Initiating a Pipeline for the Computer Industry

Using Scratch and LEGO Robotics

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***Abstract*— This paper reports on a pilot project of limited scopeto create a pipeline for the computer programming industry. It comes at a time when the demand for software programmers exceeds the dwindling supply of competent learners with suitable skills. This growing skills gap requires a bold intervention to turn this situation around. Preliminary results from a user questionnaire indicate a positive reaction to learners being exposed to programming using Scratch Software as a prelude to the introduction of Robotics using LEGO NXT units. The objective of such an intervention is to provide individuals with a hands-on experience of programming to convince them to select Information Technology as a subject in Grades 10-12 in the hope that they will one day choose a career in programming.**

Keywords—robotics; pseudo coding; career guidance; Scratch Software, Portable Apps

I. INTRODUCTION

Of the many diverse and fascinating challenges we face today, the most intense and important is how to understand and shape the new technology revolution, which entails nothing less than a transformation of humankind. We are at the beginning of a revolution that is fundamentally changing the way we live, work, and relate to one another[1]. The world is on the brink of the fourth industrial revolution where connectedness will play a major role in formulating and managing the lives of everyone and almost everything. 3D printing, artificial intelligence (AI), robotics, autonomous cars, etc., will require a new breed of individuals who are both familiar with and able to maximize the potential of the convergence of these and other technologies. This will require fundamental educational reforms in both policies and pedagogies which are needed to inculcate 21st century skills into future employees. Failure to do so will lead to the vast majority of potentially employable South Africa citizens being excluded from participating in and drawing benefit from the next industrial revolution. In simple terms, the effects of the digital divide will be further entrenched in society.

By 2020, there will be more than a million unfilled programming jobs in the United States, representing a $500 billion boost to the national economy, according to the Bay Area Council Economic Institute. America's lack of computer science graduates has forced many technology companies to look overseas for computer programmers. To prepare students to compete in a today's globalized, knowledge-based economy, national educators such as Education Secretary Arne Duncan and technology leaders such as Facebook's Mark Zuckerberg and Microsoft's Bill Gates have urged schools to begin teaching computer programming at an early age [2].

The shortage of tech talent in Africa is closely linked to the continent's infrastructure, or lack thereof. As Africa's most advanced economy, South Africa already has a solid foundation in industries such as financial technology, banking services and industrial-scale manufacturing, so the country should be best placed on the continent to train the next generation of programmers for the digital epoch. Yet, despite being a relatively new industry, South Africa's tech environment has not escaped the country's historical handicaps [3].

The (South African) department of education announced that 75.8% of matriculants passed their 2014 National Senior Certificate (NSC) exams – but in real terms, the picture is far less rosy. Of 1,252,071 pupils who entered into the South African public schooling system in Grade 1 in 2003 only 688,660 wrote their Grade 12 exams - approximately 41.7% [4].

BusinessTech [5] report that the top reasons why kids aged 7 to 18 drop out or do not attend school are:

- No money for school fees – 23.5%
- Cannot perform academically at school – 17.7%
- Have too many family commitments – 11.6%
- Suffer from illness and/or disability – 10.4%
- See education as being useless – 9.4%
- Completed education to the level they wanted – 7.8%
- Working at home – 6.7%
- Struggle getting to school – 0.5%
- 12.3% of individuals cited other, unspecified reasons.

This accounts for approximately 563,411 individuals of the class of 2014 who did not possess a Grade 12 qualification, who did not potentially reach their full potential and therefore are less likely to benefit from and contribute to a future economy. It may be argued that this cohort is very likely to contain a large number of individuals who could have gone on to successfully complete a tertiary education and are now part of yet another lost generation relegated to a life of

unemployment or low economic returns through no fault of their own.

In order for an individual to enroll for a Bachelor Degree they require 50% or more in 4 subjects, 30% remaining subjects, must have more than 40% in home language; and cannot fail (less than 30%) any subjects. The entrance requirement for a BSc in Computer Science at the different universities is defined by the individual institutions ranging from Mathematics levels 4-5 and home language level 3-4. Passes in Mathematical Literacy are certainly not considered no matter what level as this school subject does not provide the learners with adequate preparation for the demand of computer programming

Origins of the project

The e-Skills Institute (e-SI) was established in 2009 as a unit within the national Department of Communications (DOC). This was in response to a call by government leaders for a national initiative to develop the human resource skills base required to compete effectively in the international knowledge and information economy. The broad mandate was to increase the ability of all South African citizens to utilize technology for global competitiveness and prosperity, in support of National Development Plans, the Medium Term Strategic Framework, Millenium Development Goals, etc. CoLabs (originally known as hubs) were established through memoranda of agreements with universities in various provinces to carry out the mandate in a multi-stakeholder environment at a provincial and local level. In the Eastern Cape, the CoLab was established at Walter Sisulu University, a comprehensive, developmental university with an extensive footprint in urban, peri-urban, and rural communities [6].

In 2013, work began on merging the e-Skills Institute with the existing state-owned entity National Electronic Media Institute of South Africa (NEMISA – www.nemisa.co.za) into a new national entity that will be known as the iKamva National e-Skills Institute (iNeSI - www.inesi.org.za). The merging entity is currently funded by the Department of Telecommunications and Postal Services (DTPS).

The e-Skills CoLab based at Walter Sisulu University (WSU) engages in various projects with partners to achieve its objectives related to developing e-skills, research and innovation within a rural development context.

The Colab in partnership with the Nelson Mandela Metropolitan University (NMMU) initiated a project in the July holidays of 2015 to expose learners in Grades 10-12 to the world of programming. The purpose of this exercise was to influence learner's decisions to consider taking Information Technology as a school subject to Grade 12. In essence the exercise was to initiate a pipeline for the computer programming industry. The Young Engineers and Scientists of Africa (YESA – www.yesa.org.za) facilitated the training for the first group of learners from five previously disadvantaged different schools in the Port Elizabeth region.

As a result of the successful completion of the pilot project the CoLab funded a training session in the March 2016 holidays at the Walter Sisulu University (WSU) in East London in partnership with the East London district of the Eastern Cape Department of Basic Education. The LEGO NXT MindStorm units were donated to YESA by Care for Education.

The training comprised three basic points of departure which focused on providing a broad hands-on exposure to computer programming.

The first element involved an introduction to Portable Software which is designed for PCs and runs from removable storage, such as a USB flash drive. Program files are not installed on the hard disk, no configuration data is stored on a local device, and no entries need to be made in the Windows Registry. When the device containing the portable software is removed from the computer, no trace of it is left there. Carrying apps and data on a flash drive makes it possible to use just about any public or private computer without leaving a data trail on the local device or in the cloud [7].

Though the range of software titles is limited it does provide for essential tasks. A preloaded 8 Gig Flash drive provided sufficient space for a range of educational titles to be loaded including LibreOffice suite and software for image editing, mind mapping, sound editing, etc. The power of this type of software resides in the ability of the individuals to be trained on a particular program, save the training files and support material on the Flash drive and then to continue with the material when they are at home or have access to virtually any windows based PC. Learning becomes portable breaking the concept of learning being confined to the classroom or in a computer laboratory.

The second element served as an exposure to pseudo coding using Scratch which is also available as a Portable App. Scratch is a visual programming language that provides a rich learning environment for people of all ages. It allows you to create interactive, media-rich projects, including animated stories, book reports, science projects, games, and simulations. Scratch's visual programming environment enables you to explore areas of knowledge that would otherwise be inaccessible. It provides a full set of multimedia tools you can use to create wonderful applications, and you can do so more easily than with other programming languages [8].

The decision to use Scratch was based on the fact that it is Open Source software, and that it :-

- makes the ideas of computer science accessible
- makes learning intrinsically motivating
- fosters the pursuit of knowledge
- encourages hands-on, self-directed learning through exploration and discovery, and
- the barriers to entry are very low, while the ceiling is limited only by the user's creativity and imagination.

This pseudo-coding environment provides a platform for new users to be exposed to the world of programming by generating rapid results, albeit confined to the output of the computer screen.

During the original training at NMMU an element of collaborative programming was introduced using TeamViewer software. This was well received despite the complications of requiring access to the internet each time a connection was

made. This was circumvented with the introduction of TightVNC. This software is a free remote control software package which allows a user to view the desktop of a remote machine and control it with a local mouse and keyboard.

Figure 1. A group of learners assembling and programming the LEGO Mindstorm Robot to complete a challenge.

Learners worked in pairs where the one member had to load the TightVNC Server version from their flash drive. They were shown how to access the IP address of the TightVNC Server which was shared with their partner who then connected using TightVNC Desktop and the password from their own 'remote' PC. The instructions were that teams had to collaborate 'over a distance' while developing a mutual application. The results were remarkable providing a realistic experience in a stimulating and managed learning environment.

The third element delved deeper into programming using LEGO Mindstorm technologies to allow individuals the opportunities to manipulate Robotics in the real world outside the confines of the computer screen. For the purposes of this project the LEGO NXT units were used which is older technology to the more advanced EV3 units.

Watching robots may be incredible fun, but creating robots is even more exciting. For some time, the considerable expense and complexity of robotics prevented many people from pursuing it as a hobby, but technological advancements has largely swept away these barriers. The LEGO MINDSTORMS NXT set is a robotics toolset designed by the LEGO Group that empowers users to create functional robots entirely out of LEGO pieces. Generally speaking, an NXT project involves three tasks, 1) building a robot 2) programming a robot and then 3) activating the robot [9].

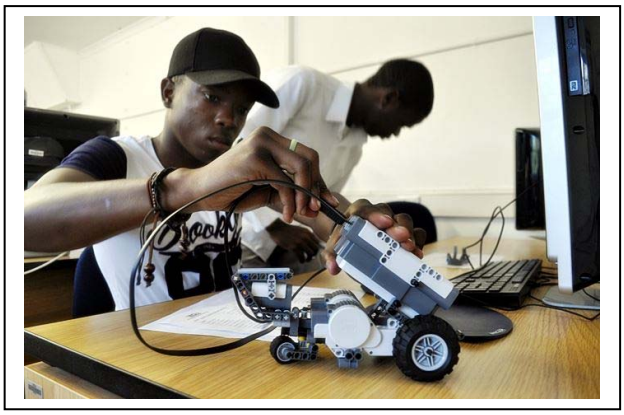

Figure 2. Learners downloading the LEGO program to the NXT Robot which can then be activated to execute the program.

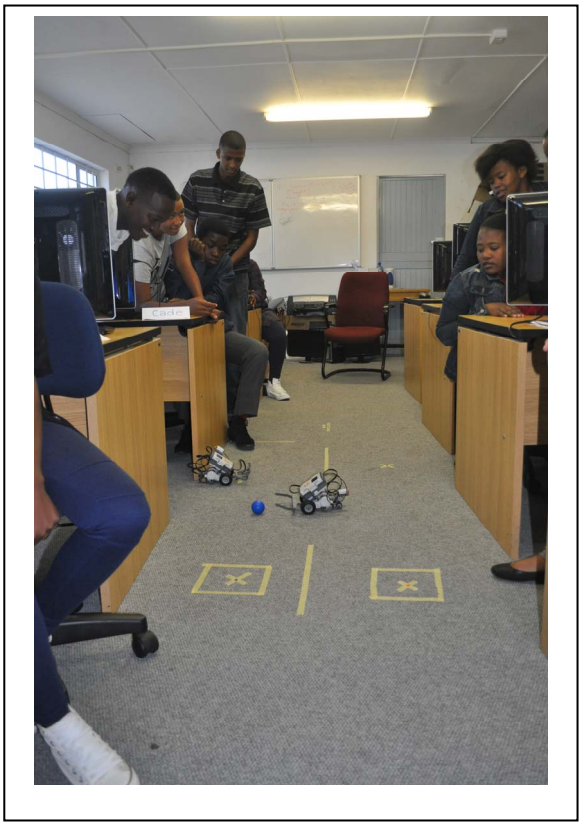

Figure 3. Teams collaborating to locate the ball, activate their partner Robot which then has to move the ball to the end of the course to complete the task.

The use of LEGO MINDSTORM NXT equipment allowed for the conceptual transition outside the confines of the virtual reality of the computer screen into the space of the three dimensional world. The NXT software was used as a continuation of pseudo-coding to reinforce the development of logic while retaining a strong element of fun learning. This was reinforced by an element of gaming to navigate the LEGO Robot around an imaginary course on the ground. This included starting the Robot from a fixed point, emerging from a 'garage', navigating round a number of objects, returning to the 'garage' and reversing in to complete the challenge. The final challenge involved two teams collaborating to firstly, find and move a ball to a predefined point and then activate their partner's Robot to find and move the same ball to the end of the course.

The pedagogy used in this course was based largely on a constructivist approach rather than a rote learning behaviorist approach. Constructivism implies that the learning process of knowledge is also the construction process of knowledge; students are the main body of learning activity and they construct knowledge on their own initiatives; teachers are the helpers and the drivers for students constructing knowledge [10]. The participants were first given sufficient information to get started and complete basic routines. On completion further instructions were provided in small chunks as the challenges became more complex where many were encouraged to go beyond this by exploring on their own while waiting for the group to complete the challenges and the next set of instructions.

II. The Research Sample

No research information was gathered from the training camp conducted at NMMU in July 2015 while permission for the March 2016 training was granted. The following information reflects the work done at WSU consisting of a group of 14 learners in Grades 11 (10 learners) and 12 (4 learners). This included 8 males and 6 females from three schools classified as previously disadvantaged, which offered Computer Application Technology (CAT) as a Grade 10-12 examination subject. Only two of the schools offered Information Technology (IT) as a subject in Grades 10-12. Learners were asked to complete a Pre- and Post-Training Questionnaire which provided the data for the following analysis.

The Pretest indicated that 50% of the participants were *interested in Studying Programming* while the remaining 50% were *uncertain*. The Posttest indicated an increase to 64.3% for *Yes to Studying Programming* with 100% reporting that the training *did help them to understand more about programming*.

Career guidance plays a critical role in the choice of careers where the group reported on their *possible career fields* as Medical (8), Computers (6), Engineering (5) and Other (4). The *source of career information* question included:-

- Your teachers 8 (57.1%)
- Experts visiting the school (0%)
- Visits by your school to career expos, companies, universities etc. 3 (21.4%)
- Your own online research 4 (28.6%)
- Your own interactions with other people, e.g. friends, family (0%)

A Posttest question on the *best way to provide ICT Career Guidance* returned a very positive response to the training session:-

- Workshops like this 14 (100%)
- Lectures by teachers 6 (42.9%)
- Multimedia presentations, videos 7 (50%)
- Interactions with professionals working in ICT 7 (50%)
- Online chat groups 2 (14.3%)
- Written brochures 0 (0%)
- Other... 0 (0%)

When best to initiate hands-on training sessions the responses included:-

- Before Grade 10 (42.9%)
- Grade 10 (35.7%)
- Grade 11 (14.3%)
- Grade 12 (7.1%)

When asked *what they liked about the training* the majority included Computers and Programming 7 (50%) as well the whole course 6 (42.9%). One respondent included the concept of problem solving. This sentiment is also reflected in the question of *what they did not like about the training* where the majority indicated they enjoyed everything 9 (64.3%). Other responses included:-

- Joining the different parts 1 (7.1%)
- It was so exhausting 1 (7.1%)
- There are less schools than I expected 1 (7.1%)
- When the robot was not working 1 (7.1%)

When asked to *suggest improvements* 1 (7.1%) raised the issue of more schools being involved in the program and more time 2 (14.2%) allocated to the training. The remainder 11 (78.7%) indicated that they were happy and did not make any suggestions for improvements.

III. Interpretation of Results

Education in South African schools is trying to address the huge backlog of ensuring that there are adequate resources for all learners in all schools. The UNESCO Institute for Statistics [11] reports that in 2015 95% of Primary and 97% of Secondary schools had electricity which is relatively higher than most other African countries compared. The Pupil to Computer Ratio (PCR) reflected 90 for Primary schools and 54 for Combined Secondary Schools on average.

Establishing computer laboratories in schools, however, is typically perceived to be a significant upgrade from classrooms with one desktop computer "at the back of the room". Computer laboratories offer the promise of a learning environment with one device per child, structured and controlled by a well-trained and knowledgeable teacher. More recently, however, educational technologists argue that computer laboratories have become obsolete and provide a disservice to education. For example, given the multitude of both school- and personally-owned devices (including laptops, tablets and mobile devices), detractors of laboratories argue they imply a separation between computing as a subject and the general curriculum. Others meanwhile argue that the inclusion of a smaller number of computers and other devices in classrooms helps to build stronger links between ICT and curriculum, facilitating the development of 'higher-order' skills [12].

Despite having access to electricity there is a potential move away from computer laboratories which are the primary means of instructions for subjects like CAT and IT. If this is the case it will have a serious effect on the quality and quantity of programmers emerging from the education system that can sustain a meaningful programming pipeline. This is also compounded by the high PCRs in the primary schools where the foundations are laid, implying that many learners who may well have been influenced to take up IT as a subject are simply not having any exposure in the primary schools.

IT as a subject requires ample time during and after school hours from adequately qualified and motivated teachers. However, with high PCRs many schools are caught in a catch 22 situation of trying to provide more learners with access to these scarce resources. Often the computer labs are blocked out for the use of a small number of CAT and IT classes intimating that the PCR does not reflect the usage of computer by all learners in a particular school. This was partially alluded to by 3 responses from the learners who reported a lack of funding and adequately trained staff for the subject of IT.

The South African education system requires that learners select 7 subjects after Grade 9 as they enter the Further Education and Training (FET) sector. The majority of responses indicated that exposure to IT should be before Grade 10 but one has to balance this with the availability of resources including trained staff. All learners agreed that the training offered in this course was certainly the way to go and that they all responded positively.

From this group of learners the message is very clear. Hands-on training can reinforce the decision to take IT as a subject and potential to migrate into a career in computers and more specifically programming. Assuming that the quality of the information from teachers is correct and up to date this can have a positive influence on the choice of subjects which should be supplemented by hands-on experiences where possible.

Information Technology as a subject in the South African Curriculum is defined as the study of the various interrelated physical and non-physical technologies used for the capturing of data, the processing of data into useful information and the management, presentation and dissemination of data. Information Technology studies the activities that deal with the solution of problems through logical and computational thinking. It includes the physical and non-physical components for the electronic transmission, access, and manipulation of data and information [13].

The course covered by this project can be mapped to most of the sections of the IT Curriculum as indicated in Table 1.

TABLE I. Areas of the Information Curriculum that are covered through this intervention

Information Technology Curriculum Areas	
Topic Area	***Sub-Topics***
Solution Development	• Algorithms and Problem Solving (√) • Introduction to Solution Development (√) • Application Development (√) • Software Engineering Principles (√)
Communication Technologies	• Networks (√) • E-communication (√)
Systems Technologies	• Introduction to Computers (√) • Hardware (√) • Software (√) • Computer Management (√)
Internet Technologies	• Internet (√) • World Wide Web • Internet Services

Information Technology Curriculum Areas	
Topic Area	***Sub-Topics***
Data and Information Management	• Data Representation • Database Management • Database Design
Social Implications	• Legal Issues • Ethical Issues • Social Issues • Environmental Issues • Health Issues • Computers and Society (√)

IV. CONCLUSIONS AND RECOMMENDATIONS

Today, the stability of the American economy faces an imminent and dire threat. The skills gap is hindering the growth and competitiveness of our companies, and shortcomings in our education and workforce development systems continue to widen the gap. Our country finds itself increasingly in an unsustainable position, with a growing number of students who are struggling to manage their transition to employment and businesses that are desperate for new workers [14].

The Media, Information and Communication Technologies Sector Education Training Authority (MICT Seta) for South Africa reports a decline of over 10 000 employees in 5 years in this sector from 76 452 (2009) to 66489 (2013) [15]. The same report indicates a shortage of 1 306 scarce skills in the Software developer sector alone over this same period. This comes at a time when 41 026 learners sat the CAT examination in 2015 while only 4 326 sat the IT examination with 4 028 (93.1%) having passed with 30% or more [16]. Mathematics only saw a 49.1% pass rate with Physical Science achieving a mere 58.6%. There is no information to trace these students further but this talent pool is diminishing rapidly where not all learners taking IT will naturally migrate into programming as a preferred qualification at tertiary level. This is further compounded by the fact that a far greater number of learners are opting for Mathematics Literacy as opposed to full Mathematics as reflected in Table II.

The demand for such scarce skills as computer skills in general and computer programming in particular, is exceeding the supply which will have dire consequences for this industry as South Africa prepares to enter the next industrial revolution, also referred to as the internet of things.

It is one thing to refine the curriculum to address these changes but this will require a bold implementation plan that addresses not just the learning side of things but also the application of knowledge in the real world.

Programs such as this pilot study have the potential to provide individuals with a realistic view of what it means to be a computer programmer where logic, lateral thinking, problem solving, team work and other skills can be demonstrated in a managed and fun environment. It is here that learners can confirm either their desire to pursue careers in programming or realise that it is not for them.

TABLE II. A COMPARISON OF MATHEMATICS VS MATHEMATICS LITERACY

Subject	2012	2015	% Increase
Mathematics Literacy	291 341	388 845	33.5%
Mathematics	225 874	263 903	16.8%

The program goes well beyond the limitations of a teacher or career guidance professional providing the basic facts to the heart of the process of walking in the shoes of a programmer for a few days. Using Open Source software especially as Portable Apps allows all participants to continue exploring their talents beyond the confines of the training venue.

The recommendation is that such a pilot project be expanded to:-

- Include more training opportunities to gather in support of the development of a pipeline for the programming industry
- Reach out to smaller towns with mobile units
- Develop and source further digital training materials
- Distribute Flash Drives with Portable Apps and associated training materials
- Be added to Science Centres in each province

This multi-skill cross-curricular program has the potential to add value in creating a more viable pipeline for the computer programming industry by providing a realistic hands-on career guidance experience. In time this can be expanded to encourage more learners to enter such programs as the First LEGO League and the World Robotics Olympiad as a means of identifying and tagging individuals with specific talents for the industry. The human capital is evident from such initiatives and every effort must be made to identify it from as young an age possible.

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