A Systematic Review On The Impact Of Educational Robots In Teaching Secondary School STEM Related Subjects

Mwangi Peter Ngugi, Christopher Maina Muriithi, Peace Agufana
Murang'a University of Technology, Murang'a Kenya,

Abstract
Robots are interdisciplinary in nature. Research in Educational robotics in the education sector has grown tremendously. The robots have been used as teaching tools in STEM subjects. However, even though research interest on educational robots is on the rise, it seems that enough attention has not been paid to the impact they have in students' interest in STEM. This study presents a systematic review of literature on the impact of educational robotics in teaching these subjects to Secondary School Students. The purpose of the review is to

i) Synthesize findings from studies that provide learning experiences through educational robotics
ii) Identify the possible impact of integration of educational robotics to teaching of Sciences.

In this review 25 research studies were included through search and review processes. A synthesis of the studies was done based on matching characteristics and for this case how the educational robots contribute to STEM education in secondary school level. The review show that educational robotics plays an active role in STEM education; however, in some situations no significant improvement was found in students' Sciences and mathematical learning. The results of the review will help curriculum developers in introducing educational robotics in pre-college levels for teaching STEM related subjects. Additionally, it will help researchers in identifying other areas that require more attention.

Keywords: Education Robotics, Systematic Review, STEM Education, Secondary School Level, Teaching Tool.

1. Introduction

1.1 Background information

Angel-Fernandez and Vincze, (2018) defined educational robotics as a field of study whose main goal is to improve learning experiences of learners by the creating and implementing activities related to robots. Educational robotic activities involve use of physical robots. There are a few examples of educational robots like LEGO Mindstorms and other robots designed purposely to support the activities. The activities can be developed for learners at different levels for instance from elementary to graduate levels. These may include design, programming, application, or experimentation with robots. Educational robotics activities usually consist of the use of a robotics kit, with which learners learn how to build and programme robots for a given task (Jung & Won, 2018). The activities can take the form of interventions, after-school activities, voluntary classes, or a whole course based on robotics. According to Danahy et al., (2014), the basis for the application of educational robots is broad, but the constructionist educational approach has been the most outstanding. Robotics kits provide a modular approach regarding programming and building, often used as creativity-enhancing interventions in the school context. In working with these kits, students can exert engineering competencies and creative solutions to a vast array of problems, starting from making a robot move between two points.

Educational Robots can be utilized in teaching Science, Technology, Engineering and Mathematics (STEM) in all levels of education. According to Luckin et al., 2016, the use innovative tools in teaching has changed the education system by improving learner experience in the classrooms.

Robotics is also viewed as an effective tool for hands-on learning, not only of robotics itself, but of general topics in Science, Technology, Engineering, and Mathematics (STEM) (Gomoll et al., 2016).

Karim et al. 2015 defined the term 'robots' to any type of robotic kits, programmable robots, and robotic platforms used in education: from kits that can only be used to describe and teach a single function to robotic kits that students can build and program or to LEGO Mind storms.

Most of the studies lack details about the implementation of educational robots within and outside school environments. This review on the existing works on applying robotics in education will focus on the benefits achieved from integrating robotics in education and the robotics platform that are currently being developed and used by educators.

2. Methods

This review comprised of two main phases. The first phase included search of many databases to locate studies related to benefits of educational robotics in precollege level. For this purpose, the related databases were reviewed which included JSTOR, Oxford Journals Online, SAGE Journals Online, Science Direct, Springer Link, and Web of Science. Related research studies were done by using various combinations of the keywords 'educational robotics', and 'secondary schools.

As a result of initial search, 5550 records were reached. Among these records, 443 records were related to current study were selected by title.

In the second phase, duplicates were excluded and the articles were reviewed to determine whether the studies were suitable for the current study, by examining the abstract, against certain criteria. These criteria were:

- Being accessible electronically
- Being related with benefits of educational robots
- Including learners in secondary schools
- Being peer-reviewed articles

As a result of this, 25 research studies were included in the study. Studies related to primary and university levels of education were eliminated.

3. Findings

For this study, 25 articles were reviewed. It was observed that majority of the studies lacked an experimental or quasi-experimental design.

Most studies were conducted in informal learning settings like summer camps and competitions rather than formal settings. Majority of the studies used LEGO Mindstorms robotic design. This review was based on common characteristics in research methodologies, results, and the findings.

The findings were be classified into two themes.

3.1 General Benefits of Educational Robots

In this theme, general benefits of educational robotics are discussed. The studies under this theme that addressed the general benefits of the use of educational robotics in post primary education without focusing on more specific aspects. The studies unanimously suggested that robotics promotes active- learning pedagogy and helps to improve the learning experience. (Mosley, Ardito, & Scollins, 2016; Sahin, Ayar, & Adiguzel, 2014.

Sahin et al, (2014) marked out the effectiveness of STEM-related after school activities. The researchers used qualitative case study design to understand and analyze students' views about activities and reported that such robotics activities with high use of design processes helped students to work in collaborative environments and partnerships, and to demonstrate uses of various 21st century skills such as commitment, problem solving, and ownership of work.

3.2 Impact of educational robotic activities

Many observations have been made on the impact of robotic activities. Some STEM education initiatives have led to improvement of results in mathematics and sciences. These have been done to prepare the learners for career progression (Becker & Park, 2011).

Hammack, et al, (2015) investigated on the effect of an Engineering Camp on Students' Perceptions of Engineering and Technology. Their research showed that students tend to have inaccurate views of who engineers are and what they do. This would hamper the choice of engineering as a career. The study intended to measure the effect of participating in a week long engineering summer camp to middle level students. The researchers concluded that participation in such a camp resulted to a positive impact on the perception and understanding all about what technology is and the work done by engineers.

Wilson, (2019) investigated the impact of educational robotics has science education. The effects of incorporating robotics to learners according to him is that it helps in improving problem solving skills in them. He also noted that robotic activities can inspire students to choose in STEM related courses in higher education and for this case Engineering and Technology.

Afari and Khine, (2017) noted that technology plays an important role in development of skills. They also noted that robotics expose learners to opportunities and challenges helping the learners to become innovative in ideas and in critical thinking. They investigated the effects of distributing Lego Mindstorms kits to schools to encourage teachers to use in their teaching. The paper highlights how robotics can be effectively used as an educational tool and the impact it has on students interests in STEM related subjects.

Educational robotics help students to go through hands-on learning experience. The environment provided by the robotics is full of fun and the learning environment resulting from them is exciting (Eguchi, 2014).

There has been a desire by educators to improve STEM education at all levels. The desire is faced with lots of challenges. Robotics can be one way of increasing interest in STEM related disciplines. One of its main advantages is its interdisciplinary nature of robots which make robotics a useful STEM pedagogical tool. It is therefore important for the education stakeholders respond to the demand for robotics specialists by offering courses in robotics and automation (Sergeyev et.al, 2014).

A good number of studies have found a number of considerable effects regarding the improvement in student interest in studying STEM related careers with new trends and technologies. One of such studies addressed the general

perception of boys being better than girls in STEM fields. In the study data was collected from 96 six-year-old children (Master, Cheryan, Moscatelli, and Meltzoff, 2017)

D'Amico et. al, (2020) investigated the effects of precollege robotic activities. They subjected students to tests before and after the robotics laboratory, to check their knowledge in the topics covered. In the research two sets of students were selected. These include experimental group and control group. The results of their research showed that students in the experimental groups had a far better understanding of concepts and higher participation to the activities than students in the control groups.

Badeleh, A. (2021) examined the effect of robotics on students' creativity and concluded that Robotics training influenced and improved creativity and learning in physics.

4. Discussion and Conclusion

Among the studies done, some educational robotics were applied in interdisciplinary teaching sciences. Different researchers used different approaches in the use of educational robotics. Some robots were applied in interdisciplinary teaching sciences. Some of approaches include focus on tournaments as way of learning (Sauza et.al, 2018, Dos Santos et.al, 2016, Strnad, 2017). Tuluri, (2015) and Usselman, (2015) addressed the teaching of physics through practical activities through robotics, while in Gerber, (2017) addressed use of robotics in biology and its experiments.

Educational robots help students in a variety of ways, these include the understanding concepts that may be deemed abstract concepts (Eguchi, 2014).

Based on our systematic review, we found a total of 25 studies published from the years 2012 to 2021.We classified the studies under 2 themes the use of educational robotics and their resulting benefits in STEM education.

In conclusion there are a considerable number of studies on educational robotics. Some studies of the studies have concluded that educational robotics have a positive effect on students' critical thinking and problem-solving skills (Okita, 2014).

Educational robots help students in a variety of ways, including the understanding of abstract concepts (Eguchi, 2014), providing them with a feedback-oriented learning environment (Bers, 2007), and giving them a collaborative working environment (Eguchi & Uribe, 2012. Touretsky (2013) suggested that robotics can support students in acquiring a deep and abstract conceptual understanding. These studies evaluated cognitive factors involved in teaching STEM education through robotic platforms by comparing control (non-robotic curriculum) and treatment (robotics-based curriculum) groups. Such comparative studies have been informative and have demonstrated the promising future of robotics in STEM education to increase students' ability to transfer knowledge. Many of these studies are short term in nature and as such it is crucial to have long-term follow-up studies.

Eguchi (2014) argued that educational robots typically motivate students and enhance their interest in STEM fields. The results, however, indicated that while a majority of these studies focused on promoting students' creativity and motivation through social, cultural, or creative avenues reported success, there were some studies that showed no effect (e.g., Delden & Yang, 2014; Wyffelset al., 2014).

5. References

Afari, E., & Khine, M. S. (2017). Robotics as an educational tool: impact of lego mindstorms. *International Journal of Information and Education Technology*, *7*(6), 437-442.

Angel-Fernandez, J. M., & Vincze, M. (2018). Towards a definition of educational robotics. In *Austrian Robotics Workshop 2018* (Vol. 37).

Badeleh, A. (2019). The Effects of Robotics Training on Students' Creativity and Learning in Physics, Educ. Inf. Technol. 26, 1353–1365. doi:10.1007/s10639- 019-09972-6

Badeleh, A. (2021). The effects of robotics training on students' creativity and learning in physics. *Education and Information Technologies*, *26*(2), 1353-1365.

Bers, M. U., & Horn, M. (2010). Tangible programming in early childhood: Revisiting developmental assumptions through new technologies. In I. R. Berson & M. J. Berson (Eds.), High-tech tots: Childhood in a digital world (pp. 49–70). Greenwich: Information Age Publishing.

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

Bers, M. U., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. Journal of Technology and Teacher Education, 21(3), 355–377.

Booch, G., & Brown, A. W. (2003). Collaborative development environments. Advances in Computers, 59, 1–27.

Breiner, J. M., Johnson, S. S., Harkness, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. School Science and Mathematics, 112(1), 3–11.

Bybee, R. W. (2010). What is STEM education? Science, 329(5995), 996. Cavanagh, S., & Trotter, A. (2008). Where is the 'T' in STEM. Education Week, 27(30), 17–19.
Chesloff, J. D. (2013). STEM education must start in early childhood. Education Week, 32(23), 27–32.
Christidou, V. (2006). Greek students' science-related interests and experiences: Gender differences and correlations. *International Journal of Science Education*, *28*(10), 1181-1199.
Danahy, E., Wang, E., Brockman, J., Carberry, A., Shapiro, B., & Rogers, C. B. (2014). Lego-based robotics in higher education: 15 years of student creativity. *International Journal of Advanced Robotic Systems*, *11*(2), 27.
Di Lieto, M. C., Inguaggiato, E., Castro, E., Cecchi, F., Cioni, G., Dell'Omo, M., & Dario, P. (2017). Educational Robotics intervention on Executive Functions in preschool children: A pilot study. *Computers in human behavior*, *71*, 16-23.
D'Amico, A., Guastella, D., & Chella, A. (2020). A playful experiential learning system with educational robotics. *Frontiers in Robotics and AI*, *7*, 33.
Dos Santos, O. L., Cury, D., Rafalski, J., & Silveira, P. D. N. (2016, October). An iot computational robotics learning laboratory in vila velha, espirito santo. In *2016 XI Latin American Conference on Learning Objects and Technology (LACLO)* (pp. 1-6). IEEE.
Ejiwale, J. (2013). Barriers to successful implementation of STEM education. Journal of Education and Learning, 7(2), 63–74.
Elkin, M., Sullivan, A., & Bers, M. U. (2014). Implementing a robotics curriculum in an early childhood Montessori classroom. Journal of Information Technology Education: Innovations in Practice, 13, 153–169.
Elkin, M., Sullivan, A., & Bers, M. U. (2016). Programming with the KIBO robotics kit in preschool classrooms. Computers in the Schools, 33(3), 169–186.
Feldman, D. H. (2004). Piaget's stages: The unfinished symphony of cognitive development. New Ideas in Psychology, 22,175–231.
Flannery, L. P., & Bers, M. U. (2013). Let's dance the "robot hokey-pokey!" Children's programming approaches and achievement throughout early cognitive development. Journal of Research on Technology in Education, 46(1), 81–101.
Fridin, M. (2014). Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. Computers & Education, 70, 53–64.
Gerber, L. C., Calasanz-Kaiser, A., Hyman, L., Voitiuk, K., Patil, U., & Riedel-Kruse, I. H. (2017). Liquid-handling Lego robots and experiments for STEM education and research. *PLoS biology*, *15*(3), e2001413.
Haylock, D., & Cockburn, A. (2013). Understanding mathematics for young children: A guide for teachers of children 3–8. London: Sage.
Jung, S. E., & Won, E. S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability*, *10*(4), 905.
Kazakoff, E. R., & Bers, M. U. (2014). Put your robot in, put your robot out: Sequencing through programming robots in early childhood. Journal of Educational Computing Research, 50(4), 553–573.
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 Education Journal, 41(4), 245–255.
Kazakoff, E., & Bers, M. (2012). Programming in a robotics context in the kindergarten classroom: The impact on sequencing skills. Journal of Educational Multimedia and Hypermedia, 21(4), 371–391.
Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. International Journal of STEM Education, 3(11), 1–11.
Lee, K. T., Sullivan, A., & Bers, M. U. (2013). Collaboration by design: Using robotics to foster social interaction in kindergarten. Computers in the Schools, 30(3), 271–281.
Leibham, M. B., Alexander, J. M., & Johnson, K. E. (2013). Science interests in preschool boys and girls: Relations to later self-concept and science achievement. Science Education, 97(4), 574–593.
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 of Technology and Design Education, 18(4), 337–359.
Mioduser, D., & Levy, S. T. (2010). Making sense by building sense: Kindergarten children's construction and understanding of adaptive robot behaviors. International Journal of Computers for Mathematical Learning, 15(2), 99–127.
Misirli, A., & Komis, V. (2014). Robotics and programming concepts in early childhood education: A conceptual framework for designing educational scenarios. In C. Karagiannidis, P. Politis, & I. Karasavvidis (Eds.), Research on e-learning and ICT in education (pp. 99–118). New York: Springer.

Moomaw, S. (2013). Teaching STEM in the early years: Activities for integrating science, technology, engineering, and mathematics.Saint Paul, MN: Redleaf Press.
National Academy of Engineering & National Research Council. (2009). Engineering in K-12 education: Understanding the status and improving the prospects. Washington, DC: National Academies Press.
National Research Council (NRC). (2011). Successful K─12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics. Washington, DC: National Academies Press.
Olgan, R. (2015). Influences on Turkish early childhood teachers' science teaching practices and the science content covered in the early years. Early Child Development and Care, 185(6), 926–942.
Rogers, C., & Portsmore, M. (2004). Bringing engineering to elementary school. Journal of STEM Education, 5(3/4), 17–28.
Sahin, A., Ayar, M. C., & Adiguzel, T. (2014). STEM Related After-School Program Activities and Associated Outcomes on Student Learning. *Educational Sciences: Theory and Practice*, *14*(1), 309-322.
Scherer, M. (2015). Helping STEM Take Flight. *Educational Leadership*, *72*(4), 7-7.
Souza, I. M., Andrade, W. L., Sampaio, L. M., & Araujo, A. L. S. O. (2018, October). A Systematic Review on the use of LEGO® Robotics in Education. In *2018 IEEE Frontiers in Education Conference (FIE)* (pp. 1-9). IEEE.
Strawhacker, A., & Bers, M. U. (2015). "I want my robot to look for food": Comparing Kindergartner's programming comprehension using tangible, graphic, and hybrid user interfaces. International Journal of Technology and Design Education, 25(3), 293–319.
Strnad, B. (2017, May). Programming lego mindstorms for first lego league robot game and technical interview. In *2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* (pp. 958-960). IEEE.
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.
Sullivan, A., & Bers, M. U. (2016a). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics
Sullivan, A., & Bers, M. U. (2016b). Girls, boys, and bots: Gender differences in young children's performance on robotics and programming tasks. Journal of Information Technology Education: Innovations in Practice, 15, 145–165.
Sullivan, A., & Bers, M. U. (2017). Dancing robots: Integrating art, music, and robotics in Singapore's early childhood centers. International Journal of Technology and Design Education, 1–22. doi:10.1007/s10798-017-9397-0
Sullivan, A., Kazakoff, E. R., & Bers, M. U. (2013). The wheels on the bot go round and round: Robotics curriculum in prekindergarten. Journal of Information Technology Education: Innovations in Practice, 12, 203–219.
Taban, F.,Acar,E.,Fidan,I.,&Zora,A.(2005).Teachingbasic engineering concepts in a K–12environment using LEGO bricks and robotics. In Proceedings of the 2005 ASEE Annual Conference and Exposition, Portland, Oregon. Retrieved fromhttps://pe
Trepanier-Street, M., Gregory, L., & Donegan, M. M. (1998). Collaboratıon among early chıldhood teachers and faculty through a reggıo ınspıred long-term project. Journal of Early Childhood Teacher Education, 19(2), 171–179.
Tuluri, F. (2015, March). Using robotics educational module as an interactive STEM learning platform. In *2015 IEEE Integrated STEM Education Conference* (pp. 16-20). IEEE.
Usselman, M., Ryan, M., Rosen, J. H., Koval, J., Grossman, S., Newsome, N. A., & Moreno, M. N. (2015, June). Robotics in the core science classroom: Benefits and challenges for curriculum development and implementation (rtp, strand 4). In *2015 ASEE Annual Conference & Exposition* (pp. 26-1349).