concepts, processes and skills through dynamic tasks could provide rich mathematical thinking and sustained engagement.	Anecdotal, Case Studies
Chen, Quadir & Teng (2011)	Elementary School, 5 students	Using robot to teach English	Robot, Zigbee, computer and book	Observations and Interviews	Use of computer with robot and book provided interactive experiences to students		Anecdotal Case studies
Young et al., 2010	Elementary School 68 (Grade 3-4); 6 students (2 boys & 4 girls) were selected as a focus group	To investigate children's perception of robot as learning companion	Rocky robot	Questionnaire survey conducted in an elementary school in Taiwan	Quantitative results: 95% have positive attitude towards using tangible learning companions. The students became more active in practicing conversation with Rocky.	The children were active in practising conversation with the robot	Mixed-method
Hong et al., 2011	Elementary School	Collaboration of learning in technological project design	POWERTECH robot	Students took part in a POWERTECH contest in Taiwan.	Each pupil was highly involved during the process and	Reflection essential for problem-solving were often raised	Non-experimental (Anecdotal records)

				Cooperation in learning basic technical processes. Collaborative problem-solving to improve design.	construction of the artefact with deep reflection.	among the team members during design. Collaboration enhances learning.	
Lin et al., 2012	Junior High School's parents: 39; 17 male, 22 female	Parents' perceptions towards educational robots		Questionnaire survey about the parent's attitude was conducted. Gender and socio-economic differences were also examined.	Results indicated that parents considered educational robots as beneficial for their children. But they were less confident in playing and teaching with educational robots with their children themselves.	Parents were willing to provide chance and encourage children to learn with educational robots. More training for parents in this area are required to boost their confidence.	Non-experimental (Cross-sectional-survey study)
Ruiz-del-Solar & Avilés, 2004	K-12 700 children and teachers in Chile	Children and teachers' perception of educational robots.	BEAM robot Parallox robot and LEGO	Reviews on use of robots since 2000 through surveys with children and teachers. • Tested the degree of child satisfaction with the workshop • Inquired the level of competence. • Determined children's interest in eventually pursing an engineering career.	92% satisfied with the workshop, 88% finished all the basic tasks during the workshop, 86% indicated they would follow an engineering or science career in the future.		Non-experimental (Longitudinal Study-using survey)
Varney et al., 2012	Elementary school	TASEM summer camp to raise interest in STEM	LEGO	Working in small groups, 1 hr/week session	Robots are effective tool for children to develop "team skills" (75% actively raised questions)	The robotic programme allowed students of different socio-economic and cultural backgrounds to participate.	Anecdotal
Sugimoto, 2011	Elementary school 25 (11-12 years old), 13 boys and 12 girls; randomly allocated into 5 groups.	A mobile mixed-reality environment. Study conducted over 2 weekends.	GENTORO robot	Children took part in a story creation by manipulating a robot and a handheld projector. The study involved 2 previous pilot studies. Study-1 : COGAME Study-2: Software modules, involving scene drawing tasks to	The children engage strongly in story expression processes and acted in a coordinated manner.		Mixed-method

				support story-telling. Quantitative results were collected with the use of Creative Product Semantic Scale on their story creation.			
Chambers et al., 2008	Elementary (9-10 yrs old) 10 girls and 12 boys	Developing conceptual understanding through robotic	LEGO Mindstorms	Hands on experiences of robot construction and gear configuration manipulation; 6 weeks – 3 sessions about 120 minutes using LEGO robotic materials. Pre and post interviews conducted. Intervention consisted of semi-structured guided scientific inquiry approach.	Results suggest that providing children with physical experiences were not sufficient to develop mechanical conceptual understanding, of the importance of timely and appropriate intervention. Results confirm that there is variability among children in how they reason about gears & conceptual development.	A guided inquiry instructional approach is proposed for the conceptual understanding development	Quasi-experimental
Chang et al., 2010	Three classes of 5th graders	Instructional tool for 2nd language	Humanoid robot	5 scenarios were tested, one per week: • Story telling • Oral reading mode • Cheerleader mode • Action command mode • Question-and-answer mode	(1) The humanoid robot performs rich gestures. Non-verbal signals are important part of communication (2) The robot can change intonation or speech rate (3) The human appearance of a robot attracted attention, even from weaker students. This may motivate them to participate more in the language class. (4) Robots' ability to interact and recognize students' commands offer a more natural way to perform	The children's reactions and the teachers' opinions indicated that robots could create an interactive and engaging learning	Non-experimental (Case studies-observational records)

					language drills.		
Bers, 2010	Prekindergarten to 2nd grade	To develop computational thinking & learning about the engineering design process in young children	Tangible K-programme	Assessment: Student's portfolio, Video journals, SSS rubic levels of understanding. After 6 TangibleK sessions, students create a final project by working individually or in pairs	TangibleK robotics was implemented in the early childhood setting by integrating it with other disciplinary learning in a developmentally appropriate way for young children.	Development of evidenced-based systemic account of children's learning according to positive technology development framework	Non-experimental (Case studies-observational records)
Whittier & Robinson, 2007	Middle school (Grade 7-8), 29 students (16 Grade 7, 13 Grade 8)	Using robotics to teach non-English proficient students in developing their understanding of science concepts	LEGO, Evobots	12 sessions of 60-minute lessons. Teachers use LEGO robotics to address state science standards.	The results showed that students having significant gains in their conceptual understanding. An increase of mean pretest 26.9% to posttest 42.3%	Students developed many science processes, problem-solving, inquiry, and engineering design skills.	Quasi Experiment study
Beran et al., 2011	184 children, 5-16 years old, 98 female, 86 male	Children's perception of animism	A 5 degree freedom robot arm, performing block stacking task	Semi-structured interviews conducted with the children. 9 questions were asked whether the robots referenced humanistic qualities.	Results from frequency and content analysis suggest that a significant proportion of children ascribe cognitive, behavioural, especially affective characteristics to robots.		Experiment Study
Salter et al., 2004	6 Children (5-7 years old)	AuRoRA project develop for use with children with autism in therapeutic and educational context.	Pekee robot	Children grouped into clusters according to their psychological classification. Sensor captures children's interaction level.	Children playing style with the robot were examined by using sensor data. Findings suggest that touch could have an important role to play in developing natural human-robot interfaces. Also, robot interaction levels could vary to suit different children.	Results indicated that robot's behaviour can be adapted to a different children. It is suggested for future to use robot to quantify and assess children's behaviour.	Experiment study using sensor and observational techniques
Woods, 2006	159 children	To examine children's perception of robots' appearance	Evaluate 40 robot images by completing a questionnaire on appearance, personality and emotions	Results showed that depending on appearance, children clearly distinguished robots in terms of their intentions,	Some robots are human-like but still distinguishable from humans and evoke a feeling of discomfort or	Study implies the value of robot design and reaction of users to it.	Non-experimental (Cross-sectional survey)

				understanding capabilities and emotional expression. Children judged human-like robots as aggressive, but human–machine robots as friendly.	repulsion.		
Kazakoff et al., 2013	Early Childhood, 29 total participant,13 pre-kindergarten, 16 kindergarten	Sequencing skills test after robotic intervention using a picture-story sequencing task	New York STEM School, CHERP tangible programme, 1 week intensive programme	A paired *t*-test was conducted on the children sequencing abilities using sequencing cards. A pre-test and post-test conducted. There was a control group.	Results indicated that it was possible to see increases in the sequencing ability of pre-kindergarten and kindergarten students participating in a robotics and programming curriculum in as little as 1 week.	Robotics offer children and teachers a new way to tangibly interact with traditional early childhood curricular themes	Quasi-Experiment Study
Bers & Portsmore, 2005	Pre-service early childhood teachers and engineering students	To engage early childhood teachers to have hands on experiences in robotics		Pre-service teachers working in partnership with engineering students during their training. The goal is to develop a model and approach for this teaching methodology.	Three models were evaluated: • Developer's Model • External Consultant's Mode • Collaborator's Model	From engineering's perspective, students gained insight into the educational system and issues involved in incorporating ICT into the classroom. Pre-service teachers saw the potential of the technology and resources needed to continue using it.	Non-experimental (Case studies)
Bers, 2013	Early childhood, 53 children, 3 different kindergartens	A study on gender differences in robotics and programming achievement	TangibleK programme	The study examined whether kindergarten boys and girls were equally successful in a series of building and programming tasks. The TangibleK Program consisted of a six robotics lessons. Pearson product-moment correlation	Results showed that boys had a higher mean score than girls on more than half of the tasks but very few differences in the results were statistically significant. Boys scored significantly higher than girls in only 2 areas: properly attaching		Correlational study

				6pt Likert-scale assessment tool	components and programming using "Ifs."		
Slangen et al., 2011	10-12 year olds	Developing of technological literacy in working with robot	LEGO Mindstorms NXT	Study on conceptual and cognitive analysis to develop a reference frame to determine students' understanding of robotics	Study concluded that robotic DMEs challenge pupils to manipulate, reason, predict, hypothesize, analyze and test. Students frequently compare test results with their objectives and expectations to refine their conceptual knowledge and skills.		Non-experimental (anecdotal study)
Michaud, et al., 2005	12-24 months children (12-18 months: 3 girls, 1 boy) (18-24 months: 3 girls, 1 boy)	To study children's interaction with robot.	Roball	To examine the potential of using robot to help children in areas of their language, affects, motor, intellectual & social skills development	Trials were conducted with the children while interacting with Roball	Roball could capture children's attention, enabling interaction studies	Experimental
Cangelosi et al., 2010			Humanoid robot	Study of embodied cognitive agents to understand cognitive development, complex sensorimotor, linguistic and social learning skills	Review of specific issues and progress, with a series of milestones is translated into a practical roadmap for future research	The milestones on the roadmap directs future work of cognitive developmenta l robotics	Short Review paper