Exploring the benefits of Educational Robots in STEM Learning: A Systematic Review

Peter Ngugi Mwangi, Christopher Maina Muriithi, Peace Byrne Agufana

Abstract: *The research interest in the use robotics for education purposes has increased greatly in the last few years. However, no much consideration has been made to the benefits that the robots have in delivering content in STEM education. Educational robots have been used to support learning of STEM subjects but in the informal learning environment at different levels of education. This review assesses benefits of use of educational robots in teaching of these subjects to learners' attitude towards the subjects and problem solving skills. In this research 25 papers were selected for the purpose of review through a process of search and review. The papers selected were analyzed based on similarity in their findings and mainly on the benefits educational robot activities towards teaching and learning of STEM subjects. The review reveals that robotic activities employed in education play an important role in enhancing STEM interest and also promoting problem solving skills. These benefits are greater to primary school learners than primary school learners and are realized greatly when the duration of experiment is not extended for longer durations. From the review it was noted that the robots have a greater impact in boys than in girls. The robots being multidisciplinary in nature can be utilized in teaching various subjects at different levels of education. The conclusions of this review will be useful as reference for future research in this field of study.*

Keywords: The Review Reveals That Robotic Activities Employed in Education Play an Important Role in Enhancing Stem

I. INTRODUCTION

According to Karim et al. [1] education robots can be described as the robot platforms, robotic kits and programmable robots which can be employed in education. The education robot support teachers and students in the teaching learning process to develop problem solving skills and also can be used in teaching content and improve practical expertise in the curricular fields [2]. Many researchers agree that the learners' attitudes towards STEM subjects affect the interest in fields that are related to STEM [3]. Nourbakhsh et al., [4] indicates that where educational robots have been used to aid in teaching, there has been great impact that has led to growth in innovation and development of learners' talents.

Peter Ngugi Mwangi*, PhD (Pursuing), Department of Electrical and Electronics, Murang'a University of Technology, Kenya.
Christopher Maina Muriithi, Professional Engineer and Associate Professor, Department of Electrical Engineering, Dean School of Engineering and Technology, Murang'a University of Technology, Kenya.
Peace Byrne Agufana, Senior Lecturer, Founding Dean School of Education, Murang'a University of Technology (MUT), Kenya.

This also agrees with the findings by Bers et al., [5] who concluded that educational robots can help develop literacy in STEM and also in computational thinking with the aim of promoting critical thinking in various disciplines and also improve innovations. Robotics have also become a great tool for purposes of application in education and also an interesting subject for learners of all ages [6] Educational robotic activities involve use of physical robots for educational purposes. There are a few examples of educational robots like LEGO Mindstorms and other robot designs whose main purpose is to support teaching process. The said activities have been developed for learners ranging from elementary level to graduate level. The developed activities include robot design process, robot programming, application of robots for educational purposes. This some cases involve the use of robotics kits where learners learn how to build various robot designs and also programming the built robots for some specific tasks [7]. The activities may be developed for interventional measures to some concepts, to be done after the formal learning process, in form of voluntary classes, or an entire course in robotics. According to Danahy et al., [8], the basis for use of robots for educational purpose is vast, but the most outstanding approach in education has been constructionist approach. Robotics facilitate learning of STEM concepts and also due to its interdisciplinary nature it also supports the interdisciplinary nature of STEM which in turn encourages team work in students [9]. Similarly, the use of robots for learning purposes engages students in the learning of science, technology, engineering, and mathematics. This has a great potential in promoting formal classroom teaching and learning [10]- [11]. Bers et al., [5] highlighted the outstanding reason for the increasing application of robots in education is that they expose learners to modern technology and as such the effects of exposure can be assessed. Luckin et al., [12] observed the use teaching tools that are innovative has led to transformation of education through improvement of the learners' classroom learning experience. Use of robots in education is considered to be useful in hands-on general learning and also support teaching and learning of topics in Science, Technology, Engineering, and Mathematics [13]. In many of the studies done, the use of the robots in education has been in informal learning processes inside and outside school environment. In the current study, the main focus will be on benefits of application of robots in STEM subject learning.

II. MATERIALS AND METHODS

Kitchenham [14] defined a systematic review is a method which is used to identify, evaluate, and interpret all available research applicable to a specific research question, topic area, or phenomenon of interest.

The search strategy in a systematic is very important as way of identifying papers reviewed and also obtaining the actual outcome of the review [15]. In this study, literature search was done first, followed by selection of literature using eligibility criteria and finally literature coding was done.

2.1 Literature Search

This review collected wide range of studies for purposes of inclusion from "Web of Science", "ERIC", "IEEE", "Science Direct", "Springer Link", among others. It also considered nearly 10 years of proceedings from "ICET", "AECT", and other proceedings as guided by the scope of the literature search. The papers considered for this study were those published from 1st January, 2012 to 31st December, 2021. The method of retrieving included combination subject words and free words. The particular keywords comprised of "educational robots", "teaching robotics", "secondary school", "STEM attitude", and "Impact of robotics".

2.2 Eligibility Criteria

The search was narrowed down to ensure that only the studies meeting the set down criteria were selected. The criteria to be met included: (a) The study must be on educational robots; (b) the study must not be a systematic review; (c) the study on educational robots for purposes of teaching STEM subjects; (d) the studies must have been carried between 2012 and 2021. The search process began with 1523 articles after which the four criteria were employed. A gradual procedure of selection yielded to 25 research studies which were then considered in this study. Studies involving higher levels of learning were excluded in this study.

2.3 The Coding of Literature

The 25 studies selected for this study were listed and data related to the studies encoded. This would enhance analysis of the results of the papers for purposes of capturing the key benefits of utilization of educational robots in STEM education. The subject matter of the coding of the papers included the author of the article, publication year, experiment duration, the academic level, the sample size, the gender of subject and the outcome variables. This is well illustrated in Table 1. The duration of experiment was divided into 4 categories: Not indicated, above one year, above 2 months and up to one year, 2 months and below. The outcome variables included STEM attitudes and Problem solving skills.
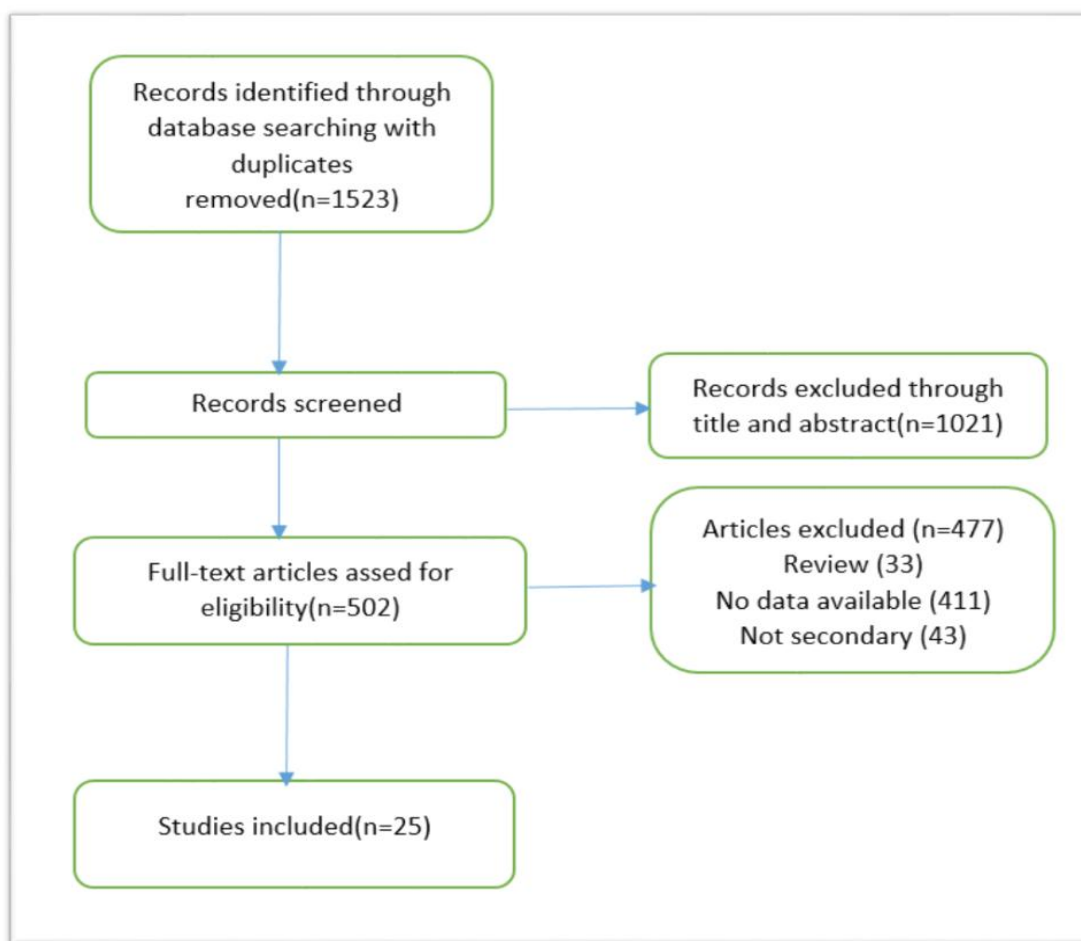

Figure 1. Selection procedure

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Table 1: Original Studies in STEM subjects in Schools

Author (year)	Participants	Gender (yes/no)	Grade level	Duration	Outcome variables
Atmatzidou & Demetriadis (2016)	75	yes	Secondary school level	11 weeks	Problem solving
Angeli & Valanides (2019)	13	yes	primary school level	1 week	Problem solving
Bers et al.(2014)	53	no	Primary School level	20 hours	Problem solving
Ching et al. (2019)	14	no	Primary School level	8 weeks	STEM attitudes
Nugent et al. (2014)	2409	Yes	Secondary school level	8 years	STEM attitudes
Sa´ez-Lopez et al. (2019)	93	no	Primary School level	2 months	STEM attitudes
Leonard et al. (2016)	20	no	Secondary school level	3 years	STEM attitudes
Barak & Assal (2018)	32	no	Secondary school level	2 weeks	STEM attitudes
Shih et al. (2013)	53	no	Primary School level	3 months	STEM attitudes
Gaudiello & Zibetti (2016)	25	no	Primary School level	8 weeks	STEM attitudes
Jackson et al. (2019)	278	no	Secondary school level	1 year	STEM attitudes
Berland & Wilensky (2015)	44	no	Secondary school level	2 weeks	Problem solving
Merino-Armero et al. (2018)	27	yes	Primary School level	1 weeks	Problem solving
Noh & Lee (2019)	155	yes	Primary School level	11 weeks	Problem solving
Ioannou & Angeli (2016)	127	no	Primary School level	16 weeks	Problem solving
Constantinou & Ioannou (2018)	16	no	Secondary school level	3 months	Problem solving
Atmatzidou & Demetriadis (2014)	35	no	Secondary school level	11 weeks	Problem-solving
Plaza et al.(2018)	8	Yes	Primary School level	4 months	STEM attittudes
Eteokleous & Ktoridou (2014).	21	yes	Primary School level	2 months	Problem solving
Leonard et.al.(2016)	101	no	Secondary school level	3 years	STEM attitudes
La Paglia et al. (2017)	60	yes	Secondary school level	10 weeks	Problem solving
Padayachee et al.(2015)	40	No	Primary School level	Not indicated	Problem solving
Master et. al. (2017)	96	Yes	Primary School level	Not indicated	STEM attitudes
Sahin et. al.(2014)	146	No	Primary School level	Not indicated	STEM attitudes
Kucuk, S., and Sisman, B. (2020).	240	Yes	Secondary school level	1 year	STEM attitudes

III. FINDINGS

This study reviewed **25** studies which were conducted between 2012 and 2021. It was noted that majority of these studies were not conducted in a formal learning set up but rather in informal settings which included competitions and vacation camps. This review concentrated on articles with similar characteristics and outcomes. A summary of the outcomes of the 25 papers reviewed is highlighted in table 1.

3.1 The types of robot used

In this review, it was noted that most of the articles utilized LEGO Mindstorms robot designs. Figures 3.1 and 3.2 show examples of the LEGO Mindstorms robot design used.

Figure 3.1 Lego Mindstorms car design (youtube.com)

Figure 3.2 Robot arm design(robocamp.eu)

3.2 The effects of using education robots on learning process.

The outcome of this study was categorized into problem solving and STEM attitudes for purposes of assessing how the use of robotics in education influenced the learning process as shown on Figure 3.3.
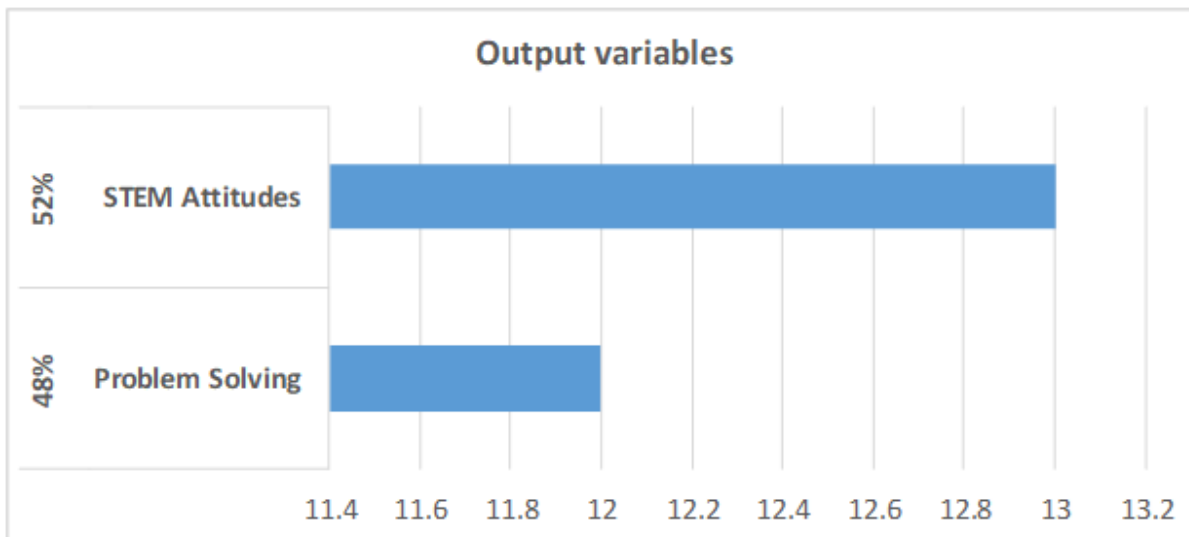
Output variables

STEM Attitudes — 52%

Problem Solving — 48%

Figure 3.3 Study output variables

Out of the 25 papers reviewed 13 of them had STEM attitude orientation outcomes while 12 had an orientation towards problem solving. From the findings of papers reviewed, it was clear that there was a remarkable difference in the way the use of robots in STEM education affected problem solving and STEM attitudes. The findings clearly indicated that educational robot use in learning STEM subjects had a greater impact in problem solving than on STEM attitudes.

3.3 The impact of using educational robots to male and female learners.

Most of the studies reviewed did not concentrate on the effects of the education robots on gender. Only 40% of the studies considered how the use of robots in STEM education affected the attitudes and problem-solving skills of the learners of different genders as shown in figure 3.4.
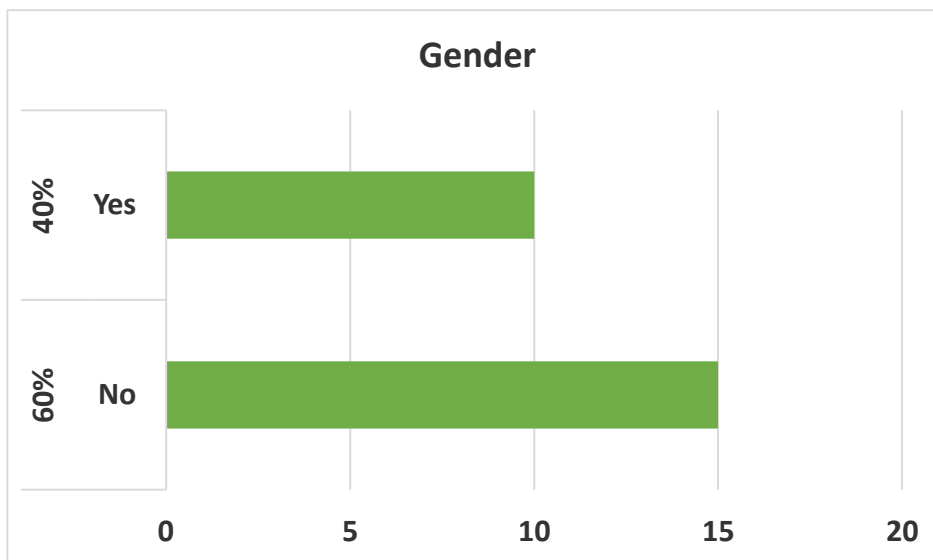
Gender

Yes — 40%

No — 60%

Figure 3.4 Gender consideration of the study)

For this review only ten articles investigated the effects of use of robots to problem solving skills and STEM attitudes while paying attention to different genders. Further scrutiny of the papers revealed that educational robots have a greater effect on the problem solving in the male students than in female ones. The findings of the reviewed papers did not reveal any considerable difference in terms of the attitudes towards STEM after the exposure to educational robots. This is in line with the findings of the previous researchers who had similar observations.

3.4 The impact of the robots to various learners' education levels.

The review investigated how educational robots influenced learning to learners at various education levels. The levels of were grouped into two main categories: primary school and secondary school. The study analyzed the outcome of 14 primary and 11 secondary school levels as shown in Figure 3.5.
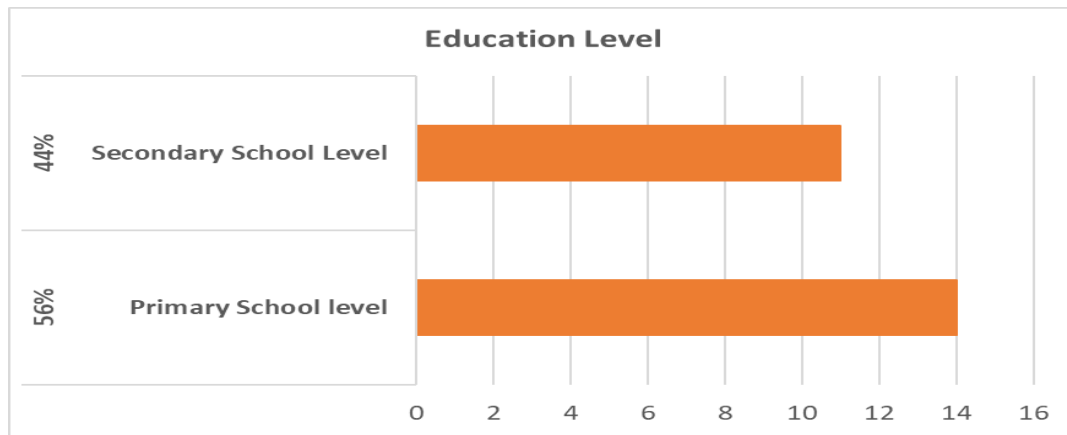
Figure 3.5 Educational levels

From the reviews the educational robots had a greater effect on learners at primary school level as compared to Secondary school learners. Zhou et al. [16] concluded that the educational robots had positive and considerable impact at each of the learning levels, but has the greatest effect in primary school level. This agrees with the findings of this review in that learners at primary school levels gained significantly in both problem solving and STEM attitudes. It can therefore be concluded that the use of robots in learning at Primary school level would be very effective and that the level is a very crucial stage for learners to improve problem solving abilities and develop the right attitudes towards STEM subjects.

3.5 The effect of Educational Robots to learning when used in varying durations.

In this review experiment durations of the literature being reviewed were divided into four different groups. These included; no duration indicated, above one year, above 2 months but less or equal to one year, 2 Months and below for analysis as shown in figure 3.6.
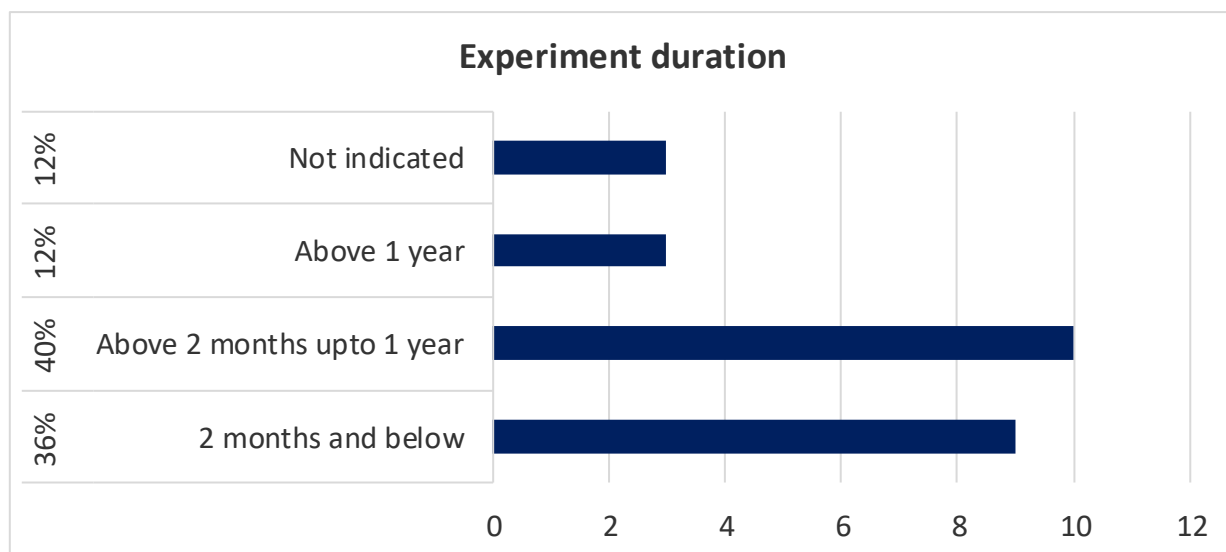

Figure 3.6 Experimental periods

From the literature reviewed the impact of educational robots utilized at different durations was different. This is a clear indication that the effects of use of educational robots for learning purposes had a certain correspondence with the duration of experiment. The impact diminishes with the increase of the duration of experiment with the greatest impact being less than 2 months. There was a gradual weakening of the impact of the education robots on the learning of STEM subjects. It can therefore be concluded that too long experiment duration reduces impact of educational robots. This may be as a result of learners becoming familiar to the robots, losing the initial freshness among other reasons.

IV. DISCUSSION

This study analyzed 25 articles on how the use of robots in education would be beneficial to STEM education to learners at various education levels. The findings reveal that the use of educational robots for learning purposes has different effects based on gender, duration of experiment, the grade levels of learners and on the learning process. From the literature, it was found out that impact of Educational Robots decreased with duration, and as such on the impact of the robots could be said to have moderate positive influence on learners' development of skills and can improve their skills growth.

Similarly, the robots can improve STEM attitudes but their role can be improved in order to improve their impact on secondary level learners especially on STEM attitudes.

4.1 Improving the performance of use of Robots in advancing Attitudes towards STEM subjects

From the findings of this study, the use of robots in education has an average impact to problem solving skills to learners and has no significant effect on improvement of students' attitudes towards STEM subjects. This is in line with other researchers' findings and which calls for further consideration on how robot use can be employed to improve the attitude. DeWitt et al. [17] concluded that the interest and the attitudes of learners towards STEM subjects decrease as age increases. A few measures could be taken to fully utilize the educational robots' potential in improving the teaching and learning process. The first measure could include setting up courses that are practical in nature to help student advance their operational ability. Secondly more attention could be paid to integrate robot activities to the actual STEM curriculum to strengthen learners learning capability and also make the STEM subjects more appealing thereby improving STEM attitudes

4.2 Strengthening educational robotic programs in order to have long term impact.

The findings of this study revealed that the impact of the robots on learners' learning experience declines with increase of the experiment duration. The programmes utilizing educational robots should be strengthened and where need be incorporated to the STEM syllabus so that use of the robots can have long term impact. The strengthening can be achieved by using robotic technology together with other technologies like artificial intelligence, 3D design and printing, Solar technology, voice recognition among others. The incorporation of the additional technologies can reinforce learners understanding of the STEM concepts and hence improve their attitudes towards the subjects. The integration has the potential of introducing more openings for the future utilization of robots for educational purposes [18].

Wu, M., et al. [19] indicated that the incorporation of artificial intelligence to education has a greater chance changing the future trend of Education and is therefore an important source of motivation in education and further research. According to Khanlari [20] robotics and other technologies are considered to influence learners positively and have capability of improving earners long term learning skills.

V. CONCLUSION

From the findings of the article review, the following conclusions can be drawn;

i) Educational robots have a significant impact on teaching and learning of STEM subjects. This is supported by the findings of authors like Okita [21] who concluded the robots improved the learners' logical thinking and skills in problem solving. Afari, E., & Khine, M. S. [22] had similar observations in that they indicated that the use of robotics in Science education will improve learner's problem solving and programming skills.

ii) The educational robots are beneficial to learners' in that they assist in making complex and non-realistic science concepts easier and clearer. This is similarly alluded to by Eguchi [23] and Touretsky [24].

iii) The robots could improve the learners' interest towards STEM subjects and could motivate them to pursue STEM related careers. According to the review the robots have a greater effect on learners' interest in primary school levels. It was also noted that with some improvement they could also be helpful at higher levels of learning and may lead to interest in STEM related careers. The studies reveal a great future of educational robots in teaching and learning STEM subjects.

RECOMMENDATIONS

The main objective of this study was explore the benefits that the use of robotics in education have on students learning STEM subjects. The study reviewed articles published between 2012 and 2021 and concluded that the use of robots refined the learners' problem solving skills and attitudes towards STEM subjects. In order to get more accurate results, more papers may be reviewed. In most of the studies reviewed, it was noted that surveys on students was carried out right away after the exposure to educational robotics like a workshop or any other organized educational programme. Longitudinal studies could be carried out rather the short term ones in an effort to follow up future decisions of the learners, like careers undertaken, which would facilitate researchers to evaluate long term effects of exposure to educational robotics. It would also be more beneficial to use variety of robotic designs and programming languages to compare their impact with that of LEGO Mindstorms. Finally, more studies can be carried out in secondary school levels to evaluate the effect of integration educational robotic activities in the curriculum and the possible impact on students' career path.

REFERENCES

1. Karim, M. E., Lemaignan, S., & Mondada, F. (2015, June). A review: Can robots reshape K-12 STEM education? In *2015 IEEE international workshop on Advanced robotics and its social impacts (ARSO)* (pp. 1-8). IEEE. [CrossRef]
2. 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. [CrossRef]
3. Bonvillian, W. B. (2002). Science at a crossroads. *Technology in society*, *24*(1-2), 27-39. [CrossRef]
4. Nourbakhsh, I. R. (2015). *Robot futures*. Mit Press.
5. Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157. [CrossRef]
6. Kopcha, T. J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., ... & Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning*, *1*(1), 31-44. [CrossRef]
7. Jung, S. E., & Won, E. S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability*, *10*(4), 905. [CrossRef]
8. 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. [CrossRef]

9. Yuen, T., Boecking, M., Stone, J., Tiger, E. P., Gomez, A., Guillen, A., & Arreguin, A. (2014). Group tasks, activities, dynamics, and interactions in collaborative robotics projects with elementary and middle school children. *Journal of STEM Education*, *15*(1).
10. Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, *91*, 14-31. [CrossRef]
11. Kucuk, S., & Sisman, B. (2017). Behavioral patterns of elementary students and teachers in one-to-one robotics instruction. *Computers & Education*, *111*, 31-43. [CrossRef]
12. Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). Intelligence unleashed: An argument for AI in education.
13. Gomoll, A., Hmelo-Silver, C. E., Šabanović, S., & Francisco, M. (2016). Dragons, ladybugs, and softballs: Girls' STEM engagement with human-centered robotics. *Journal of Science Education and Technology*, *25*(6), 899-914. [CrossRef]
14. Kitchenham, B., Brereton, O. P., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering–a systematic literature review. *Information and software technology*, *51*(1), 7-15. [CrossRef]
15. Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, *103*(1), 45-76. [CrossRef]
16. Zhou, J., Chen, X., Chang, U., Lu, J. T., Leung, C. C. Y., Chen, Y., ... & Wang, Z. (2019). A soft-robotic approach to anthropomorphic robotic hand dexterity. *IEEE Access*, *7*, 101483-101495. [CrossRef]
17. DeWitt, J., Osborne, J., Archer, L., Dillon, J., Willis, B., & Wong, B. (2013). Young children's aspirations in science: The unequivocal, the uncertain and the unthinkable. *International Journal of Science Education*, *35*(6), 1037-1063. [CrossRef]
18. Wu, Q., Lin, C. M., Fang, W., Chao, F., Yang, L., Shang, C., & Zhou, C. (2018). Self-organizing brain emotional learning controller network for intelligent control system of mobile robots. *IEEE Access*, *6*, 59096-59108. [CrossRef]
19. Wu, M., Kozanoglu, D. C., Min, C., & Zhang, Y. (2021). Unraveling the capabilities that enable digital transformation: A data-driven methodology and the case of artificial intelligence. *Advanced Engineering Informatics*, *50*, 101368. [CrossRef]
20. Khanlari, A. (2016). Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula. *European Journal of Engineering Education*, *41*(3), 320-330. [CrossRef]
21. Okita, S. Y. (2014). The relative merits of transparency: Investigating situations that support the use of robotics in developing student learning adaptability across virtual and physical computing platforms. *British Journal of Educational Technology,* 45(5), 844-862. [CrossRef]
22. 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. [CrossRef]
23. Eguchi, A. (2014). Educational robotics for promoting 21st century skills. *Journal of Automation Mobile Robotics and Intelligent Systems*, *8*(1), 5-11. [CrossRef]
24. Touretzky, D. S. (2013). Robotics for computer scientists: what's the big idea?. *Computer Science Education*, *23*(4), 349-367. [CrossRef]

AUTHORS PROFILE

Peter Ngugi Mwangi, received his B.Ted in Electrical and Electronics Engineering in 2005 from Moi University, M.Sc. in Electronics and Instrumentation from Kenyatta University in 2016. He is currently pursuing PhD in Technology Education (Electrical and Electronics) at Murang'a University of Technology. His current research interest includes Electronics and Instrumentation, Educational robotics, and Artificial intelligence. Mr. Mwangi is a member of the institution of Engineering Technologists and Technicians (IET) Kenya.

Christopher Maina Muriithi, received his BSc and MSc in Electrical Power Engineering from Moscow Power Engineering Institute (National University) in 2001 and 2003 respectively. He has a PhD in Electrical Engineering from Jomo Kenyatta University of Agriculture and Technology (2012). He is a Professional Engineer and an Associate Professor of Electrical Engineering and the Dean, School of Engineering and Technology, Murang'a University of Technology. His research interests include Power Systems Analysis, Artificial Intelligence Applications and Renewable Energy Technologies.

Recent publications:
1. R.A. Soumana, M.J. Saulo, C.M. Muriithi, New control strategy for multifunctional grid-connected photovoltaic systems, Results in Engineering (2022), doi: https://doi.org/10.1016/j.rineng.2022.100422.
2. Rebeccah Kyomugisha, Christopher Maina Muriithi, George Nyauma Nyakoe, "Performance of Various Voltage Stability Indices in a Stochastic Multiobjective Optimal Power Flow Using Mayfly Algorithm", Journal of Electrical and Computer Engineering, vol. 2022, Article ID 7456333, 22 pages, 2022. https://doi.org/10.1155/2022/7456333
3. E. O. Apiyo, C. M. Muriithi, and L. M. Ngoo, "Impact of Energy Management on a Solar Photovoltaic Microgrid," International Journal of Engineering and Advanced Technology, vol. 11, no. 5. Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP, pp. 65–73, Jun. 30, 2022. doi: 10.35940/ijeat.e3542.0611522.

Peace Byrne Agufana, (Ph.D.) holds a PhD in Educational Communication and Technology from Moi University, Kenya. Currently, he is a Senior Lecturer, and the founding Dean School of Education at Murang'a University of Technology (MUT). He has served as an Assistant Commission Secretary, Programme Accreditation, at the Commission for University Education, Kenya. He has also served as an Assistant Director Quality Assurance & Standards, in the Ministry of Education, Kenya. Under the Teachers Service Commission, he served as a Lecturer. He is a Peer Reviewer for Education academic programmes with the Commission for University Education, Kenya. He has taken part in many peace education initiatives in Kenya, and also been a trainer of volunteer teachers. He has participated in many local and international conferences.

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