The Impact of Prior Exposure to Engineering Through the MUT Pre-College Course - A Case Study of Kangema Sub-County Secondary Schools

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Abstract
In Kenya, secondary schools have a great role in preparing learners for career progression. In order to realize industrial growth, it is important to prepare more students for careers in STEM. There is relatively little research that exists on the impact of prior exposure to Engineering through pre-college sessions to students' attitude in STEM subjects. In addition, Industry 4.0 requires that the 21st century student be exposed to current trends in the industry. The purpose of this research is to investigate the impact of the pre-college sessions as a mode of prior exposure to Engineering to secondary school students on learning STEM subjects. The pre-college exposure course entailed introducing the students to green energy through Solar photovoltaic systems, automation using Arduino, advanced manufacturing through 3D printing and robotics. The research was conducted in secondary school students from Kangema sub-county. The target population is Form 1 and Form 2. In this research, the first cohort entailed 30 students who were selected from 3 secondary Schools through stratified, systematic and purposive sampling. The students were taken through the pre-college sessions. The study explored the impact of the precollege sessions to the attitude learning of STEM subjects. The study established that the students exhibited an improved attitude in learning of the STEM subjects.
Keywords: Pre-college, STEM, Career Progression, 3D Printing, Industry 4.0

1. Introduction
1.1 Background information

The Kenyan vision for the education sector for 2030 is to have globally competitive quality Education, training and research for sustainable development. Science, technology and innovation have been identified as part of strategic areas for support based on their impacts on the economic, social and political pillars (Kenya vision 2030).

Improving the STEM (Science, Technology, Engineering, and Mathematics) workforce is a top priority for policy makers, practitioners, and researchers who need to recruit and retain more students to work in STEM-related fields (Heilbronner 2011), prepare students to compete in the global market, and improve STEM literacy for all students (Bybee 2010).

Research has shown that student dispositions toward disciplines such as mathematics and science are shaped long before they begin college (Sadler et al. 2012). Further, students' attitudes toward STEM are an important factor influencing their motivation to learn STEM subjects and to pursue a STEM career (Maltese and Tai 2011).

Bringing engineering to Secondary school is one method of increasing the numbers in the STEM field, resulting in an increase of formal and informal pre-college engineering programs (National Academy of Engineering & National Research Council, 2009). The support for these programs is based on the assumption that prior exposure to engineering will encourage students to pursue careers in engineering and help them succeed in these pursuits (Fantz, Siller, & Demiranda, 2011).

There is a need for more students to be interested in pursuing degrees in STEM fields in order to meet the growing demand for STEM workers, a strong focus has recently been placed on programs designed to increase the attainment of STEM degrees at both the bachelor and graduate levels (Augustine, 2005).

The prior exposure to Engineering can be achieved through invention education, explore café and pre-college sessions.

Students who have participated in pre-college engineering programs tend to perceive lasting benefits of participation in their university engineering studies. These perceived benefits include increased technical knowledge and abilities, increased comfort with engineering design, and improved professional skills such as the ability to work on a team or communicate technical ideas (Salzman and Strobel 2010).

A pilot project conducted in Tanzania to examine the use of solar powered toys was shown to enhance students' attitude, skills and knowledge towards being creative, problem solvers, and innovative. The students having perceived the use of green and renewable energy were also sustainability-conscious. (Juliana Machuve* and Edward Mkenda, 2019)

(Recayi (Reg) Pecen , Jill L. Humston, Faruk Yildiz, 2012) indicate in their research that students in rural areas are less likely to pursue engineering. However, collaboration with institutions of higher learning and exposure to renewable energy technologies through their curriculum and camps increases the interest of students towards engineering.

This study focuses on the effects of prior exposure to Engineering on secondary school students to choose engineering and Technology as a career. Understanding the effect of these pre-college engineering activities may guide education stakeholders to provide the best environment for secondary school students and help them to be more successful in their engineering career.

1.2 Pre-college engineering activities

There is increased focus on STEM education globally which includes engineering as part of their education standards for both students and teachers, and the popularity of co-curricular and extracurricular engineering activities, young people have unprecedented ability to explore engineering. The activities both promote outcomes that benefit all students regardless of career aspirations such as increased math and science achievement and greater technological literacy and can also serve as an effective approach to recruiting, preparing, and retaining undergraduate engineering students.

Hammack, R.et al (2015) investigated on the effect of an Engineering Camp on Students' Perceptions of Engineering and Technology Research indicated that students tend to hold stereotypical views of engineers, which would hinder engineering as a career choice. The purpose of this study was to measure how participating in a week-long engineering summer camp affected middle school students' (N519) attitudes towards engineering and their conceptions of engineering and technology. Results indicated that participation in the programs had a positive impact on the students' understandings of what technology is and the work engineers do.

The growth of pre-college engineering programs means that incoming university engineering students will increasingly have had some exposure to engineering prior to matriculation into undergraduate engineering programs. However, the effects of pre-college engineering experiences on undergraduate engineering students are relatively unexplored. In some cases undergraduate engineering programs may take into account pre-college engineering experiences when placing students in first-year engineering sections or forming design teams, most undergraduate programs assume little to no formal exposure to engineering prior to matriculation.

Wilson, 2019, studied the impact robotics inspired science education and noted that many nations have shifted focus to science, technology, engineering, and mathematics (STEM) education and critical thinking has been a major focus of most countries. The study established that the incorporation of robotics related experiments in students' learning activities creates problem-solving skills in them, that robotics can be leveraged to simplify complex engineering problems and also that robotics inspires students to pursue higher education in STEM related courses including those which employs and deploys high end technology.

Utley et al., 2019 investigated the Effect of Project Lead the Way Participation on Retention in Engineering Degree. The researchers conducted a transcript analysis in order to compare the retention of entering engineering majors at a university based on whether or not they participated in Project Lead the Way (PLTW) in high school. They found out that the study offered little support regarding the impact of students' PLTW participation on engineering degree completion. Their findings suggest some support for the impact of PLTW participation

Cunningham et al., 2019 investigated the impact of engineering curriculum design principles on elementary students'. In the study schools were randomly assigned to either the treatment curriculum or to a comparison curriculum that addressed the same learning goals but did not include several critical components. Results showed that students who used the Engineering is Elementary treatment curriculum regardless of demographic characteristics outperformed students in the comparison group on outcome measures of both engineering and science content learning. The results show that curriculum design affects student-learning outcomes.

Most of the researchers do not follow up on the choice of the career made after exposure to the pre-college engineering activities.

2. Methodology

This research investigated the effects of pre-college exposure to engineering. Secondary school students were taken through a three day workshop where they were exposed to educational robots, Green energy, 3D design and printing. The activities were integrated in the STEM subjects they learn which include Physics, Mathematics, Chemistry and Computer studies. To evaluate the effects of these activities, a mixed-method approach was used to collect data quantitatively from an analysis of student responses on a Student Interests towards Engineering Career Questionnaire (SIECQ).

2.1 The Project

The project was initiated through the Royal Academy of Engineers grant titled "Engineering Skills Where they are Most Needed". Murang'a University of Technology (MUT) was the lead institution, while Ischoolclimate

Ltd was the partner. Through the grant, the University aims to promote engineering at degree level and TVET level through hands on exercises that will inspire high school students to choose engineering oriented programmes.

2.2 Participants

The participants of this study were Form 1 students from Murang'a County Kangema sub county. The secondary school students, Physics and Mathematics teachers, Murang'a university staff and Students in the School of Engineering students participated in this precollege program. There were 30 secondary school students who came to Murang'a County, Kangema Sub-county. The workshops were carried out on Saturdays.

2.3 Precollege Sessions for Secondary Schools (PSSS)

This PSSS program has two surveys: an opening survey on the first day and an end of program survey on the last day. Coupled with demographic information collected at the student recruitment stage, these two surveys provide rich information on participants' perceptions of Engineering and the Engineering career. Findings from the surveys can help education stakeholders to develop curriculum activities that match the preferences and learning styles of high school students, thus stimulating greater interest in STEM.

The precollege sessions included the following areas: green energy activities, education robotic activities, programming and 3D printing activities. The activities were integrated in the STEM subjects.

The sessions were designed to have the students introduced to the following main aspects:

2.3.1 General Introduction and career progression pathways

The first lesson was designed to introduce the high school students to engineering and the pathways for career progression as enshrined in the Kenya National Qualifications Framework Act 2014 (KNQA, 2014). Here the different pathways towards attaining a career in engineering were explained as portrayed in Figure 1A in the Appendix 1. Further to this, the engineering career was introduced as the key driver for the Industry 4.0 revolution, the ongoing automation of traditional manufacturing and industrial practices, using modern smart technology.

2.3.2 Solar Photovoltaic - Introduction to Green energy concepts

Introduction of green energy concepts was done using Solar photovoltaic panels. A 30 W panel was selected for the experimental part. The current levels of this panel and the voltage are within safe levels for use by the high school students. The students were exposed to solar energy generation, measurement of electricity and the use of various measuring tools. The students were also introduced to the process of sizing of the panels for a solar home system. The students then assembled a system as shown in Figure 1.

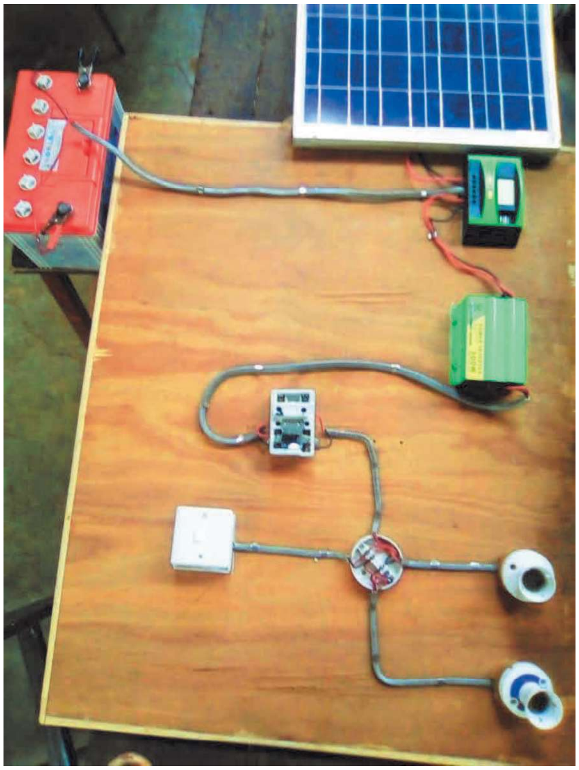

Figure 1. Solar PV system

2.3.3 3D printing - Introduction to advanced manufacturing

The students were exposed to computer aided design and 3D printing. The project selected a locally manufactured 3D printer based on Arduino mega as the main controller. The local manufacturer trained our staff and our students and guided them very well on all the functions of the 3D printer.

2.3.4 Arduino - Introduction to programming and automation

Arduino is selected for this project, being an open source microcontroller, because it can be easily programmed, erased and reprogrammed at any instant of time. The Arduino platform was designed to provide an inexpensive and easy way for hobbyists, students and professionals to create devices that interact with their environment using sensors and actuators.

2.3.5 Educational Robot activities- Introduction to machine to machine communication

Using the STEM robots, learners were taken through various robots and their applications. Students were exposed to the education of robots and their application in learning concepts in Mathematics (Geometry, calculation of speed among others), Physics (Forces, Motion, Conversion of energy, Electronics), Computer application (Arduino microcontroller, programming). The robotics they engaged it can be categorized to the following activities:

a. Line follower robot

This robot uses three infrared based tracking sensors. The sensors send information about the robot's present location to the Arduino microcontroller. The microcontroller on the other hand instructs the motors to move the robot to the required location. The wiring diagram is illustrated in Figure 2.

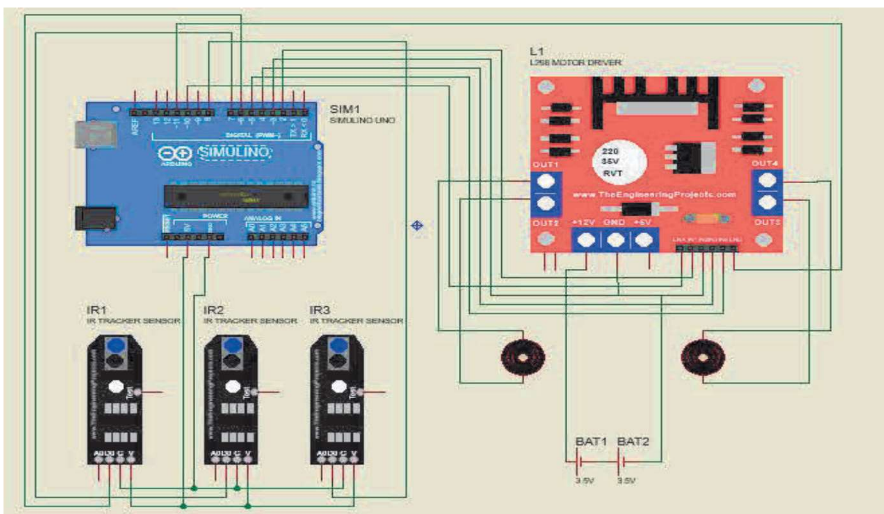

Figure 2: Line follower wiring diagram

b. Obstacle avoiding robot

This robot uses an ultrasonic based sensor. The sensor has four pins. Two for power (GND and VCC) and two for signals. (Echo and trigger). The wiring diagram is illustrated in Figure 3.

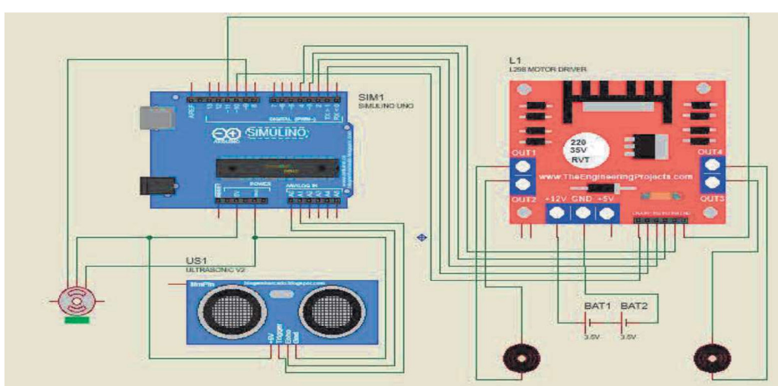

Figure 3: Wiring diagram for an obstacle sensor robot.

c. Robot arm

This robot uses four servo motors to pick a load at a particular point and drop it at another point. The wiring diagram is illustrated in Figure 4.

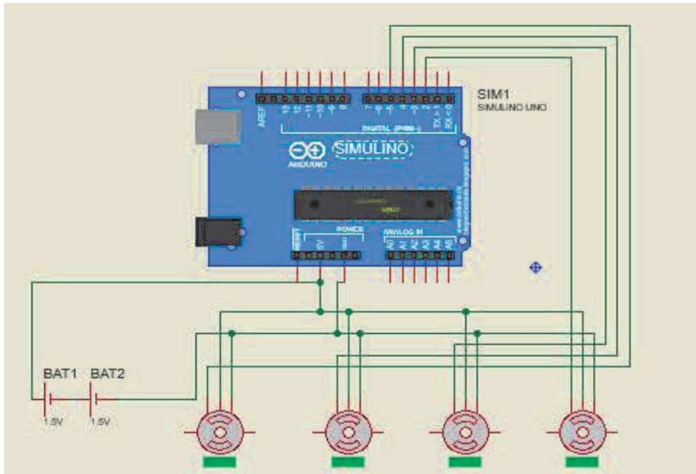

Figure 4: Wiring diagram for robot arm

2.4 Data description

The primary data sources for this study are the opening and closing surveys conducted at the beginning and the end of the programme. Survey instruments were developed based on educational robots and robotic arms designed and were tested 6 months before the data used in this article were collected. In two surveys, students were asked to self-report their academic backgrounds, evaluate their STEM knowledge improvements, assess program educational instruments, and provide written comments. A total of 30 high school students participated in this PSSS program.

3. Results and Discussion

3.1 Solar photovoltaic

After introducing the students to green energy concepts using solar photovoltaic panels, they were able to perform various measurements.

The students also managed perform some sizing procedure of panels for solar home systems.

3.2 3D printing

The student were able to do some basic 3D shapes. They were able to design and print parts of a robotic arm used in this research. Figure 5 and 6 illustrate the 3D printed arm as used both by a stationery arm, Figure 5, and mounted in a robot car, Figure 6.

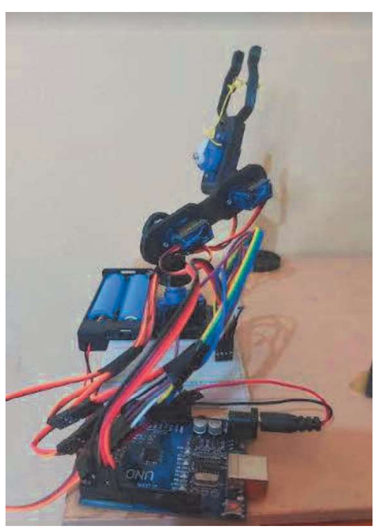

Figure 5: Robotic arm

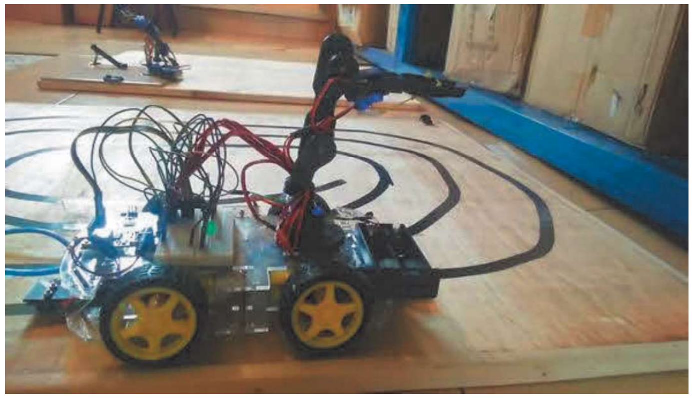

Figure 6: Robot Truck

3.3 Programming and robotics

The students did some simple programmes successfully. Some of the programmes written include;

- Programming of an LED
- Programming servomotor
- Programming a dc motor

As a result they were able to programme the robotic arm to move in different directions and angles. They were also able to programme a robotic car to move generally, avoid an obstacle and follow a line.

3.4 Educational robotic activities

Using the STEM robots designed, learners carried out various activities. In Mathematics, they were able to do some geometry, determination of circumference, revolutions of wheels of the robotic car, measurement of distance and speed. In Physics the students worked on forces, Motion, Conversion of energy, and basic Electronics.

3.5 The General perception of the pre-college programme

Overall, this PSSS program was well received and considered useful by program participants. Of the participants, 80% (24 out of 30) rated their satisfaction level with their overall experience as "highly satisfied," 20% (6 out of 30) responded that they were "satisfied," none were "partially satisfied," and none were "not satisfied." When asked whether they agreed that this program gave them better understanding of STEM subjects and what Engineering Career entails, 70% (21 out of 30) responded that they "strongly agree," 20% (6 out of 30) said they "agree," 3 students (10 %) chose "partially agree," and none of the participants selected "not agree."

The above is also verified from the quizzes we gave the students, and as indicated, as we moved from Day 1 to Day 3, Figure 7 and 8, the awareness level increased.

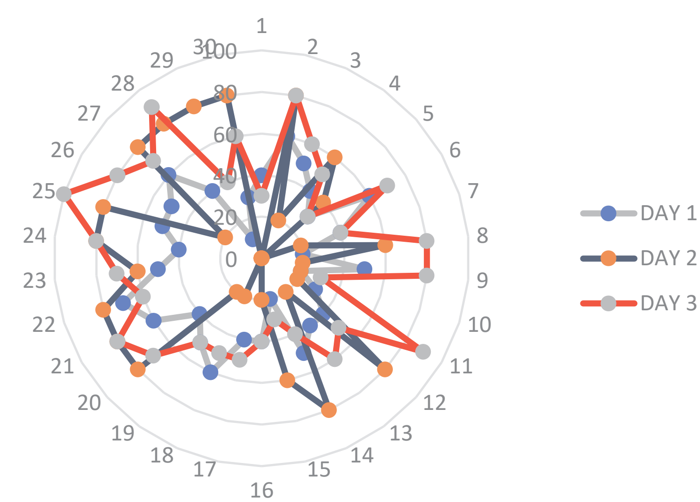

Figure 7: Solar Photovoltaic Awareness Chart

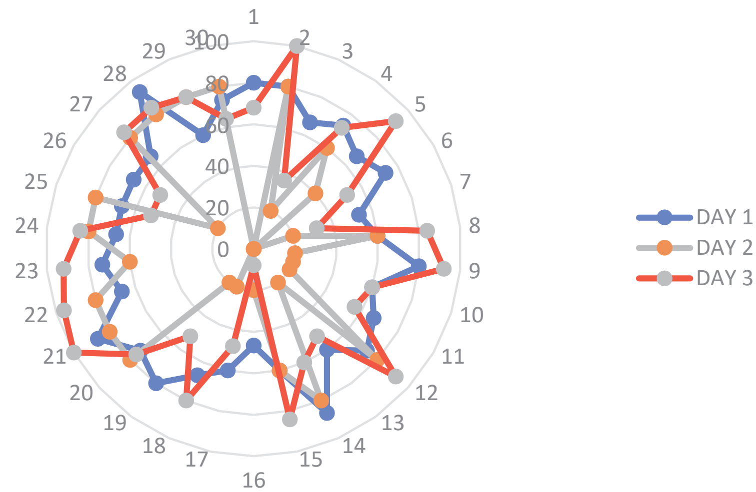

Figure 8: Robotics Awareness Chart

4. Conclusion

The Pre-college Sessions for Secondary Schools (PSSS) program presented in this article takes an integrated approach to raising participants' awareness of engineering career opportunities. The host university Murang'a University of Technology, Royal Academy of Engineering and Ischool climate made significant contributions to the program development and implementation. This integrated approach is effective at convincing students that a STEM college education is feasible and rewarding by providing them with diverse perspectives. Many prior studies have examined the impacts of pre-college outreach programs, but a quantitative approach to measuring the effectiveness of such programs for participants with diverse backgrounds and different program experiences is lacking. This article fills in this knowledge gap by examining multiple factors affecting a PSSS programmes effectiveness at promoting engineering career choice. The students acquired the following gains:

a) A fuller, lasting grasp of science, technology, engineering and mathematical concepts
b) The ability to think critically to solve problems
c) Resilience which builds confidence.
d) Collaboration skills through distributed tasks
e) The ability to communicate clearly in speech, writing and drawing

The unique features of the MUT pre-college course are:

1. General introduction of what engineering entails, who can do engineering and the career paths as established under KNQ framework.
2. Introduction to renewable energy – Solar Photovoltaic Systems – in easy to understand notes and experiments.
3. Introduction to the building blocks of robots: Arduino programming, sensors, motors, 3D drawing and 3D printing.
4. Hands-on experience on each component in the building process and integrating each lesson to topics in Mathematics, Physics, Chemistry, Geography etc.
5. Using a locally designed 3D printer (Arduino mega) to print robot parts leading to cost reduction.

5. Acknowledgement

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References

1. R. Connaughton and M. Modlin (2009), "A modular and extendable robotics platform for education," in Frontiers in Education Conference, 2009. FIE '09. 39th IEEE, 2009, pp. 1–4.
2. Utley, J., Ivey, T., Weaver, J., & Self, M. J. (2019). Effect of Project Lead the Way Participation on Retention in Engineering Degree Programs. Journal of Pre-College Engineering Education Research (J-PEER), 9(2), Article 3. https://doi.org/10.7771/2157-9288.1209
3. Salzman, N. (2014) A phenomenographic study of students' experiences with transition from pre-college engineering programs to first-year engineering. *Purdue University*

4. Salzman N. and Strobel, J.(2010) "Motivations and Benefits for College Students Serving as Mentors in a High School Robotics Competition," in Proceedings of the 2010 American Society for Engineering Education Annual Conference & Exposition, Vancouver, BC.
5. Hammack, R., Ivey, T. A., Utley, J., & High, K. A. (2015). Effect of an Engineering Camp on Students' Perceptions of Engineering and Technology. Journal of Pre-College Engineering Education Research (J-PEER), 5(2), Article 2. https://doi.org/10.7771/2157-9288.1102
6. Todd, D. F., Thomas, J. S., Michael, A. D. (2011) Pre-Collegiate Factors Influencing the Self-Efficacy of Engineering Students. *Journal of Engineering Education*, 100(3), *604-623* https://doi.org/10.1002/j.2168-9830.2011.tb00028.x
7. Salzman, N., & Ohland, M. W., & Cardella, M. E. (2016, June), *Measuring the Effects of Pre-College Engineering, Year 3* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.25703
8. Cunningham, C. M., Lachapelle, C. P., Brennan, R. T., Kelly, G. J., Tunis, C. S. A., & Gentry, C. A. (2020). The impact of engineering curriculum design principles on elementary students' engineering and science learning. Journal of Research in Science Teaching, 57(3), 423–453.
9. Wilson, Michael; Okraku-Yirenkyi, Yaw 2019. Impact of the Robotics inspired Science Education (RiSE) Program on Education in Ghana Journal of Engineering and Economic Development; Beverly Hills Vol. 5, Iss. 2: 11-22.
10. Maina, M. W. (2020). Influence of Personal Factors on Change of Programme of Study among First-Year Undergraduate Students in Kenyan Universities. *Journal of Education*, *3*(1), 22 - 40. Retrieved from http://stratfordjournals.org/journals/index.php/journal-of-education/article/view/493
11. Martinez Ortiz, Araceli; Rodriguez Amaya, Laura; Kawaguchi Warshauer, Hiroko; Garcia Torres, Sara; Scanlon, Erin; and Pruett, Michelle. (2018). They Choose to Attend Academic Summer Camps? A Mixed Methods Study Exploring the Impact of a NASA Academic Summer Pre-Engineering Camp On Middle School Students in a Latino Community. *Journal of Pre-College Engineering Education Research, 8*(2), pp. 22-30.
12. Heilbronner NN (2011) Stepping onto the STEM pathway. J Educ Gifted 34(6):876–899
13. Bybee RW (2010) Advancing STEM education: a 2020 vision.Technol Eng Teach, 70(6):30–35. Retrieved from http://www.iteaconnect.org Chawla L, Cushing DF
14. Maltese AV, Tai RH (2011) Pipeline persistence: examining the association of educational experiences with earned degrees in STEM among U.S. students. Sci Educ 95(5):877–907
15. Sadler PM, Sonnert G, Hazari Z, Tai R (2012) Stability and volatility of STEM career interest in high school: a gender study. Sci Educ 96(3):411–427
16. Junior,L. A. Neto, O. T. Hernandez, M. F. Martins, P. S. Roger, L. L. and Guerra,F. A. (2013) A Low-Cost and Simple Arduino-Based Educational Robotics Kit. *Journal of Selected Areas in Robotics and Control (JSRC)*
17. Adebola, S. O. Odejobi O. A. and Koya, O. A.(2013) Design and implementation of a locally-sourced robotic arm, *Africon*, Pointe-Aux-Piments, 2013, pp. 1-4, doi: 10.1109/AFRCON.2013.6757721
18. Juliana Machuve* and Edward Mkenda, Promoting STEM Education Through Sustainable Manufacturing: Case Study of Photovoltaic Toys, 16th Global Conference on Sustainable Manufacturing - Sustainable Manufacturing for Global Circular Economy
19. Recayi (Reg) Pecen , Jill L. Humston, Faruk Yildiz, Promoting STEM to Young Students by Renewable Energy Applications, Journal of STEM Education Volume 13 • Issue 3 May-June 2012
20. Kenya National Qualifications Act 2014

Appendix 1 Career Progression Pathways

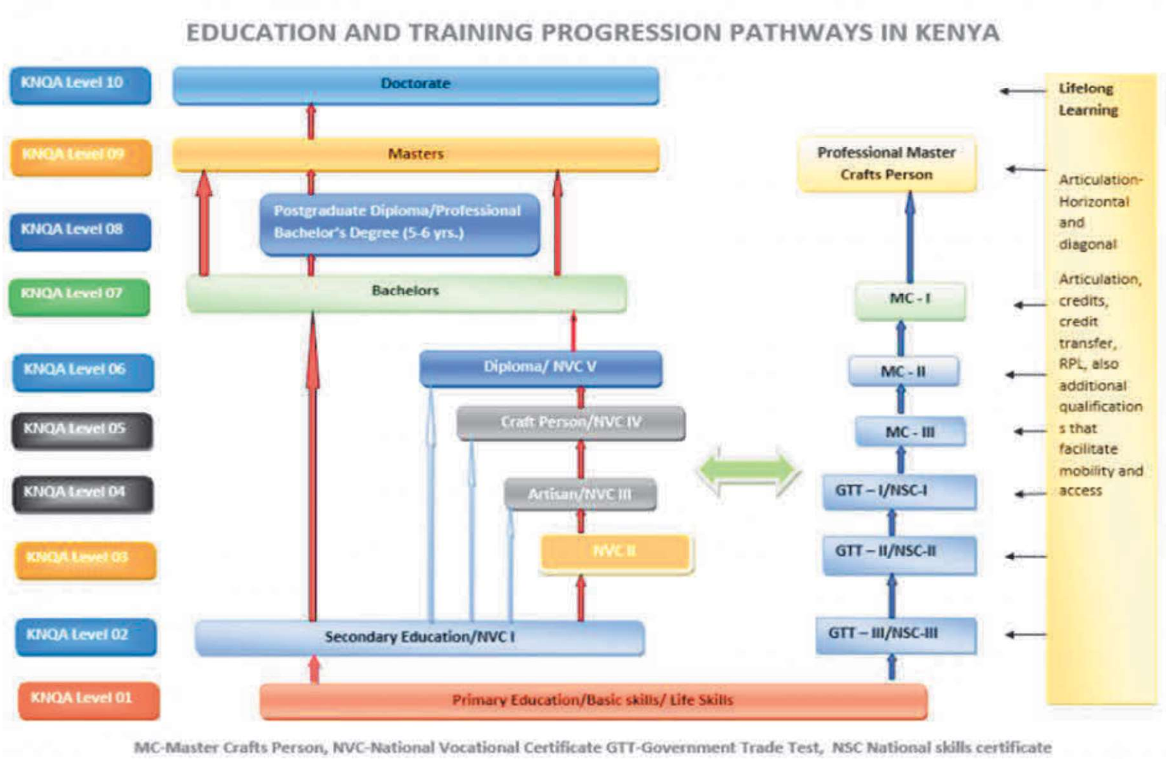

Figure 1A Career Pathways, retrieved from https://www.knqa.go.ke/