A ROBOT AS A TOOL FOR COGNITION

Derrick Kachisa and Linn Gustavsson
University West
Sweden

Abstract

Various kinds of robots are available for use in education; however, their mere availability should not be enough reason to use them as a learning tool. Different types have different appearances, structures (hardware), systems (software) and functions (behavioral outcomes). These features serve an important role in determining the curricula, the instructional activities, and the learning objectives. The suitability of a robot as a learning tool depends on how it fits into a learner's environment, the role it plays and how learners engage with it in order to achieve a learning objective. This study presents a theoretical framework, key research areas, and practical examples of how we use robots in practical learning examples both in an academic educational environment and in industry. Challenges and benefits are discussed.

Introduction

Teaching and learning robotics is becoming an important subject and has gained special attention from educators and researchers. Robot education aims to provide learners with practical experiences for understanding technological and mechanical language of systems, accepting and adapting to constant changes driven by complex environments, and utilizing knowledge in real situations or across time, space, and contexts (Verner, Waks & Kolberg, 2009). Comprehensive and detailed studies of properties of robots, their roles and how learners actually engage with educational robots in line with their learning objectives are needed.

In this paper, an analytical overview of educational robotics is presented followed by a suggestion for a categorization of educational robots. The aim of this overview is to firstly provide a summarized description of educational robotics and to understand the foundations that underlie this prevailing field of robots in education. The research in the area covers a vast space across the theories, the levels of studies, robot types, setting and the subject domain. Secondly, the overview should help identify the different roles that robots play in the field of educational robotics, and how they influence the learning objectives and engagement of learners. Thirdly, the overview elaborates on the role of robotics and the robot as a tool for teaching and learning. The gaps that exist in the use of a robot as a tool for cognition are highlighted. At last, based on literature, a full-value robot system that would serve as a tool in learning and teaching is proposed and defined. We will also use a few different practical examples from our robotics education to try to highlight how to practically access a full value-like system.

Method

This study starts by reviewing existing studies and literature on educational robotics. To establish a reliable review, we used the systematic review process suggested by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, 2009) and as used by Jung and Won (2018). To collect relevant studies, six explicit criteria were set based on the following keywords: contents, research type, technologies, research setting, targeted academic level, and publication type. Each research study was comprehensively reviewed for the following key characteristics: type of robots employed, theoretical frameworks underlining the study, the learning environment, the subject or modules taught, and the role the robot played in meeting the learning objective.

The second part of the paper is based on observations in academic education of robot master students during a time span of two years as well as education within industry when transforming from manual to automated assembly. Lessons learned and how different types of robots can be used for educational purposes are described.

Theoretical Assumptions

The main theoretical assumptions or frameworks that are mainly employed widely across the reviewed studies are: Piaget's constructivism (Piaget, 1973), Papert's constructionism (Papert, 1980) and Vygotsky's ZPD (1986). Piaget and Papert's theories are used as the foundation of the rationale of educational robotics.

Piaget (1973) argues that manipulating artefacts is a key for learners to construct their knowledge. This suggests that hands-on experimentation is the essential basis for cognitive development. Papert's work (Papert, 1980) is as a natural extension to Piaget's work, but adds the idea that knowledge construction happens especially effectively in a context where the leaner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a technological artefact. Vygotsky, on the other hand, viewed knowledge as a process, which basically depends on technological and cultural scaffolding i.e., breaking up complex tasks into smaller tasks, a common occurrence in robotics education. The artefact becomes an "object to think with", which can be used to explore and express ideas that are related to the field (the thing) under investigation. For instance, robots can be used as an educational tool for artificial life and biological investigations, as described by Miglino, Lund, and Cardaci (1999).

These theoretical frameworks have underlined the basis with which curriculums in educational robotics are designed and implemented as they provided thick information about robotics curricula, teaching methods, and learning environments, thereby contributing heavily to building solid pedagogical foundations for most studies (Alimisis, 2012). In a systematic review by Jung and Won (2018), these theories have been extensively juxtaposed to research reviewed in the appendix section, hence giving a clear picture on how dominant the frameworks are in studies.

It is also important to mention that analogous to the theory of constructionism lie the principles of active learning (Harmin & Toth, 2006) and learning by design (Goldman, Eguchi, & Sklar, 2004) that advocate a hands-on approach to increase the motivation of learners. 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 (Clark & Chalmers, 1998).

Jung and Won (2018) narrowed down the theories of learner engagements into a technical deterministic paradigm. This kind of determinism tends to simplify the interactions of learners with robot artefacts as unidirectional and decontextualized, rather than bidirectional and content specific; therefore, the engagement of learners with educational robotics and their participation from a social, cultural, political and historical perspective may have been ignored. This then suggests that the studies focus more on the expected results of a learning activity rather than the process, which is important in understanding how robots aid in cognitive development.

Subjects, Topics and Level of Study

Robots are used both in technical education and non-technical. In most cases of technical education, especially in lower levels of study, this is done to introduce the concepts of computer science and programming to familiarize the students with technology in general (Balch et al., 2008). The pupils are introduced to the use of robots and eventually light programming tasks, before being able to apply their full knowledge practically. As these subject areas progress, the activities become more hands on and often involve constructing and building robots (Barker & Ansorge, 2007). This hands-on approach has been shown to provide a strong sense of ownership and enhanced interest among learners (Mubin, Bartneck, Feijs, Hooft van Huysduynen, Hu, & Muelver, 2012). Educational robotics fosters learning of technology and science through the design, analysis, application and operation of robots and their systems (Verner, Waks, & Kolberg, 2009).

In non-technological areas, the robots are used as tools to impart knowledge to students. In subjects such as mathematics and geometry, the movement of robots is typically the main principle upon which the learning is based (Highfield, Mulligan, & Hedberg, 2008), whereas in biology, the robot acts a form of artificial life and biological representation to enable biological investigations (Miglino, Lund, & Cardaci 1999). In literature, robots are used to teach a second language or music. For example, in Japan children were taught English by the Robovie robot (Kanda, Hirano, Eaton, & Ishiguro, 2004), and in Korea children were taught music using the Tiro robot (Han, Kim, & Kim, 2009). Robots are now socially assisting in the cognitive and intellectual development of children as well (Kanda, Hirano, Eaton, & Ishiguro, 2004).

Educational robotics is highly utilized in low levels of study mainly because it is considered as a means of cultivating the engineering thinking in schoolchildren and developing their interest in technical creativity (Ospennikova, Ershov, & Iljin 2015).

At higher levels of study, colleges and universities, educational robotics is used to teach robotics itself as an independent subject. At this level there are two focuses: (1) contributions to the learning of concepts/subjects; and (2) skill development/improvement through robotics (Spolaôr & Benitti, 2017). The use of robots in education is either intra-curricular or extra-curricular.

Intra-curricular activities are part of the school curriculum and a formal part of the syllabus. Even a robot competition could be part of formal learning, as an assessment-based learning (Almeida et al., 2000). Extra-curricular learning is generally more relaxed and takes place after school hours, as workshops under the guidance of instructors, at home under the guidance of parents or just self-discovery.

Role and Behaviour of Robots Used

A robot can take a number of different roles in the learning process, depending on the level of involvement of the robot during the learning task. The choice depends on the content, the instructor, type of student (mainly defined by the level of study) and the nature of the learning environment (the area of study and setting). Two main perspectives exist when establishing these roles.

The first perspective regards robotics as a means or technological environment to teach other subjects. Here the focus is mainly on motivating young learners to grow their interest in a subject and to provide a tangible platform for learning (Jung & Won, 2018). The robot in this case can take the role of co-learner, peer or companion and normally has an active spontaneous participation (Okita, 2009).

The second perspective regards robotics as a tool to teach robotics itself. This positions robotics as a discipline by itself, or in some cases coupled with computer technology, and is mostly common at higher levels of study. Here the robot takes a passive role, is used a teaching aid or is the object of study in itself. Building, programming and operating robots are normally the main learning activities that surround this view of educational robotics.

However, upon analysis, it is evident that a clear mapping is not drawn out linking the learning activity to the interaction style of the robot. Mubin, Stevens, Shahid, Al Mahmud, & Dong, (2013) continue to explore this path as they investigate the degree of social behavior required by the role that a robot plays in the learning environment.

Classifications of the Educational Robot

Different types of robots have different appearances, structures (hardware), systems (software) and functions (behavioural outcomes) (Benitti, 2012).

These features play an important role in determining the curricula, the instructional activities, and the learning objectives. According to Russell and Norvig (2003), educational robotics is a wide range of robot technologies used for teaching and learning, which range from toy-like constructions to state-of-the-art robotics (Virnes, 2014). To define the educational robot, properties derived from hardware, software and the action environment of the robot are used (Russell & Norvig, 2003). It is also widely agreed that educational robots have different built-in pedagogical solutions that direct learners to certain actions and which help them learn the different subjects and modules. According to Shin & Kim (2007), educational robotics as learning tools aim at providing novel and extended possibilities to learn with, from and about educational robotics.

Most high-level education in robotics emphasizes industrial robots and hence uses products from industrial robot manufacturers as tools for the curricula. Low level robotics in primary and high schools mainly uses social robots and robot toys as it focuses more on interaction (Virnes, 2014). Another important classification of robots for education is robotics kits. Unlike other classifications, robotics kits allow students to create, build, and/or program robots (Virnes, 2014). Robot kits in this case give a broader view of a robotics learning environment as they engage a learner through designing, constructing and programming (operating) robots.

Robotic Toys

Robotic toys are generally presented as single model artefacts with limited features and mostly focus on form in a learning activity, meaning the physical appearance of the toy heavily guides or determines the application. They are widely available and ready to use for play and/or entertainment. Toy robots may imitate advanced social robots in their appearance and functions, but their implementation is based on lower-level technologies.

Robot Kits

Robot kits are programmable construction kits for building and programming a robot artefact. They consist of building blocks for creating a robot and a programming environment with a graphical user interface to create functions for the robot. A robot kit can vary from simple building blocks to advanced platforms but often imitates industrial robots and other advanced technologies (Virnes, 2014). They exist in different product variations, such as the famous LEGO Mindstorms by LEGO Group, The Bioloid STEM standard Kit by Robotis Bioloid, and the most recent ones, the Arduino Robot kit by Arduino.

Social Robots

Social Robots are single model artefacts that exist as autonomous robots and are able to recognize other, communicate and engage in social interaction (Fong, 2003). State-of-the-art social robots have primarily been developed to improve robotic devices, artificial intelligence and human-robot interaction. The educational context is often mentioned as a potential of application (Shin & Kim 2007), often as agents to teach subjects that require engagement in social interaction. Compared to toy robots and robot kits, social robots are preconstructed and pre-programmed with an emphasis on learning through active social interaction and communicate by following social behaviors and pedagogical practices attached to their role. To achieve this effectively, an applied artificial intelligence has to be used through educational software applications (Tanaka, 2005). Fong, Nourbakhsh, & Dautenhahn (2003) define a wide range of social behaviors that make a robot social, like: express and perceive emotions, communicate using high-level dialogue, establish social relationships, exhibit a distinctive personality, and use natural cues (gaze, gestures, etc.). Examples of social robots are: Robota and Kapsar, used in mediating social interactions with children on an autistic spectrum in the context of therapy and education (Robins & Dautenhahn, 2010).

Industrial Robots

Industrial robots are considered the classical form of robots in educational robotics and their definition is more inclined to their industrial nature. According to the Robotic Industries Association (RIA ANSI/RIA R15.06-2012), an industrial robot is defined as *"A programmable, multifunctional manipulator designed to move materials, parts, tools or special devices through programmed motion for the performance of a variety of tasks"*.

Industrial robots are not widely adopted in the educational space and are mostly limited to learners already studying robotics. In education, learners program and analyze the robot and are not really involved in designing and building the robot as this is already done by those in industry and made available as commercial products.

Robot as a Tool for Cognition

Educational robotics provide active development of the entire complex of the cognitive processes, like perception, problem solving, imagination, thinking strategies, memory, and speech in learners. When looking at how learners engage with educational robots two distinct dimensions can be seen: (1) Technology-led action; and (2) Learner/user-led action. Combining the dimensions with the role and type of robot used in a learning setup four orientations can be identified: (a) implementation process driven action regarding industrial robots; (b) design process driven action regarding robot kits; (c) robot-driven action regarding social robots; and (d) encounter-driven action regarding a full-value educational robot (see Figure 1).

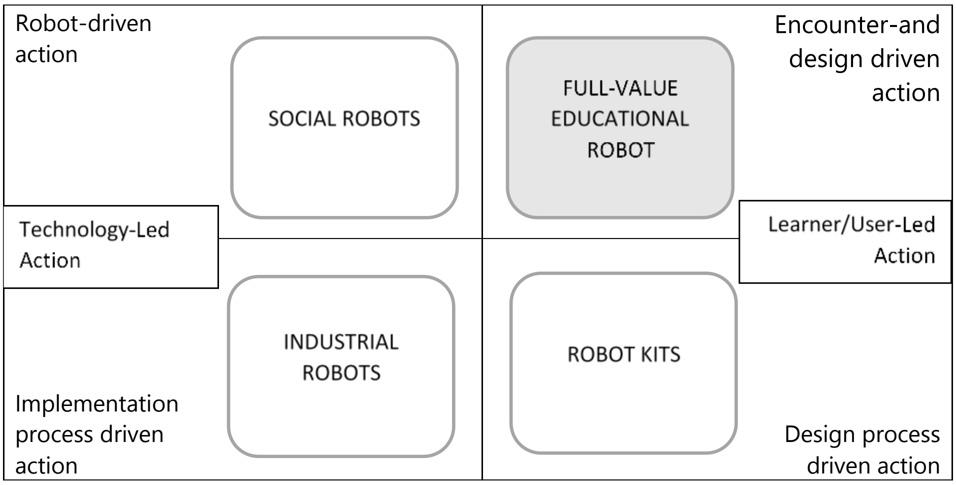

Figure 1. Categorization of educational robots – four categories describing how to divide robots based on learning outcome and how much ability the robot provide for the learner to experiment and investigate.

Industrial and Social robots are developed with objectives of improving or achieving set goals in their respective industries. Social robots improve artificial intelligence and human-robot interaction while industrial robots are built to support production spaces in manufacturing. These robots represent high degrees of technology in education and as such contribute to the technology-led action dimension. This standpoint emphasizes technical development before pedagogical design and the application of advance technologies into education. Learning from a social robot, for example, makes the user/learner an observer and imitator of the technology. Technology-led action is realized from an industrial robot, particularly when programming. Even though the learners can build various robot working environments and program the robot to manipulate its behavior, they do so from a manufacturer's instruction manual. This makes the learners a recipient of the technology rather than a creator of the technology, and therefore their role remains as a user.

Learner/user led action in educational robotics is realized more with robot kits that allow learners to create artefacts more freely without specifications. Here, learners get to design, build and modify their creations freely as action is open-ended.

Defining a Full-value Educational Robot

What then would make up a full value educational robot as a tool for education? From the dimensions discussed, it is clear that both technology-led actions and user-led actions are needed to have a well-balanced learning tool. The tool has to provide ability to get in touch with existing technology and also allow users to be able to maneuver their way around this technology by examining them, understanding them and also be able to use what they have learnt to build upon their ideas through design. A full value robot is encounter and design driven. So far, most robots that exist appear as a black box, where the technology is closed and a learner can only be seen to learn what the robot has to offer. This is rather limited, as seen in industrial robots, which are used as an implementation and process driven tool.

A full-value robot system that involves modelling of robots and their systems both physically and virtually would likely be the best approach. Modelling is one of the important methods of cognition that exist, since with the help of models one can successfully study the properties and functionality of real technical objects. Modelling of designs and functionality of robots in a virtual environment enables engineers to find the most efficient conceptual and design solutions. Using special software, not only is modelling of robot constructions implemented, but also the development of their complete digital dummies. In connection to this, certain requirements are imposed on the software environments for the development of a robot kit: 1) opportunity to create a virtual model of robot similar to its real physical model; 2) opportunity to model virtually the behavior of a robot in an environment similar to the real physical world; 3) three-dimensional visualization model of a robot and its behavior in a virtual environment; 4) opportunity to use programs written for a virtual model of a robot for a real similar robot (Ospennikova et al., 2015).

A variety of designer kits in educational robotics have been created and try to implement full-scale modelling; these include Lego for education, Lego Mindstorms and Fun & Bot. However, in these kits, the ability to have a digital twin in form of a virtual model is very limited and therefore both the physical and computer modelling of such robots is distinguished. When teaching students (just like in the real scientific and technical research), technologies of full-scale and virtual modelling of robots, as a rule, have to be implemented jointly.

Practical experience

In our curriculum for teaching robotics to academic students, we try to combine different solutions to reach the effect of a full value system.

We have a full automated line (see Figure 2) with regular industrial robots where the students can learn how to program and use the robots individually first and then connect them and create an integrated system for a line setup. They start with the theoretical framework of how to logically understand the programing environment and coordinate systems of the robot. Practically they then implement first simple tasks and learn how to use the robot in practice. They then progress to more and more advanced assignments. They solve the tasks in groups so they can discuss and learn from each other and then the final tasks are assessed individually. We can observe that the students are much more active learners when they are allowed to physically access the robots. It is a process driven learning and based on hands on problem solving, which follows Piaget’s theories quite well (Piaget, 1973). The students are also working with software like Robot Studio to create robot paths and actions. This allows them to model, test, simulate and design more advanced technical solutions.

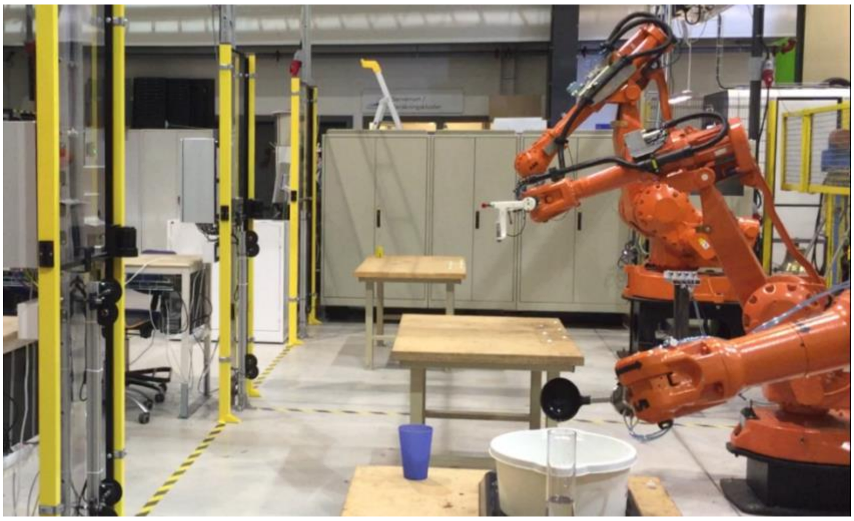

Figure 2. Three standard ABB Industrial robots in a university teaching lab, used by students in mechanical engineering and robotics educations to learn basic robotics.

In parallel to the physical robot lab we also have toy robots, a LEGO Mindstorm class set, which we use for conceptual design, problem solving and logic. The students design, construct and program the robots. Sensors can be attached for path finding and detection of outer world parameters. A graphical programing language is used to give instructions to the robot. This learning is more experimental and user driven but still very hands on.

By using combinations of these robots as learning tools we try to reach a full-value system. Part of robotics is also to understand design and construction of production lines; how to create a flow and a robot layout; how to make them cooperate. To understand process planning, we add an additional dimension by introducing a Virtual Reality (VR) environment. The learners can access CAD drawings and step into a realistic robot line to get an understanding of what they are building. Ergonomics, heights and positions can be evaluated physically. Also simple robot paths can be created from within the VR environment.

Educational robotics should implement active, constructive, intentional, authentic and cooperative learning manners (Jonassen, Howland, Moore, & Marra, 2003) and raise learners’ engagement (Mishra, 2013), which we try to create within our education.

Conclusion

This review paper has presented a well-grounded summary of educational robotics while exploring all the aspects that make it a worthy area of study. It is clear that not only are robots built on advanced technology and help shape up technology-led actions but they also have the potential of providing tangible representation of learning outcomes: a valuable aspect of using them in education. An outcome of the review is to explore the role of robots as tools and to encourage pedagogical experts to further understand the practical aspects of the utilization of robots in education specifically in line with their technological properties, learners' engagement and the roles chosen for the robots to play. While typically, it appears that theoretical and pedagogical aspects of educational robotics are not given enough weight, this review tries to bring out the properties of a good educational robot and define what would make up a full-value robot system for education. Different perspectives could potentially be taken in researching this domain, for example, from the perspective of how the full-value robot would influence education focusing on learning outcomes, from technology focusing on design and development or from robot interactions focusing on the themes of learners' engagements with robots.

References

Alimisis, D. (2012, September). Robotics in education & education in robotics: *Shifting focus from technology to pedagogy*. In Proceedings of the 3rd International Conference on Robotics in Education (pp. 7-14). Prague, Czech Republic.

Almeida, L. B., Azevedo, J., Cardeira, C., Costa, P., Fonseca, P., Lima, P., ... & Santos, V. (2000). Mobile robot competitions: fostering advances in research, development and education in robotics, Proc. CONTROLO, 592–597.

Balch, T., Summet, J., Blank, D., Kumar, D., Guzdial, M., O'hara, K., ... & Jackson, J. (2008). Designing personal robots for education: *Hardware, software, and curriculum*. *IEEE* Pervasive Computing, 7(2), 5-9.

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

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

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7-19.

Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and autonomous systems*, 42(3-4), 143-166.

Goldman, R., Eguchi, A., & Sklar, E. (2004, June). *Using educational robotics to engage inner-city students with technology*. In Proceedings of the 6th international conference on Learning sciences (pp. 214-221). International Society of the Learning Sciences. Santa Monica, California.

Han, J. H., Kim, D. H., & Kim, J. W. (2009, August). Physical learning activities with a teaching assistant robot in elementary school music class. In 2009 *Fifth International Joint Conference on INC, IMS and IDC* (pp. 1406-1410). IEEE.

Harmin, M., & Toth, M. (2006). Inspiring active learning: *A complete handbook for today's teachers*. Association for Supervision & Curriculum Development.

Highfield, K., Mulligan, J., & Hedberg, J. (2008). *Early mathematics learning through exploration with programmable toys*. In Proceedings of the Joint Meeting of PME (Vol. 32, pp. 169-176).

Jonassen, D. H., Howland, J., Moore, J., & Marra, R. M. (2003). *Learning to solve problems with technology: A constructivist perspective (2nd ed.)*. the United States of America: Merrill Prentice Hall.

Jung, S., & Won, E. S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability*, 10(4), 905.

Kanda, T., Hirano, T., Eaton, D., & Ishiguro, H. (2004). Interactive robots as social partners and peer tutors for children: *A field trial. Human–Computer Interaction*, 19(1-2), 61-84.

Miglino, O., Lund, H. H., & Cardaci, M. (1999). Robotics as an educational tool. *Journal of Interactive Learning Research*, 10(1), 25-47.

Mishra, P., Cain, W., Sawaya, S., & Henriksen, D. (2013). *Rethinking technology & creativity in the 21st century: A Room of their own*. TechTrends, 57(4), 5.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine*, 151(4), 264-269.

Mubin, O., Bartneck, C., Feijs, L., Hooft van Huysduynen, H., Hu, J., & Muelver, J. (2012). Improving speech recognition with the robot interaction language. *Disruptive Science and Technology*, 1(2), 79-88.

Mubin, O., Stevens, C. J., Shahid, S., Al Mahmud, A., & Dong, J. J. (2013). A review of the applicability of robots in education. *Journal of Technology in Education and Learning*, 1(209-0015), 13.

Okita, S. Y., Ng-Thow-Hing, V., & Sarvadevabhatla, R. (2009, September). Learning together: ASIMO developing an interactive learning partnership with children. In RO-MAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication (pp. 1125-1130). IEEE.

Ospennikova, E., Ershov, M., & Iljin, I. (2015). Educational robotics as an inovative educational technology. *Procedia-Social and Behavioral Sciences*, 214, 18-26.

Papert, S. (1980). Mindstorms*: Children, computers, and powerful ideas.* Basic Books, Inc. New York, USA.

Piaget, J. (1973). To understand is to invent: *The future of education*. Viking Press: New York, USA.

Robins, B., & Dautenhahn, K. (2010, November). Developing play scenarios for tactile interaction with a humanoid robot: *A case study exploration with children with autism*. In International Conference on Social Robotics (pp. 243-252). Springer, Berlin, Heidelberg.

Robotic Industries Association, (2012) [standard: electronic format] ANSI/RIA R15.06-2012 American National Standard for Industrial Robots and Robot Systems- Safety Requirements (PDF Download) https://www.robotics.org/

Russell, S. J., & Norvig, P. (2003). *Artificial Intelligence: A Modern Approach* (2nd Ed.). Upper Saddle River, NJ, the United States of America: Prentice Hall.

Shin, N., & Kim, S. (2007, August). Learning about, from, and with Robots: Students' Perspectives. In RO-MAN 2007-The 16th IEEE International Symposium on Robot and Human Interactive Communication (pp. 1040-1045). IEEE.

Spolaôr, N., & Benitti, F. B. V. (2017). Robotics applications grounded in learning theories on tertiary education: A systematic review. *Computers & Education*, 112, 97-107.

Tanaka, F., Fortenberry, B., Aisaka, K., & Movellan, J. R. (2005, August). Developing dance interaction between QRIO and toddlers in a classroom environment: *plans for the first steps*. In ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005. (pp. 223-228). IEEE.

Verner, I. M., Waks, S., & Kolberg, E. (2009). Educational robotics: An insight into systems engineering. *European Journal of Engineering Education*, 24(2), 201–212.

Virnes, M. (2014). Four Seasons of Educational Robotics: *Substantive Theory on the Encounters between Educational Robotics and Children in the Dimensions of Access and Ownership*, Dissertations in Forestry and Natural Sciences, No. 169, University of Eastern Finland.

Vygotsky, L. S. (1986). Thought and language-Revised edition. Cambridge; MIT Press.

Author Details

Derrick Kachisa
derrick.kachisa@student.hv.se

Linn Gustavsson
linn.gustavsson@hv.se