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Development of Educational Robotics Activities for Secondary School Students to Promote Interest in Engineering Career Path

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Abstract: ***There is currently low interest in STEM subjects at secondary schools which leads to low interest in STEM career path in Kenya. Secondary schools have a great role in preparing learners for career progression through the subjects they teach and career guidance. In order for any country to meet the ever increasing need for a STEM related workforce, more learners should be motivated to pursue careers in STEM. Educational Robotics have been recognized to be vital teaching tools for practical learning about STEM topics in general. However, not enough attention has been paid to the development of robotics activities and their suitability for integration in Physics and Mathematics subjects. In this study robotic activities are developed which expose learners to many opportunities of enriching learning of Physics and Mathematics. The activities developed were then implemented through a 3-day workshop held at Murang'a University of Technology in Kenya for students and teachers in Physics and Mathematics. The activities were developed in a systematic manner and adopted an Active learning model. In order to assess the suitability, relevance and the impact of the developed activities to learning of Physics and Mathematics, 192 form 2 students and 10 teachers from Kangema Sub-County, Murang'a County in Kenya were selected purposefully. A questionnaire and an interview schedule were used to collect data from students and teachers respectively. From analysis of the data collected it was concluded that the activities were suitable and made learning of Physics and Mathematics fun and consequently improved learners interest to the subjects and their participation in class. The developed activities can therefore be integrated into the Physics and Mathematics curriculum for either in-class sessions or after-school sessions.***

Keywords**: *Active learning, Career, Integration, Pre-college, Robotic activities.***

I. INTRODUCTION

1.1 Background information

Educational robotics have been defined as a field of study whose main goal is to improve learning experiences of learners by the creating and implementing educational robotic activities [1].

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There are a few examples of educational robots like LEGO Mindstorms, makeblock mbot, Robo Wunderkind, NAO and others whose main function is to aid in teaching and learning. Educational robotic activities can be developed to suit learners at different educational levels beginning from elementary to the higher educational levels. The activities may vary in their depth depending on the level of the learners and may include basic to advanced programming, use of robots for demonstration of STEM concepts. The activities involve utilization of robot kits to aid learners in understanding the science behind robot designs and programming robot parts [2]. The activities can be implemented in various modes including having the activities done after school set up, optional classes, or a whole course in robotics. According to Danahy et al., [3], the fundamental principle of the use of robots in education is broad with the most conspicuous basis is constructionist approach. The robots can be used to teach programming in a systematic manner and the building of robots could promote creativity in education. According to Breuch and Fislake, [4], using drones to teach robotics motivated learners to learn programming at different levels of education. Robotic activities can facilitate active learning, promote active reasoning and creative thinking. It can also promote learners' motivation to solve problems and understand abstract concepts in Sciences. The educational robotic field has made tremendous progress and is endowed with great prospective to considerably impact the way engineering and sciences are taught education at all educational levels [5]. Luckin et al., [6], concluded that using modern tools in teaching and learning has transformed and improved the learning experience by learners. Educational robotic activities are considered to provide very practical activities which makes learning better especially in STEM subjects since the activities are hands-on [7]. Jin et al., [8] developed hands-on activities that would support learning at K-12 level and indicated that the activities would promote learning. The activities would also be conducted in groups hence it helped learners understand the value of sharing with one another and also caring for each other.

In this study educational robotic activities have been developed and a workshop organized in order to implement the activities to form 2 learners. Several factors were taken into account during development of the activities which include suitability and the relevance of the activities to the form 2 learners, ease of breaking the activities into simple tasks and affordability of the robots used for the development of the activities [9].

1.2 Robotic activities and precollege programmes

Robotic activities can be developed for educational purposes and implemented at different levels of education. Precollege programmes can provide avenues of implementation of these activities. According to Baltes and Anderson [10] some educational robotics activities are either integrated or not in the class subjects learnt. In the informal set-up, the learners are exposed to the robotic activities and allowed to learn by themselves where they can try different tasks. They can learn from their own mistakes as they perform the tasks. However, the learners still learn without the learning objectives and develop knowledge which is useful in the formal setting [11]. The use of robots through robotic activities in a classroom set-up would result to greater competence and would therefore produce learners that are more skill based [12]. In some cases, the activities are integrated in school subjects and hence making the implementation formal and more so in STEM education. The activities are integrated to the topics in various ways and depends on the need for implementation. Some of the activities are integrated following a programmatic step, hence reducing chances for creativity. Other activities are integrated such that they follow a flexible model thereby promoting an interdisciplinary approach and hence the learners can develop in creativity, teamwork and problem solving skills [13]. Wilson et al [14] studied the impact robotics inspired science education and noted that many nations have focused on STEM education. The study established that the integration of robotics activities to learners' learning activities inculcates in them skills in problem-solving. According to Mwangi et. al [15] exposing learners' robotics activities through precollege programmes would lead to learners understanding what engineering is all about and would help them improve their attitudes towards STEM subjects. According to Mataric et al. [16], robotic activities can be organized in a systematic manner which will lead to improvement of learners' interest in STEM subjects. The activities must be developed from robots that are developed using cheap materials and also the educational platforms must be affordable so that it is available to many users. The activities must also be carried out at a time convenient to all players. Rokbani et. al. [17] developed educational robotic activities in Tunisia, where trained educators used the activities to assess the learners' perceptions towards them and towards STEM and Engineering fields. From the feedback obtained they found out that the activities were perceived to be helpful in learning and that there was a positive perception after the activities Most of the researchers develop activities and do not assess the suitability, relevance and effects of the activities to the learners at the pre-college levels. The activities developed in this study were implemented in a pre-college workshop held at Murang'a University of Technology.

II. METHODOLOGY

Robotic activities were first developed using the Active Learning Model. The activities identified, developed and selected for implementation in a 3-day workshop. In this study the activities were developed in a systematic manner after which the organized workshop was conducted to ascertain the suitability and relevance of the robotic activities. The feedback on the suitability and the relevance of the developed activities was obtained through questionnaires by the students and interviews administered through the teachers. The process of development of the activities was carried out as shown in Figure 1.

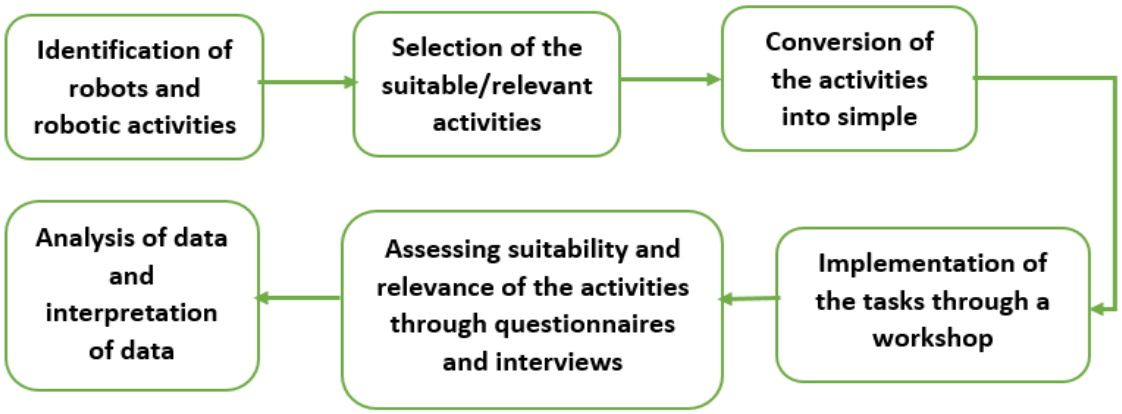

Figure 1. The process of development of robotic activities

2.1 Development Robotics Activities For Educational Purposes

The development of the educational robotics activities was done in five steps as shown in Figure 2. The first step included the selection of the robot designs from which the activities would be derived from. The second step included the development of educational robotics activities carried out with an activity plan. The third step included design of activity blocks using a constructionism approach, a teaching strategy based on problem-based- learning, and the ALC model. The step also included the development of teaching materials which included the working sheets, the feedback documents and the tests to be administered. The fourth step included assessment of the educational robotics activities developed in relation to their suitability in teaching and learning Physics and mathematics. The last step included the use assessment results to carry out the redesigning of the educational robotic activities.

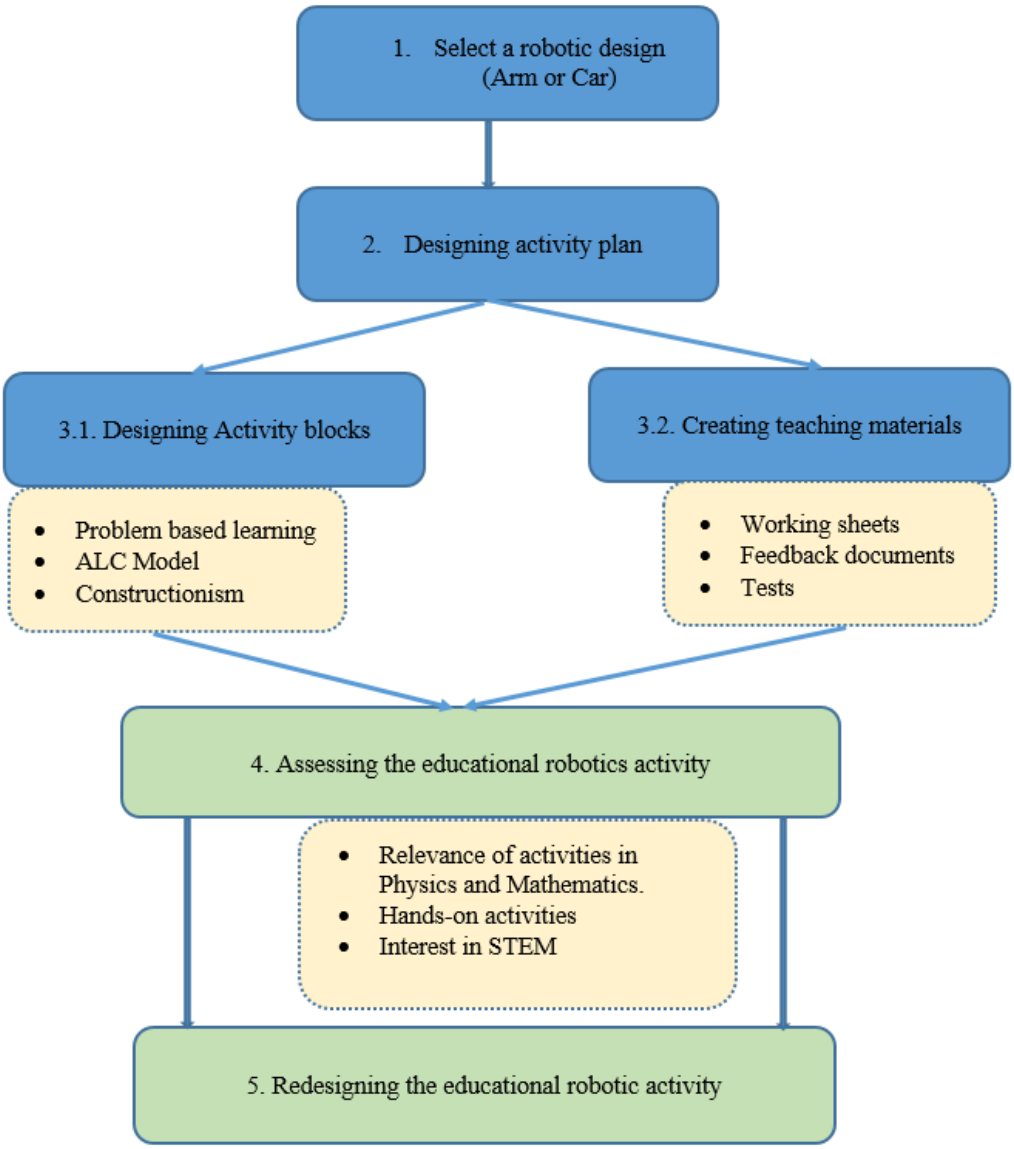

Figure 2 Steps in development of educational robotic activities

The designs adopted for this study were robotic car, robotic arm and a robot truck as shown in figure 3,4 and 5.

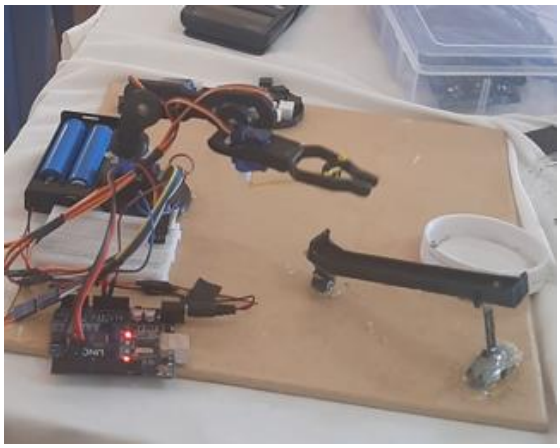

Figure 3. Robotic Arm

Figure 4. Robotic car

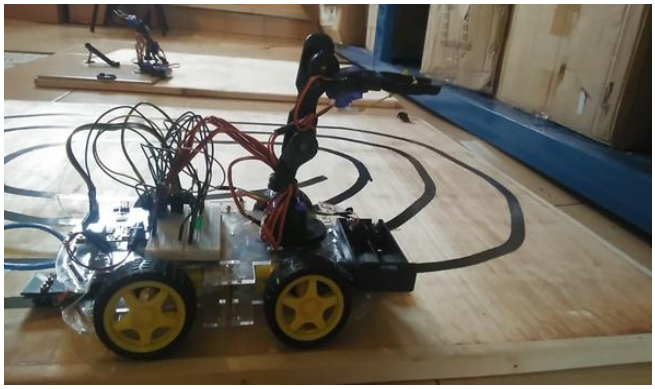

Figure 5. A robot truck

2.2 Development and selection of activities through the ALC Model

Graven, and Samuelsen [18] supported the development of robotic activities through active learning. The active learning model is beneficial in that:

i. It helps learners remain active in the learning process since the activities are engaging
ii. It leads to growth in creativity and develops learners interest towards Engineering
iii. It contributes to making the learning environment active by improving learner participation in classes.

In this research, we developed a 3-day workshop for teachers, and form 2 students where the developed activities were implemented. The robotic activities were built on our robot designs. The activities implemented in the workshop were developed around 4 steps. These included;

i. **The content**: This included Robot and concept definitions in Physics and Mathematics.
ii. **Demonstration:** Types of robots, use of solar panel in various applications including in robots and 3D-design and printing.
iii. **Application:** The use of Robotic arm and robotic car (line follower and obstacle avoidance) to learn Physics and Mathematics.
iv. **Problem:** Solving Physics and Mathematics problems and competitions involving robot control.

2.3 Development of tasks from robotic activities

The developed robotic activities were divided tasks related to STEM subjects learnt in Form 2 syllabus and included;

1. Basic Technical drawing activities to design basic shapes in preparation of 3D printing.
2. 3D printing activities to print robot parts.
3. Basic electronics activities including measurement of electrical components.
4. Solar energy activities.
5. Activities involving identification of robot parts like sensors, motors and microcontrollers.
6. Basic robot parts programming.
7. Line following robot activities.
8. Obstacle avoidance robot activities.
9. Robotic arm rotational dynamics activities.
10. Competitions involving control of robots and creativity.

2.4 Implementation of the developed activities through the workshop.

The workshop included presentations and discussion on robot designs and activities based on the robots. The objectives of the pre-college workshop included:

- To illustrate the Science principles through the use of robotic activities.
- To expose learners to basic programming activities.
- To guide learners through hands-on practices for effective learning.

The workshop schedule included 3 days where the implementation of the activities was planned as follows: The activities developed were spread into the 3 days of the workshop. The last day included workshop evaluation, which was done through questionnaires and Interviews.

The teachers were interviewed while students were issued with questionnaires where they gave feedback on the suitability and relevance of the activities to Physics and Mathematics education.

The pre-college sessions were conducted at Murang'a University of Technology. Each day's topics and challenges were developed in form of activities guided by the following.

Content

Content was delivered using a variety of approaches. The major approach was demonstration. Which gave learners the basic foundational information they needed before they could start assembly and programming of robots.

Demonstration

This is where models were used to illustrate the robotics concepts and design challenges. The workshop instructors demonstrated what the robots were supposed to do because the challenges typically involved the robot interacting with an environment, such as following a line, avoiding obstacles, or picking up an object.

Application

After interacting with the concepts and having seen models of what they are supposed to do, learners applied their knowledge through assembly or programming robot parts like sensors, motors before combining all parts. These set of activities were hands-on in that learners were working with the robotics kits and the programming software.

Problem Solving

In this steps the learners were exposed to problems in Physics and mathematics in relation to the activities. This was done to help students improve their problem solving skills using robotic activities.

2.5 Testing of the activities and interpretation of data obtained

The form 2 learners were issued with questionnaires in order to assess the suitability and relevance of the activities that had been subdivided into simple tasks. The teachers of Physics and Mathematics were interviewed in order to get their opinion on the activities developed in teaching of Physics and Mathematics. The researchers then analyzed data from both students and teachers.

III. RESULTS AND DISCUSSION

3.1 Developed Activities

In this study various activities were developed. Each activity had purpose ranging from demonstration of robot design and integration into Physics and Mathematics topics. Table 1 shows the activities developed, the subdivided tasks from the activity and the purpose of each activity

Table 1 Developed Pre-College Robotic Activities

Developed Activity	Tasks related to the activity	Purpose of the activity
Basic Technical drawing activities	Drawing of basic 2-D shapes like Square, rectangle, Circle, oval. Extruding the shapes to obtain 3D models	To demonstrate the design of robot parts
3D printing	Tasks involving printing of the 3D shapes developed	To demonstrate the printing of robot parts
Basic electronics activities	Measurements of basic electrical quantities tasks like resistance, electric current, voltage and power	Integration of the activities to Physics and Mathematics
Robot part identification and assembly	Tasks involving identification of types of Sensors and their applications, transducers, Tasks on involving types of dc motors, microcontrollers	To integrate the activities in Physics topics
Basic programming.	Programming tasks on robot parts which majorly include sensors and motors	To appreciate how commands can be issued with the aim of controlling the robot car and arm
Line following robot activities.	Tasks on Linear motion involving calculation of Speed ,Acceleration, determination of Area, Perimeter and Circumference	To integrate the activities in Physics and Mathematics topics
Obstacle avoidance robot activities.	Tasks involving waves, reflection of waves, distance Calculation	To integrate the activities in Physics and Mathematics topics
Robotic arm rotational dynamics activities.	Tasks involving reflection, rotation and effects of a force	To conceptualize and integrate the various activities to Physics and Mathematics topics.

From the activities developed, the researchers found out that

i. the activities could be developed into simple tasks,
ii. the tasks could be carried out by Form 2 learners
iii. the tasks could easily be integrated into Physics and mathematics topics
iv. The tasks were hands-on

The characteristics of the activities developed agrees with the findings by Mataric et. al.[9].

3.2 The suitability of robotics activities in learning Physics and Mathematics.

The study included 192 participants, where 104 were boys while 88 were girls as shown in figure 5.

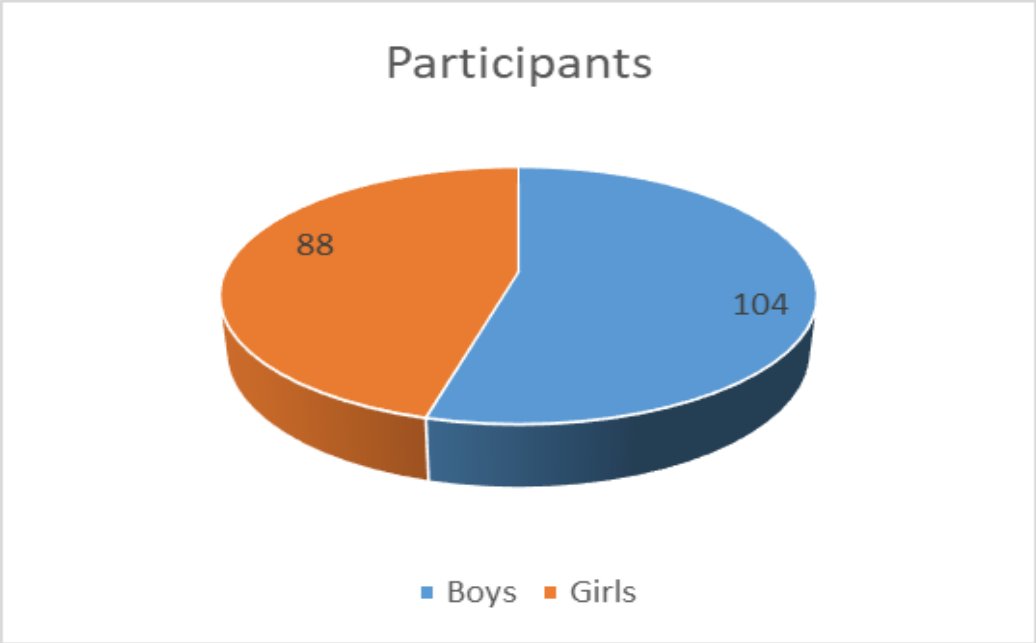

Figure 5 Participants in the workshop

After participating in the workshop which was comprised of the developed robotic activities, the students were presented with questionnaire items where they were required to indicate their level of agreement/disagreement on the suitability of the activities in terms of being fun and enjoyable, hands-on, interesting and exciting and whether they would be carried out with ease. The findings are as reported in Table 2.

Table 2: Suitability of Developed Robotic Activities

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
It was fun and enjoyable to undertake the robotics activities	5 (2.6%)	5 (2.6%)	14 (7.3%)	87 (45.3%)	81 (42.2%)
The robotic activities gave me practical experience of what to expect in Engineering	5 (2.6%)	1 (0.5%)	17 (8.9%)	78 (40.6%)	91 (47.4%)
The robotic activities were interesting and exciting	11 (5.7%)	5 (2.6%)	14 (7.3%)	70 (36.5%)	92 (47.9%)
I would carry out the activities with a lot of ease	3 (1.6%)	5 (2.6%)	11 (5.7%)	76 (39.6%)	97 (50.5%)

Source: Research Data (2022)

From the results in Table 2, 45.3% (87) and 42.2% (81) of the learners agreed and strongly agreed that it was fun and enjoyable to undertake the robotic activities; 7.3% (14) neither agreed nor disagreed, 2.6% (5) disagreed and another 2.6% (5) strongly disagreed. Further, 47.4% (91) and 40.6% (78) of the respondents strongly agreed and agreed respectively that the robotic activities gave them practical experience of what to expect in engineering; 8.9% (17) neither agreed nor disagreed, 2.6% (5) strongly disagreed and 0.5% (1) disagreed. The findings also demonstrated that 47.9% (92) and 36.5% (70) of the participants strongly agreed and agreed respectively that the robotic activities were interesting and exciting; 7.3% (14) neither agreed nor disagreed, 5.7% 911) strongly disagreed and 2.6% (5) disagreed. Lastly, 50.5% (97) and 39.6% (76) of the learners strongly agreed and agreed respectively that they would carry out the robotic activities with a lot of ease; 5.7% (11) neither agreed nor disagreed, 2.6% (5) disagreed and 1.6% (3) strongly disagreed. From the findings obtained it can be concluded that the robotic activities are both suitable for the form 2 students. From the findings in the questionnaires, the developed activities were fun and enjoyable. They also gave the learners me practical experience of what to expect in Engineering and were interesting and exciting. The researchers therefore agreed that suitable activities can be developed for purposes of teaching STEM subjects thereby making the subject more interesting to the learners. The findings agreed with the conclusion made by Ziaeefard et al. [19]and were defined by Cross et al. [20].

3.3 The Effect of robotics activities in learning of Physics and Mathematics

After participating in the developed robotic activities, the students were presented with questionnaire items where they were required to indicate their level of agreement/disagreement on the impact of the activities in terms of being fun and enjoyable, hands-on, interesting and exciting and whether they would be carried them out with ease. The findings are as reported in Table 3.

Table 3: Effects of Developed Robotic Activities

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The Activities can make learning of Physics and Mathematics interesting.	4 (2.1%)	5 (2.6%)	10 (5.2%)	90 (46.9%)	83 (43.2%)
The robotic activities gave me clear understanding of some difficult Physics and Mathematics topics	5 (2.6%)	4 (2.1%)	14 (7.3%)	78 (40.6%)	91 (47.4%)
The participation in the robotic activities changed my perception of Engineering career	8 (4.2%)	5 (2.6%)	14 (7.3%)	73 (38.0%)	92 (47.9%)
The introduction of the activities would make Physics and Mathematics more practical	1 (0.5%)	4 (2.1%)	11 (5.7%)	76 (39.6%)	100 (52.1%)

Source: Research Data (2022)

From the results in Table 3.2, 46.9% (90) and 43.2% (83) of the learners agreed that the activities can make learning Physics and Mathematics interesting; 5.2% (10) neither agreed nor disagreed, 2.6% (5) disagreed and another 2.1% (4) strongly disagreed. Further, 47.4% (91) and 40.6% (78) of the respondents strongly agreed and agreed respectively that the robotic activities gave them clear understanding of some difficult Physics and Mathematics topics; 7.3 % (14) neither agreed nor disagreed, 2.1% (4) disagreed and 2.6 % (5) strongly disagreed. The findings also demonstrated that 47.9% (92) and 38.0 % (73) of the participants strongly agreed and agreed respectively that participation in the activities changed their perception of Engineering career; 7.3% (14) neither agreed nor disagreed, 4.2 % (8) strongly disagreed and 2.6% (5) disagreed. Lastly, 52.1% (100) and 39.6% (76) of the learners strongly agreed and agreed respectively that the introduction of the robotic activities would make Physics and Mathematics more practical; 5.7% (11) neither agreed nor disagreed, 2.1% (4) disagreed and 0.5 % (1) strongly disagreed.

From the findings obtained it can be concluded that the robotic activities are relevant for the form 2 students in that they could support learning of the STEM subjects. The activities make students to actively participate in the learning process and therefore support the learning process. The support is majorly in the learning of physics and Mathematics subjects. They make learning of Physics and Mathematics interesting and giving clear understanding of some difficult Physics and Mathematics topics if integrated which agrees with findings of Screpanti et al.[21]The participation in the robotic activities would change perception of learners to pursuing an Engineering career. The introduction of the activities would make Physics and Mathematics more practical

3.4 Suitability and effect of the robotic activities in teaching Physics and mathematics.

Interviews were carried out with the key informants so as to evaluate the suitability and the relevance of the developed activities in the learning of Physics and Mathematics. In order to assess the suitability of the educational robotic activities, Physics and Mathematics teachers were interviewed. The teachers admitted that they had faced numerous challenges explaining some physics concepts and explaining some mathematical problems and therefore some relevant activities would be very useful in the teaching learning process. To ascertain the suitability of the robotic activities, the researcher formed the basis of seeking opinion from the key informants in regard to the suitability of the activities.

To ascertain the suitability of the robotic activities, the researcher formed the basis of seeking opinion from the key informants in regard to the suitability of the activities. To unravel this the guiding question was, "What would you say about the suitability of the activities developed from the robotic designs in Physics and Mathematics teaching?" It is worth noting that all teachers agreed that the activities developed from the robotic designs were suitable for teaching and learning of Physics and mathematics. They however gave various reasons on their opinions. The respondents noted that:

"The activities prepared were fun themselves and made learning of Physics and mathematics fun. They kept the learners awake and as such if adopted they will improve the understanding of the subjects"-TPM 8

"The robotic activities are vital in solving particular problems and hence improving the learner's ability to learn Physics and Mathematics and creativity thereof"-TPM1

"The activities are appropriate and can aid in teaching Physics and Mathematics. In Physics the activities aid in teaching and learning areas like measurements, effects of forces while in mathematics they can aid in topics like rotation and angles"-TPM4

Thus from the sentiments of some of those interviewed, it is worth noting that the developed educational robotic activities are good and suitable for teaching and learning STEM subjects in Secondary schools. They can enhance the active teaching and learning process of Physics and Mathematics and other STEM subjects.

The key informants also gave their opinion on the relevance of the activities. They all agreed that the activities made teaching of Physics and Mathematics easier and clearer. To ascertain the relevance of the activities, the researcher formed the basis of seeking opinion from the key informants in regard to the relevance of the activities. To unravel this, the guiding question was, "In your own opinion, how are the robotic activities relevant to teaching of Physics and Mathematics to the form 2 learners?" The teachers gave various reasons on their opinions. They noted that:

"The robot activities assist in simplifying hard concepts in Physics and Mathematics with the robots acting as demonstration aids hence improving understanding of the subjects. They help in mastery of science subjects" TPM6

"The activities play a great role in making clear some abstract concepts in Physics and Mathematics" TPM2

"Physics and Mathematics are practical subjects. The activities bring to the learners, the real-life situations for instance rotation of the robotic arm where the learners can relate the rotation of the arm with rotation in Mathematics. This promotes understanding of the subjects."-TPM3

"In teaching of Physics and Mathematics, the activities can aid learners in understanding of topics like measurements, effects of forces, rotation and angles which are clearly demonstrated by the activities developed around the robotic car and arm"-TPM10

From the sentiments by those interviewed it can be concluded that the developed educational robotic activities can make Physics and Mathematics subjects in Secondary schools more interactive and hence improve the learners' ability to understand the various Physics and Mathematics topics. They can promote the learning process of Physics and Mathematics and can therefore be considered to be relevant. This agrees with the finding by Mwangi et.al, [22].

IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

In this research, we share our experiences related to the development of educational robotics activities based on the active learning model. From our findings it can be concluded that:

i. The use of robotic activities can aid learners understanding abstract concepts in Physics and Mathematics and STEM subjects in general which agrees with the findings by Mwangi et al, [22].
ii. Interacting with robots and the activities developed around them would enhance and promote STEM education which agrees with the findings by Ben-Bassat and Ben-Ari [23].
iii. The use of the robotic activities makes learning fun, interesting and could motivate learners to choose STEM subjects hence improving choice of career towards an engineering career path.
iv. The use of the robotic activities for teaching and learning process makes active since the activities are hands-on.
v. Teaching and learning of Sciences will be more effective where learners participate in the learning process actively and where engineering concepts presented practically through the use of engineering-based activities like the robotic activities.

4.2 Recommendation

The researcher recommends further analysis of the relationship between the different factors and the long-term effect of using the activities in teaching and learning of STEM among students.

The researcher also recommends development of activities that can aid teaching and learning of other Sciences and art related subjects.

There should be a tool developed to assess the interest in robotics with time to provide useful information about the effect of educational robotics activities.

Further research should be conducted to develop relevant and suitable activities for elementary and higher levels of education.

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