National Technical Association · Sudanese Knowledge Society · JEF Inc · NCCBPE

Proceedings of

8th International Conference on Appropriate Technology
Songhaï Center,
Porto-Novo, Benin
November 22-25, 2018

Endogenous Knowledge, Appropriate Technology and Innovation:
Linking the Past and the Future

Gibela-TUT Partnership

Rail Manufacturing and Skills Development

International Network on Appropriate Technology (INAT)
www.appropriatetech.net

SECTION: KNOWLEDGE AND TECHNOLOGY TRANSFER

Edited by

Gada Kadoda

International Planning Committee

***L. Abdalla,* Sudan**
***M. Awad,* Sudan**
***J. Bemley,* USA**
***P. Bofah,* USA**
***H. Carwell,* USA**
***M. Castro,* Puerto Rico**
***A. Dafalla,* Qatar**
***T. Dalgety,* Guyana**
***C. M. Fadel,* Senegal**
***J. Fortunak,* USA**
***J. Gwamuri,* Zimbabwe**
***G. Kadoda,* Sudan**
***J. Kiplagat,* Kenya**
***K. Madzima,* RSA**
***L. Mahjoub,* Sudan**
***K. Mpofu,* RSA**
***M. Muchie,* RSA**
***A. B. Nyoni,* Zimbabwe**
***K. Ngige,* Kenya**
***K. Osama,* Nigeria**
***M. Poe,* USA**
***F. Salaheldin,* Sudan**
***W. Seed Ahmed,* Sudan**
***D. Soumonni,* RSA**
***Brian Stephenson*, USA**
***V. Sivasubramanian,* India**
***J. Tharakan,* USA**
***J. Thomas,* India**
***J. Trimble,* RSA**
***A. Yousif,* KSA**
***C. Verharen,* USA**

Local Organizing Committee

A. Segla

TABLE OF CONTENTS

Knowledge and Technology Transfer Oral Presentation Papers

Knowledge and Technology Transfer Poster Presentation Papers and Abstracts

Manufacturing of durable furniture for rural households in South Africa using glass reinforced polymers

Nyangani Mtimkulu (B-Tech)
Tshwane University of Technology; Pretoria, South Africa
MtimkuluNS@tut.ac.za
Tamba Jamiru (PhD)
Tshwane University of Technology; Pretoria, South Africa
JamiruT@tut.ac.za
Lodewyk Beneke (PhD)
Tshwane University of Technology; Pretoria, South Africa
BenekeLW@tut.ac.za
Khumbulani Mpofu (PhD)
Tshwane University of Technology; Pretoria, South Africa
MpofuK@tut.ac.za
Raisibe Pheme (B-Tech)
Tshwane University of Technology; Pretoria, South Africa
PhemeRR@tut.ac.za

Abstract

A number of South African rural households experience problems with roof leakage and flooding during rainy seasons and it results in the damage to their furniture. In most cases, the furniture is manufactured out of wood and these materials are not designed to withstand exposure of water for prolonged duration of time, their exposure limit is especially low that they can withstand enough water for cleaning. This paper aims to provide ordinary South Africans with durable, water resistant and aesthetically appealing furniture by providing the technical shrewdness for manufacturing the furniture using glass reinforced polymer (GRP) material. The employment of the recommendations from this paper will not only provide a solution to the green environment by saving the trees but also provide the personalized shapes and designs at economical costs, quicker as well as the creation of job opportunities for communities thus adding to the country's gross domestic product.

Keywords: GRP furniture manufacturing, composite moulding, green environment.

INTRODUCTION

South Africa experiences heavy and severe seasonal rainfalls; despite the climate change, the impact of these rainfalls is still significant. The intensity of the rainfall events over the past 10 year period increased by over 10 mm (Mason, Waylen, Mimmack, Rajaratnam & Harrison, 1999). According to Kruger and Nxumalo (2017) the precipitation tends to increase extremely over some parts of the country with the increase in annual frequency of very heavy rainfalls. The continuous wet days in the country is mostly in summer season for most part of the country with the exception to the south-western Cape. For the south-western Cape has the longest wet days, and to make matters worse they occur during the winter season where days are shorter than nights, the sun is further away from the surface of the earth and there is fog in the mornings.

The furniture used in most South African households is manufactured from wood and sheet steel, the furniture manufactured out of wood is preferred due to its aesthetic appearance, durability, low density, low thermal expansion and strength whereas the steel one is preferred due to the strength to weight properties (Broman, 2001; Hyvönen, Piltonen & Niinimäki, 2005; Wang, Chen & Chang, 2005)

The wonderful properties offered by the wooden furniture mainly depend on the maintenance and use of such furniture, particularly during wet conditions (Stark, Matuana & Clemons, 2004). The organic nature of wooden furniture makes it susceptible to organic decay; the decay is formed when a fungus is formed at a certain moisture and oxygen conditions for a certain period of time. The deterioration on the other hand is due to the combination of biological and physical process where the fungus causes decay or discoloration (Hyvönen, Piltonen & Niinimäki, 2005; Schultz, Nicholas & Preston, 2007; Stark, Matuana & Clemons, 2004).

In wood there may be water in the form of free water, bound water and water vapor (Hyvönen, Piltonen & Niinimäki, 2005; Kozłowska & Kozłowski, 2012). Free water fills the lumen by absorption using capillary action; the water does not bond to the wood hence it is referred to as free water. Bound water is attracted by hydroxyls to the cell wall and bound through monomolecular adsorption or polymolecular adsorption. In monomolecular adsorption the bond is stronger than polymolecular one and it is also difficult to separate the water from the hydroxyl group. Water vapor resides in the cavities of the cell wall and the lumina (Hyvönen, Piltonen & Niinimäki, 2005).

According to Hyvönen, Piltonen and Niinimäki (2005) the failure of wooden furniture due to water first starts with the adsorption of water, leading to the increase in volume proportional to the adsorbed water causing the swelling. Swelling increases until the cell wall is saturated with water, the increased saturation leads to a point where the water remains free water and no further swelling will occur. The moisture gradient between the surface and interior of the furniture causes stress resulting into surface warping, twisting and cracking. Above moisture saturation level fungi causes serious damage to the furniture, however this saturation level is not reached by water vapor but can be by exposure to liquid water.

The wood however can be preserved using the principle of toxicity and also by managing the fungi by controlling the temperature and removing the oxygen supply, the latter is however highly impractical (Schultz, Nicholas & Preston, 2007; Wang, Chen & Chang, 2005). The more practical way to manage the moisture content is via surface coatings that are achieved by applying water repellents and dimensional stabilizers to the surface. Common surface coatings used are varnish, lacquer or paint which are effective if there are no scratches, openings and imperfections on them. Absorption of water can be reduced by rendering the wood hydrophobic; this is very effective on the furniture that is used outdoors. The liquid water can only penetrate the hydrophobic layer unless the external pressure is greater than the capillary pressure. Typical water repellents are waxes, oils, resins (natural & synthetic), fungicides, insecticides and solvents. Water also gives rise to dimensional changes in the wood, to preserve the wood for biological durability, concentrations are vital in treatments. The developed preservatives can achieve a 50 year service life in the furniture; the typical example is in the wood used as railway sleepers. (Hyvönen, Piltonen & Niinimäki, 2005).

GRP material use and manufacturing is said to increase steadily since the introduction of this material during the 2nd world war (Abramovich, 2018; Bar, Alagirusamy & Das, 2018; Cooper & Turvey, 1995; Kaw, 2005; Patil & Ingale, 2018; Rafiee, 2013; Turvey & Zhang, 2006; Zou, Reid, Li & Soden, 2002). The growth is due to amongst others factors costs, weight, corrosion resistance, low friction factors, chemical resistance, excellent fatigue and impact resistance as well as damage tolerance (Avci, Şahin & Tarakçioğlu, 2007; Chandra, Singh & Gupta, 1999; Cooper & Turvey, 1995; Farshad & Necola, 2004a, 2004b; Hogg, 1983; Hogg, Hull & Legg, 1981; Jones, 1989; Kawada & Srivastava, 2001; Khalili, Mittal & Kalibar, 2005; Knox, Cowling & Hashim, 2000; Melot, 2018; Noble, Harris & Owen, 1983; Prakash, Srivastava & Gupta, 1987; Price & Hull, 1987; Rafiee, 2013; Salibi, 2001; Stokke, 1988; Turvey & Zhang, 2006; Vallittu & Sevelius, 2000; Yang & He, 2016).

METHODOLOGY

There are a number of ways to manufacture furniture using glass-fiber reinforced polymer (GRP) materials, the main purpose is not to deviate from the strength, appearance and appeal to the user's eye (Broman, 2001). To achieve the two, the price and the weight should be kept at a minimal level, this paper considers the manufacturing of the furniture using GRP material. The simplest methodology is to create a mold that will help achieve the required shape, in this work this is achieved by manufacturing three layers i.e. inner layer, outer layer and middle layer.

The inner layer is manufactured to have the strength to contain and withstand the contents of the furniture; in most cases the product in contact with the furniture has the certain level of moisture content. It is because of this reason that the inner layer needs to be manufactured in order to protect the furniture from the moisture, chemical attack and the electrical conduction.

The middle layer is the critical layer because it is the layer that is to be used to give the furniture its shape, has low weight and strength and can be used as a mold. Figure 1 (A-F) below shows the polystyrene foam in different forms, properties and quality. All as indicated below come in different colors, and can be shaped as seen below as in B and F. B and D are the most economical as they are available in portable spray bottles at a low cost. Their advantage is that the user can only use what is close to the required amount and thus eliminating the material losses. C and E are available as part of the packaging for furniture and fragile materials that are transported, the advantage of these is that they can be recycled to lower the costs and improve the environment. The most important use of these is to create the required shape before the resin material cures; as such, the foam is crafted into the required shape as seen in B and F.

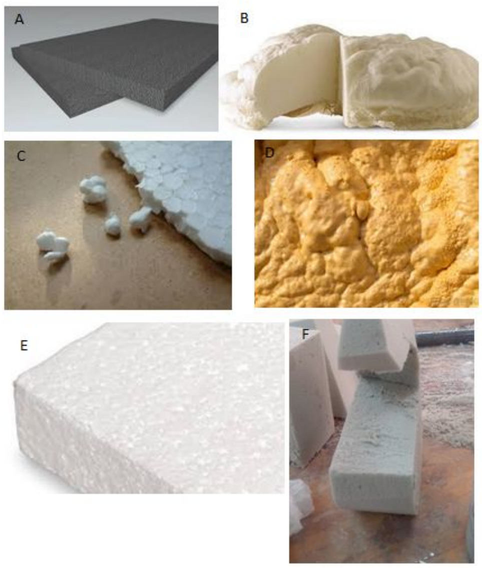


Figure 1: Polystyrene

The outer layer on the other hand is designed and manufactured to have an appealing look to the eye of the user as well as water resistance, durability, versatility strength and customized colors according to the user's requirements. This can be seen in Figure 3 below where a lap jointed material that contains three layers discussed in this work is used.

Figure 2: Plastic ball as a mold

The layers stated above do not necessarily have to be seen physically, a typical demonstration of this can be seen in Figure 2 where a plastic ball was used as a mold and as soon as the GRP material had cured its use was no longer relevant. In this particular instance, it became evident that the GRP material is strong enough to be used without the inner layer and the thickness of the material was not significant. It is common and assumed by most people that metals are stronger materials, but this assertion was proven otherwise by the introduction of GRP materials that are lighter in weight. In order to give the end user certainty about the strength of the product, the inner layer is added to increase the width of the furniture material as in Figure 3. The inner layer may well be considered in instances like during the manufacture of chair legs, etc.

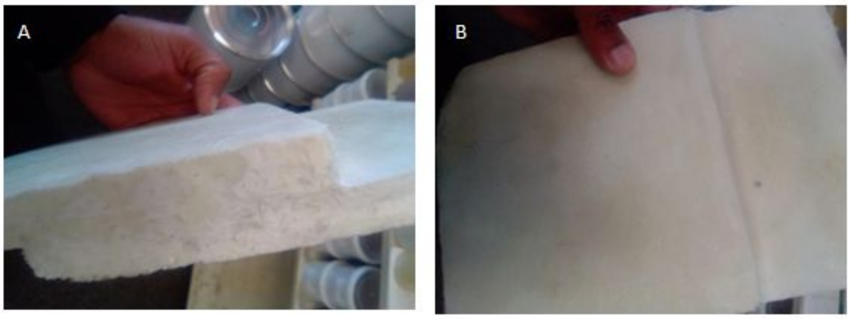


Figure 3: GRP Section

Because this paper is not mainly addressing mass production of furniture, but rather focusing on customized furniture the middle layer is used as a mold. It is worth indicating that the industrial type molds that are suitable for mass production are expensive for ordinary individuals and startup businesses. Because of these costs, the ordinary African can use what is available and is on their disposal. The basic model is to use polystyrene foam or cardboard material, prepare it to the required shape. Apply the resin layer and then the reinforcement. The number of layers determine the thickness and depend on the required strength of the furniture, as in most materials the thicker the cross sectional area the stronger the material.

RESULTS AND DISCUSSION

Manufacturing furniture using GRP has proven to be able to provide the benefits offered by metallic and wooden furniture combined. The material is durable, if one has to compare the metallic or wooden furniture with the same durability and weight GRP furniture will be the best option. The resin has high water resistance and will play a vital role in protecting the fiber from absorbing water because the water will cause the fiber to lose the durability in a long run. The aesthetic appeal of the GRP manufactured furniture will give the end user the feeling of fulfilment, as with the wooden furniture the owners still do their best to preserve using varnish and other similar solvents. With the GRP there will be no need to buy solvents to preserve, rather only a small amount of water is required to wipe the dirt on the furniture.

The costs associated with the manufacturing of the furniture are reasonably low with the minimal material loss because only the required amount can be used and the one that is not used can be reused. With the implementation of this, jobs will be created and thus help in building the economy of the country as well as contributing to the increase in the gross domestic production.

CONCLUSIONS

Purchasing inferior quality furniture is far more expensive than buying expensive quality furniture. What is more fulfilling and satisfactory to any African is to manufacture the furniture that is appealing to their eyes, strong, inexpensive and water resistant with a very simplified manufacturing process. In addition to this the end user of the furniture also deserves the value for their money and to be rest assured that the quality of the product is suitable to their needs. These GRP furniture is the best solution to Africans to make own furniture and will also help small and micro enterprise to grow and create employment the and thus contribute to gross domestic product of country and the continent. With the combination of both properties offered by the wood and steel that the GRP materials offer, the furniture that can be manufactured in this fashion can be the best option.

References

Abramovich, H. 2018. Introduction to composite materials. In: *Stability and Vibrations of Thin Walled Composite Structures*. Elsevier:1-47.

Avci, A., Şahin, Ö.S. & Tarakçioğlu, N. 2007. Fatigue behavior of surface cracked filament wound pipes with high tangential strength in corrosive environment. *Composites Part A: Applied Science and Manufacturing,* 38(4):1192-1199.

Bar, M., Alagirusamy, R. & Das, A. 2018. Advances in Natural Fibre Reinforced Thermoplastic Composite Manufacturing: Effect of Interface and Hybrid Yarn Structure on Composite Properties. In: *Advances in Natural Fibre Composites*. Springer:99-117.

Broman, N.O. 2001. Aesthetic properties in knotty wood surfaces and their connection with people's preferences. *Journal of wood science,* 47(3):192-198.
Chandra, R., Singh, S. & Gupta, K. 1999. Damping studies in fiber-reinforced composites–a review. *Composite structures,* 46(1):41-51.
Cooper, C. & Turvey, G. 1995. Effects of joint geometry and bolt torque on the structural performance of single bolt tension joints in pultruded GRP sheet material. *Composite Structures,* 32(1-4):217-226.
Farshad, M. & Necola, A. 2004a. Effect of aqueous environment on the long-term behavior of glass fiber-reinforced plastic pipes. *Polymer testing,* 23(2):163-167.
Farshad, M. & Necola, A. 2004b. Strain corrosion of glass fibre-reinforced plastics pipes. *Polymer testing,* 23(5):517-521.
Hogg, P. 1983. Factors affecting the stress corrosion of GRP in acid environments. *Composites,* 14(3):254-261.
Hogg, P., Hull, D. & Legg, M. 1981. Failure of GRP in corrosive environments. In: *Composite structures*. Springer:106-122.
Hyvönen, A., Piltonen, P. & Niinimäki, J. 2005. 5.4. Biodegradable substances in wood protection.
Jones, F. 1989. The role of moisture diffusion and matrix plasticisation on the environmental stress corrosion of GRP. *The Journal of Strain Analysis for Engineering Design,* 24(4):223-233.
Kaw, A.K. 2005. *Mechanics of composite materials.* CRC press.
Kawada, H. & Srivastava, V. 2001. The effect of an acidic stress environment on the stress-intensity factor for GRP laminates. *Composites science and technology,* 61(8):1109-1114.
Khalili, S., Mittal, R. & Kalibar, S.G. 2005. A study of the mechanical properties of steel/aluminium/GRP laminates. *Materials Science and Engineering: A,* 412(1-2):137-140.
Knox, E., Cowling, M. & Hashim, S. 2000. Fatigue performance of adhesively bonded connections in GRE pipes. *International journal of fatigue,* 22(6):513-519.
Kozłowska, A. & KozłowskI, R. 2012. Analysis of water adsorption by wood using the Guggenheim-Anderson-de Boer equation. *European Journal of Wood and Wood Products,* 70(4):445-451.
Kruger, A.C. & Nxumalo, M. 2017. Historical rainfall trends in South Africa: 1921–2015. *Water SA,* 43(2):285-297.
Mason, S.J., Waylen, P.R., Mimmack, G.M., Rajaratnam, B. & Harrison, J.M. 1999. Changes in Extreme Rainfall Events in South Africa. *Climatic Change,* 41(2), February 01:249-257.
Melot, D. 2018. Present and Future Composites Requirements for the Offshore Oil and Gas Industry. In: *Durability of Composites in a Marine Environment 2*. Springer:151-172.
Noble, B., Harris, S. & Owen, M. 1983. Stress corrosion cracking of GRP pultruded rods in acid environments. *Journal of Materials Science,* 18(4):1244-1254.
Patil, M.J.S. & Ingale, S. 2018. Study of Multilayered Composite Pipe subjected with Metal Interlayer.
Prakash, R., Srivastava, V. & Gupta, G. 1987. Behavior of adhesive joints in corrosive environment. *Experimental Mechanics,* 27(4):346-351.
Price, J. & Hull, D. 1987. Effect of matrix toughness on crack propagation during stress corrosion of glass reinforced composites. *Composites Science and Technology,* 28(3):193-210.

Rafiee, R. 2013. Experimental and theoretical investigations on the failure of filament wound GRP pipes. *Composites Part B: Engineering,* 45(1):257-267.
Salibi, Z. 2001. Performance of reinforced thermosetting resin pipe systems in desalination applications: a long-term solution to corrosion—the Arabian Gulf example. *Desalination,* 138(1-3):379-384.
Schultz, T.P., Nicholas, D.D. & Preston, A.F. 2007. A brief review of the past, present and future of wood preservation. *Pest management science,* 63(8):784-788.
Stark, N.M., Matuana, L.M. & Clemons, C.M. 2004. Effect of processing method on surface and weathering characteristics of wood–flour/HDPE composites. *Journal of Applied Polymer Science,* 93(3):1021-1030.
Stokke, R. 1988. Use of glass fiber-reinforced plastics (Grp) in seawater pipe system offshore. *Offshore Technology Conference.* Offshore Technology Conference.
Turvey, G. & Zhang, Y. 2006. A computational and experimental analysis of the buckling, postbuckling and initial failure of pultruded GRP columns. *Computers & Structures,* 84(22-23):1527-1537.
Vallittu, P.K. & Sevelius, C. 2000. Resin-bonded, glass fiber-reinforced composite fixed partial dentures: a clinical study. *Journal of Prosthetic Dentistry,* 84(4):413-418.
Wang, S.-Y., Chen, P.-F. & Chang, S.T. 2005. Antifungal activities of essential oils and their constituents from indigenous cinnamon (Cinnamomum osmophloeum) leaves against wood decay fungi. *Bioresource technology,* 96(7):813-818.
Yang, R. & He, Y. 2016. Optically and non-optically excited thermography for composites: A review. *Infrared Physics & Technology,* 75:26-50.
Zou, Z., Reid, S., Li, S. & Soden, P. 2002. Modelling interlaminar and intralaminar damage in filament-wound pipes under quasi-static indentation. *Journal of composite materials,* 36(4):477-499.

Leveraging on Technological Learning for Scaling-up in Clustered Micro-Firms in Nigeria

Oluseye Oladayo Jegede

SARChi Industrial Development, University of Johannesburg, South Africa +27 62 174 2075
oluseyej@uj.ac.za

Abstract

The study outlined how the microenterprises overcame the barrier of capital and credit through 'open development' characterised by collective sharing of knowledge, tools, equipment and workforce amongst competing microenterprises. Also by belonging to trade/professional associations which ensured that knowledge becomes a public good that can be accessed by everyone who needs it. The study also found out that majority of the microenterprises experienced scaling-up within few months to around three years from inception, while only a few scaled up only after three years. Scaling-up of microbusinesses was captured with four proxy variables: increase in number of employees, increase access to capital, increase in gross earnings and increase in gross sales. The study concluded that clustering of small businesses in Africa could be a potential avenue to overcoming the popular financial constraints and an enabler of firm growth.

Keywords: Constraint, Finance, Small firms, Knowledge and Scaling-up

BACKGROUND TO THE STUDY

Industrialization can be seen as the process by which an economy moves away from smallscale artisanal production to large-scale machinery-based production. The process of industrialisation involves the extensive re-organisation of the economy for the purpose of manufacturing (O'Sullivan *et al.,* 2003). Tregenna (2015) defines structural change as changes in sectoral composition of output and employment contributing to higher economic growth and increased utilisation of underutilised resources, especially labour. Tregenna in her article thus associated structural change with shifting labour and capital to higher-productivity (Tregenna, 2015).

Within the economy, entrepreneurs are active drivers of industrialisation. Entrepreneurs create new firms, offering new products and introducing new processes, a term referred to as creative destruction by Joseph Schumpeter in 1934. On another note, entrepreneurs also run their business through agglomeration and economies of scale, a term referred to as creative accumulation by Joseph Schumpeter in 1942. It is widely accepted that large firms significantly practice division of labour which helps them in promoting skills specialisation and improve their efficiency. There is also body of literature that supports the notion that the clustering of competent, highly specialized large firms lead to global value chains and localization economies (Malmberg & Maskell 2002; Henderson, 2003; Mander, 2014). Localization economies help to promotes knowledge exchange, knowledge spill overs and technology transfers by encouraging innovation and rapid industrialisation which is most needed in Africa. Industrialization can be seen as the outcome of the activities of entrepreneurs (Mander, 2014).

Entrepreneurs have been known to play vital roles in developing and transition economies (Brasil, India, China and South Africa) because they played crucial role in structural transformation from low tech based labour intensive economies to high technology, knowledge based economies through adoption, assimilation and adaptation of foreign technologies from developed countries (Etzkowitz *et al.,* 2015). Thus, the entrepreneur is the indispensable machinery for knowledge creation and knowledge diffusion (Braunerhjelm, Ács, and Audretsch 2010).

As important as these entrepreneurs are, they are faced with a lot of challenges and most times their effort do not materialise in the desired output. This is because these entrepreneurs operate mostly as informal enterprises in developing countries. Most of the studies carried out on micro and small enterprises in Africa have identified financing (lack of access to capital) as the major constraints they face in the smooth running of their daily business activities (Peterson and Rajan, 1994; Berger and Udell, 1998; Cavalluzzo, Cavalluzzo and Wolken, 1999; OyelaranOyeyinka 2006; Oyelaran and Lall 2006; Zeng 2008; Adeyeye *et al.* 2016, Egbetokun *et al.,* 2016; Jegede *et al.,* 2016, Jegede 2017a; 2017b; Oyelaran 2017). Despite the contribution of the informal sector to economic growth, attention hasn't been paid to it fully by governments and researchers as well.

There are lessons to learn from newly industrialising countries. For instance, China's rapid industrialization over the last few decades disconnect with the popular widely accepted path in which developed countries in Europe took – having some financial standard and framework (Allen, Qian, and Qian 2005). In particular, the vast majority of small firms had little or no access to credit from state-owned banks (Ruan and Zhang, 2009; Firth et al 2009; Lin, 2011). Despite this major constraints, China has achieved industrialization in less than a quarter of the time it took Europe. How was China able to do this? Through the clustering mode of production (Allen, Qian, and Qian, 2005; Fisman and Love, 2003a; 2003b). It can be assumed that by dividing a cohesive production process (which agglomeration offers) into several incremental phases, clustering can lower capital entry obstacles, creating a pathway for more entrepreneurs to join production industries. Also, clustering promotes inter-firm trade credit therefore reducing the pressure of looking operating capital.

Nigerian entrepreneurs are taking a peek from the Chinese story and trying to follow the shorter part towards industrialization. The Nigerian government too has been supporting the development of clusters as through its industrial policy and programmes. The Nigeria Industrial Revolution Plan (NIRP) was designed to facilitate the development of industrial cities, parks, and clusters while focusing on making hard infrastructure available within these industrial zones. Currently Nigeria ranks second in West Africa in industrial cluster development (World Competitiveness Report, 2015). The top cluster destinations in Nigeria include: Nnewi (Automotive), Otigba (ICT), Yaba (Technology), Onitsha (Plastics), Aba (Footwear) and Kano (Leather). Asides these major clusters, there exists several hundreds of other smaller clusters. The government of Nigeria has also established several free trade zones in different geopolitical zones of the country even though not all of these free trade zone in Nigeria were created by government at the Federal and State level, but these free trade zones have enjoyed the support of government. Within the free trade zones, goods may be landed, handled, manufactured or reconfigured, and re-exported without the intervention of the customs authorities. The government created and strengthened, an institution called the Nigerian Export Processing Zones Authority for promoting and facilitation local and international investments into license free zones in Nigeria. Table 1 shows the currently available free trade zones we have in Nigeria.

Table 1: Free Trade Zones in Nigeria

Name	**Location**	**Developer**	**Land Size (ha)**	**Status**
Calabar Free Trade Zone (CFTZ)	Cross River	Federal Government	220	Operational
Kano Free Trade Zone (KFTZ)	Kano	Federal Government	463	Operational
Tinapa Free Zone & Resort	Cross River	PPP	265	Operational
Snake Island	Lagos	Nigerdock Plc.	59.42	Operational
International Free Zone				
Maigatari Border Free Zone	Jigawa	State Government	214	Operational
Ladol Logistics Free Zone	Lagos	GRML	n/a	Operational
Airline Services EPZ	Lagos	Private	n/a	Operational
Sebore Farms EPZ	Adamawa	Private	2,000	Operational
Ogun Guandong FTZ	Ogun	PPP	10,000	Operational
Lekki Free Zone	Lagos	State Government	n/a	Operational
Abuja Tech Village FZ	FCT Abuja	FCT	702	Under construction
Ibom Science & Tech FZ	Akwa Ibom	State Government	122.14	Operational
Lagos Free Trade Zone	Lagos	Eurochem Technology	218	Operational
Olokola Free Trade Zone	Ondo Ogun	PPP	10,500	Operational
Living Spring Free Zone	Osun	State Government	1,607.86	Under construction
Badagary Creek Integrated Park	Lagos	Kaztec Engineering	531	Under construction
Ogindigbe Gas Revolution Industrial Park (GRIP)	Delta	Alpha GRIP Development Co.	2,506.03	Under construction
Nigeria Aviation Handing Co. (NAHCO)	Lagos	NAHCO	10	Under construction
Nigeria International Commerce City	Lagos	Eko Atlantic FZ Ltd	1,000	Under construction

Ogogoro Industrial Park	Lagos	Digisteel	52	Under construction
Ondo Industrial City	Ondo	State Government	2,771.2	Under construction

Source: Compiled from http://www.nepza.gov.ng/index.php/about/downloads

This paper attempts to establish the link between clustering, financing, and firm performance, by exploring one of Nigeria's most successful clusters – the Otigba Computer Village. The study focuses on the Otigba Computer Village, in Ikeja, Lagos State, Nigeria, because it has been adjudged the biggest ICT market in Africa, the ICT hub of West Africa and the Silicon Valley of West Africa because of the size and volume of business activities carried out daily in the cluster (Oyelaran-Oyeyinka, 2006).

STATEMENT OF THE PROBLEM

Studies carried out in the Otigba cluster so far have evaluated size capacity, evolution of the cluster, mode of operation, performance, production capability, sustainability and constraints of the industry. Hence, this study was carried out on two hundred randomly selected microenterprises in the cluster. It examined how the success story how the micro and small enterprises in the cluster overcome the constraints of financing and how the enterprises managed to 'scale-up' since 'start-up'. It also shed some light on how the cluster grew from a business unit to over several hundred business units, became the biggest ICT market in Africa and a major contributor to the economy of Lagos State in Nigeria – a cluster that remained largely informal and outside of governments regulation and support. This study thus seeks to:

a) Understand the dynamics of knowledge acquisition and diffusion in the cluster
b) Investigate the forms of scaling-up among the enterprises in the cluster

METHODOLOGY CONCEPTUAL FRAMEWORK

Studies on industrial districts and networks was first popularise by Michael Porter (Porter, 1985;1990;1998) where he referred to these industrial districts and networks as clusters. Literatures have shown that the two main indicators for clusters are rapid firm growth and new firm entry (Porter 1990; Swann and Prevezer, 1996; Baptista, 1996; Porter, 1998; Beaudry et al., 1998; Swann et al., 1998; Baptista and Swann, 1999; Cook et al., 1999; Pandit *et al.,* 2000; 2001a, 2001b; Beaudry and Swann, 2001). Swann *et al.* (1998) in their study also found out that enterprises in clusters are more innovative hence, grow faster than standalone enterprises. It also found out for high technology hubs, the strength of the science base in a cluster had a strong positive effect on new firm formation and growth of enterprises in that cluster. Other studies corroborated the fact industry location raises factor productivity (See for instance Henderson, 1986).

All the above listed researches outlined that being part of a cluster allows companies to productively source for inputs; access information, technology and institutions; and integrate with other enterprises both on the horizontal and vertical levels. This is because enterprises in vibrant clusters can take advantage of the proximity of a wide range of specialised and experienced human and financial capital, thereby lowering their research costs and learning time (Porter, 1998). In Saxenian's (1994) work, cooperation amongst enterprises may happen in different forms: cross-licensing, and joint technology purchase, patents agreements and joint-ventures. The study further buttressed the fact that proximity improves communications and interactions with the suppliers also. Another knowledge advanced in the work was that clustering creates avenue for monitoring and benchmarking with other enterprises in the cluster and industry.

Our study draws insight from these literatures. In our study, we proposed that knowledge sharing in geographical clusters leads to rapid knowledge diffusion which eventually leads to scaling-up of the enterprises in the cluster as well as the cluster as a whole. We also advanced our concept that scaling-up of clusters can happen in at most four stages viz: input stage, process/activity stage, output stage and finally impact stage. Hence, innovation as a result of knowledge sharing and diffusion can produce a combination of or any of the four stages of scaling-up.

Research scope

The research was grounded on the collection of first-hand data, by developing and administering survey instruments designed to capture the attribute of the Otigba hardware market, the channels of knowledge diffusion in the cluster and the different forms of scaling-up in the cluster. The survey results were used for undertaking descriptive analyses responding to the study's objectives. The information gathered was benchmarked with additional information from literature.

The study included developing a methodological framework capturing cluster attributes, knowledge diffusion and forms of scaling-up in the informal ICT enterprises in the cluster and undertaking full scale surveys on two hundred informal (200) ICT microenterprises randomly selected from the approximately four thousand (4000) microenterprises in the cluster representing an estimated 5% of the cluster population.

Research Instruments and Subjects

The main research instrument was a set of questionnaire administered on the owners of the business units at Otigba hardware market. These microenterprises comprise of businesses having employee size of less than ten offering a range of technical services such as:

(i) Networking services,
(ii) Production/installation,
(iii) Branded computer/equipment,
(iv) Sales of hardware and software of computer,
(v) IT services/marketing,
(vi) General IT maintenance and repairs,
(vii) Assemblage of computer& accessories, and
(viii) Sales of peripherals & other items.

RESULTS AND DISCUSSION

Socio-Demographic Features of the Enterprises

Table 4.1 shows that about all the enterprises examined (85.5%) are micro enterprises i.e. they have 1-9 employees; only a few (14.5%) had over 9 employees.

This classification is in line with Small and Medium Enterprise Development Association of Nigeria (SMEDAN) in their sorting of enterprises. They classified enterprises with 1-9 employees having a capital below 5 million naira as micro-firms. This can be interpreted that the Otigba cluster is dominated by micro-firms. To corroborate this, about an average (52%) of the enterprises claimed that they had an initial start-up capital of about two hundred to four hundred thousand naira while about one quarter (22%) of the firms started with nothing less than a hundred thousand naira. The rest of the firms, about (24%), had well over four hundred thousand naira as their start-up capital as shown in Table 4.2. This means that on the average, a firm can join this cluster with an average of two hundred thousand naira and do well. This explains one of the reasons for the vibrancy of the cluster. The start-up capital is still within the reach of an average Nigerian.

Figure 4.1 also depicts the business activities that the firms engaged in. Engineering and repairs were the main activities (80%) that the enterprises engaged in. The other leading activities were sales and services (40%), as well as services and installation (30%). Other activities as software engineering, phone engineering, and laptop troubleshooting, amongst others, were at minimal. The ICT business terrain in Nigeria is such that most computer operators go beyond just vending the equipment. They also learn how to make (assemble) and maintain/repair the commodities they sell. The survey carried out showed that the enterprises were engaged more in repairs and services than in software development. The implication of this is that while they go through the process of repairing equipment, they tend to develop competence in and knowledge of the product they work on. Figure 4.2 reveals the types of products the enterprises vend. Mostly sold in this cluster were phones, phone accessories, laptop, inverters and batteries. All these represent modern technologies with a lot of frequent incremental innovations. As regards the ownership of the business, majority of the firms claimed that their businesses were operated as an entity and not a family business (Fig. 3). In Nigeria, most people prefer to separate family relationship from business so as to enhance accountability. Hence the reason why most of the firms in Otigba market clusters operated their business as an entity. However, few that claimed that their enterprises were family business while some also reported that they had well over 80% of the staff as family members (Fig. 4.4).

Table 4.1: Number of Employees

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1-9 employees	171	85.5	85.9	85.9
	10-49 employees	21	10.5	10.6	96.5
	50-249 employees	3	1.5	1.5	98.0
	250 and above	4	2.0	2.0	100.0
	Total	199	99.5	100.0	
Missing	System	1 200	.5 100.0		
Total					

Table 4.2: Initial Start-up Capital for the Business

		Frequency	Percent	Valid Percent	Cumulative Percent
	Less than 100,000	4	2.0	2.0	2.0
	100,000-1,999,999	44	22.0	22.0	24.0
	2,000,000 -3,999,999	103	51.5	51.5	75.5
	4,000,000 - 5,999,999	8	4.0	4.0	79.5
Valid		20	10.0	10.0	89.5
	6,000,000 - 7,999,999	5	2.5	2.5	92.0
	8,000,000 - 9,999,999	3	1.5	1.5	93.5
	10,000,000 - 11,999,999	3	1.5	1.5	95.0
	12,000,000 and above	10	5.0	5.0	100.0
	Total	200	100.0	100.0	

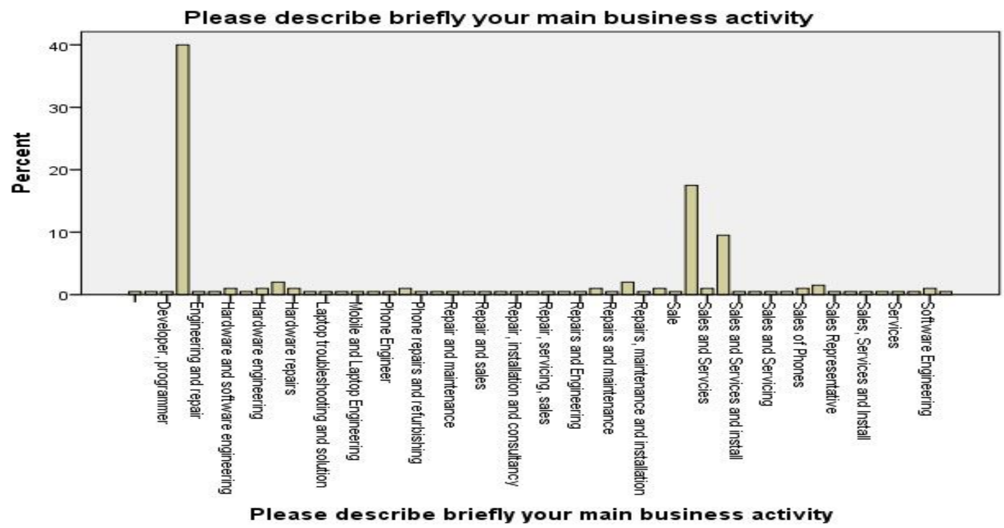


Figure 4.1: Business Activities in the Cluster

Table 2 further reveals the nature of the cluster. All of the firms reported that they usually exchange information with other technicians, share experience with other technicians, engage technicians from other firms, and share tools and equipment with other technicians, though none of them had a joint purchase of expensive equipment and importation of inputs. The reason for this disparity could be to avoid the conflict that comes with joint venture. Also the cluster placed more emphasis on sharing what they had than combinational effort.

Table 2: Modes of Open Innovation Mechanism in the Cluster

	N	Min	Max	Mean	Std. Dev.
Exchanging information with other technicians	200	0	4	3.45	.855
Sharing experience with other technicians	200	0	4	3.20	1.130
Engaging technicians from other firms	199	0	4	3.17	1.172
Sharing tools with other technicians	200	0	4	3.07	1.354
Sharing equipment with other technicians	200	0	4	3.03	1.398
Joint purchase of expensive equipment	197	0	4	0.32	.644
Joint importation of inputs	194	0	4	0.14	.529
Valid N (listwise)	193				

Scale: Always = 4 Usually = 3 Occasionally = 2 Rarely = 1 Not at all = 0

Dynamics of Knowledge Acquisition and Diffusion in the Cluster

The acquisition and development of technology knowledge (i) relates to an entrepreneur's ability to create products that meet market demands (Clarysse *et al.,* 2011), (ii) helps them respond to changing markets via rapid product development and (iii) allows them to stay abreast of technical changes related to venture performance. In the Nigerian setting, apprenticeship system of education is a viable substitute for formal education. This is usually practised more in the informal settings. Hence, in this paper, learning on the job is loosely categorised as apprenticeship. Fig. 1 confirms this showing that majority of the workforce went through different kinds of training on the job. Hence, the traditional apprenticeship system was the most important process of acquiring skills in the Otigba Hardware cluster as seen from the study. Oyelaran (1997) and Akinbinu (2001) works also confirmed this claim. They found out from their studies that the most popular mechanism for technological learning in the informal setting was through tradition apprentice system. This notion is also in line with OyelaranOyeyinka (2006) that shows that learning-by-doing was an important component of non-formal learning in the African small firms which are rooted in crafts apprenticeship. Most of the businesses asserted that they carry out internal trainings in their enterprises as a means of knowledge development (Fig. 2). According to Burger & Gochfeld (2008) and Burger & Shaffer (2008), technology development implies firms having relevant knowledge regarding the products, technologies, and/or processes that pertains to their business. The study showed that majority of the firms upgraded their knowledge weekly (Fig. 3). The essence of upgrading weekly was to keep abreast with customer's needs. They major in the repairs of phones, laptops, etc., and this are products that come with a lot of technical changes as the products change from the producers. This is one of the reasons why the firms upgraded often so as to have the latest technical requirements as the market changes. Another way through which the firms develop their knowledge was through trainings sourced within the enterprise, as shown in Table 4. Other modes of transferring knowledge among the employees, aside training include learning under experienced personnel. Over 50% of the firms claimed this claim (Fig 5). Learning through experienced personnel literally means learning the easy way as the apprentice tends to learn from the mistake of the superior and hence shorter learning duration. About 40% reported that they acquired knowledge through the simple task that was been assigned to them while only about 10% said that assignment of task with close supervision was the method through which they acquired knowledge.

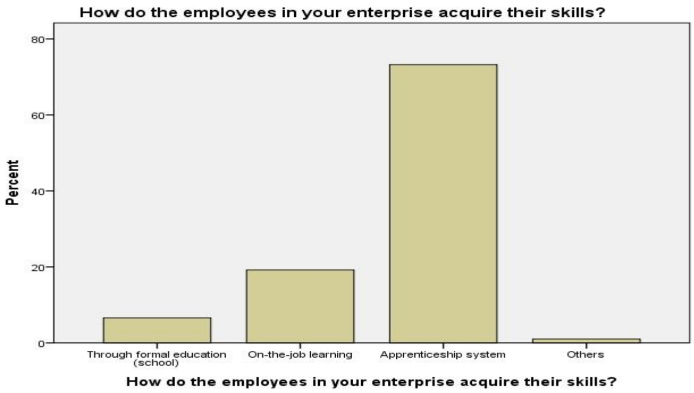


Figure 1: Ways through which Employees Acquire Skills

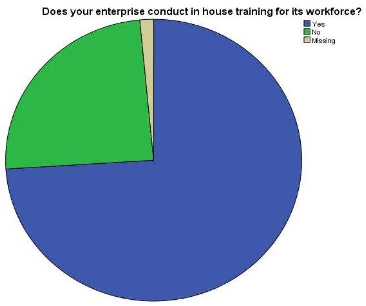


Figure 2: Existence of In-house Training

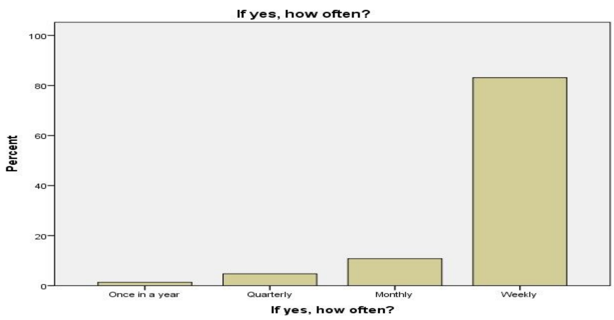


Figure 3: Rate of Knowledge Development in the Cluster

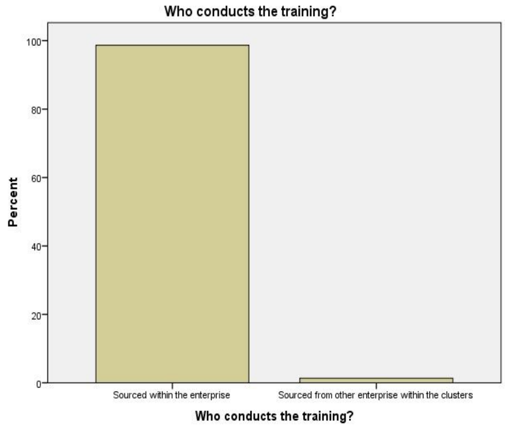


Figure 4: How the Firms in the Cluster Conduct Training

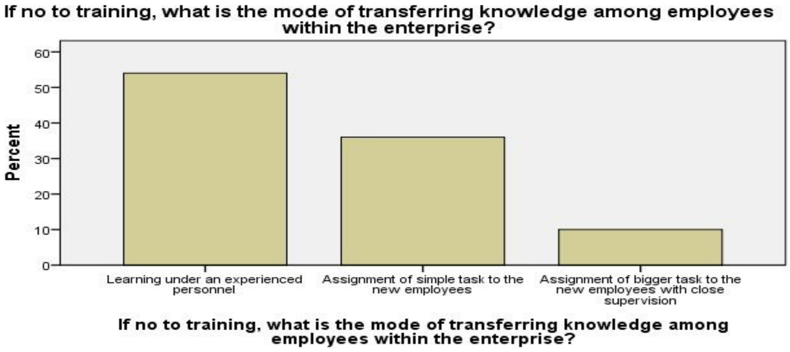


Figure 5: Other Modes of Transferring Knowledge Aside Training

One channel of diffusing knowledge in the enterprises and in the cluster was through rotation of jobs (Fig 6). Table 3 shows that about 55.5% reported that allotting task with close supervision was the utmost diffusion mechanism. Another diffusion mechanism was 26.5% inhouse training and 16.5% allowance of employees to collectively undertake task. This way, the employees would be able to work with their hands, know their ability, learn from their mistakes and improve as time goes on. This may be relatively slow as compared to receiving the formal type of training but it has been proven to be worth the while as the employee tends to retain all the experiences they gain from this process and in no time gain independence to start-up their own. Informal knowledge diffusion method is a proven method of advancing a cluster as shown by the Otigba cluster.

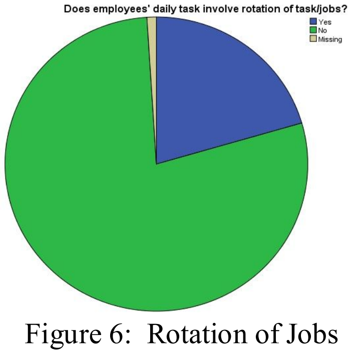


Figure 6: Rotation of Jobs

Table 3: Knowledge Exchange Mechanism for Knowledge Diffusion

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Allotting task with close supervision in-house training	111	55.5	56.1	56.1
	Allowing the employees to collectively	53	26.5	26.8	82.8
	undertake task	33	16.5	16.7	99.5
	Others	1	.5	.5	100.0
	Total	198	99.0	100.0	
Missing System		2	1.0		
Total		200	100.0		

Figure 7 illustrates that majority of the firms reported that there were informal association. They affirmed that the associations that existed were CAPDAN and COPTON. These associations regulate knowledge dissemination amongst them. trade associations serve as information intermediaries that collect useful information from individual enterprises and then aggregate them into sector-wide information for collective use – public good accessible by any member of the association (also including non-members see for instance the suppliers of equipment, machinery, tools and then customers). In the Otigba hardware cluster, the enterprises reported to have benefitted greatly from this information. The information they share range from very technical problem solving information to less important general information about the trend in the industry.

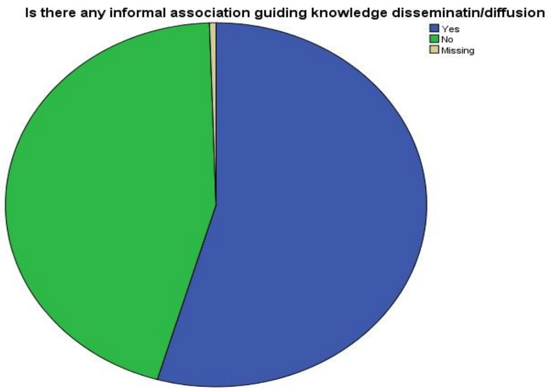


Figure 7: Informal Associations Guiding Knowledge Dissemination in the Cluster

Forms of Scaling-up Among the Micro Enterprises in The Cluster

The study captured scaling-up using four proxy variables viz: (i) improved access to finance, (ii) increase in workforce, (iii) percentage increase in gross earnings of the enterprises and (iv) percentage increase in gross sales. Most of the enterprises increased their capital base or accessed larger funds after inception (Fig. 8). The source of increased fund was majorly through commercial banks followed by co-operative societies (Fig. 9). These were trailed by business angels and micro-credit organisations. It is noteworthy that interest rates, charged by commercial banks in Nigeria, are usually in the two digits - about 30%. However, co-operative societies have been a common feature of the traditional African societies. This is in tandem with some previous works on social innovations in the Nigeria (Akinbinu, 2001; 2003; Oluwale, Ilori and Oyebisi, 2013). Majority of the enterprises increased their work force to run their businesses (Fig. 10). Most of the enterprises (Fig. 11). About 45% had an increase in the number of employees ranging between 1 and 5, 10% had an increase in the number of employees ranging between 6 and 10 while very few had an increase in the number of employees ranging between 11 and 14.

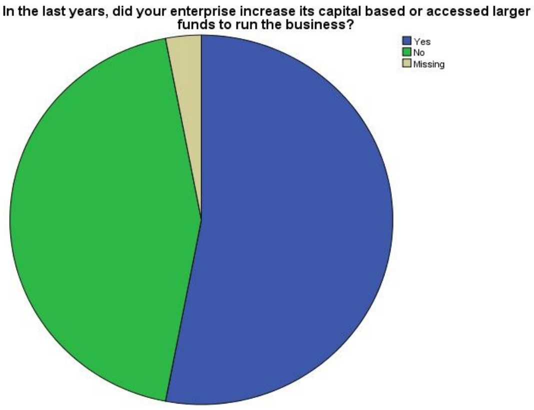


Figure 8: Increase in capital base or access to larger funds to run business

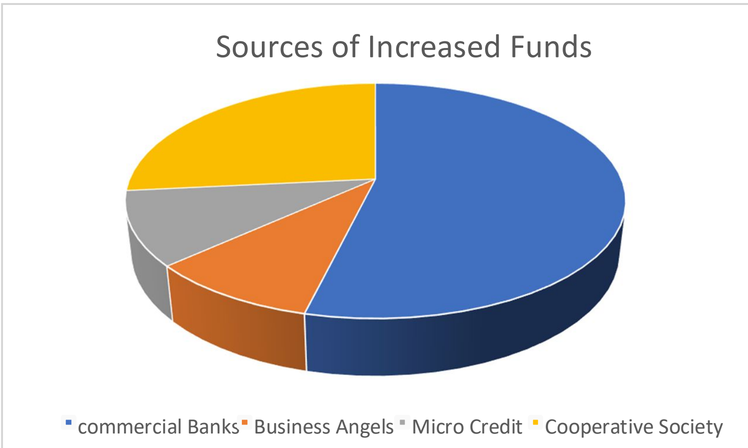


Figure 9: Sources of increased fund

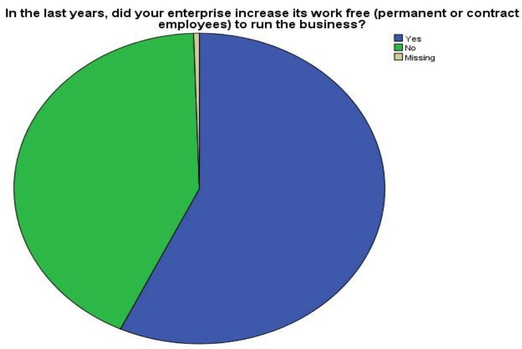


Figure 10: Enterprise's increase of work force to run business

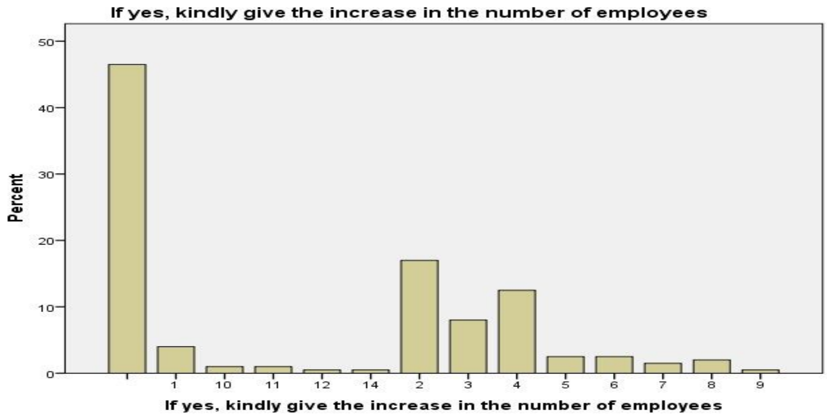


Figure 11: Increase in the number of employees

Most of the enterprises recorded increase in their annual gross earnings over the years which is a positive sign of growth (Fig. 12). The growth in annual gross earnings was less than 15% for most of the firms' while only few had increase in annual gross earnings ranging between 20% and 25% (Fig. 13). In the same vein, most of the enterprises recorded increase in their annual sales volume over the years as a sign of growth (Fig. 14). The growth in annual sales volume was also less than 15% for most of the firms' while only few had increase in annual gross earnings of between 20% and 25% (Figure 15).

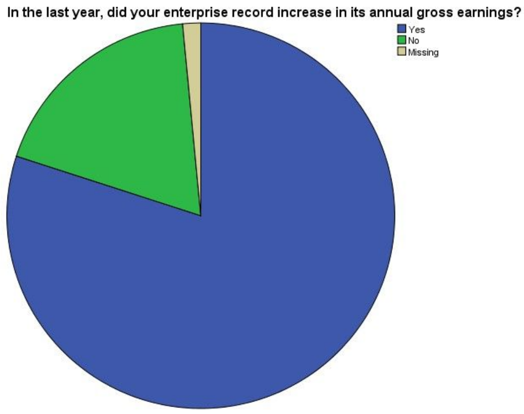


Figure 12: Firms' increase in annual gross earnings

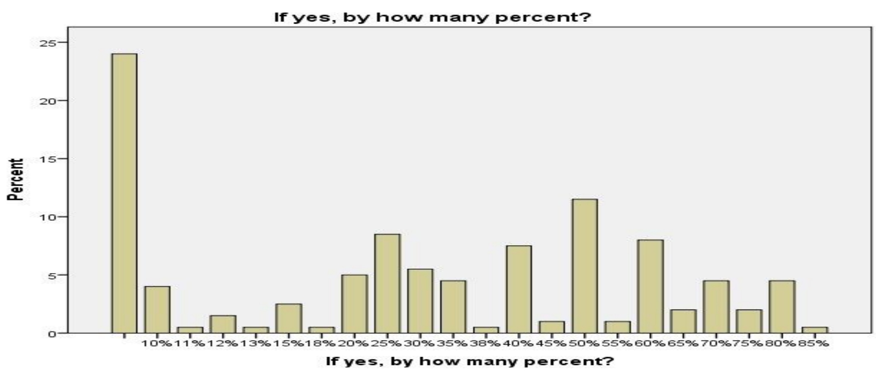


Figure 13: Percentage growth of enterprises in annual gross earnings

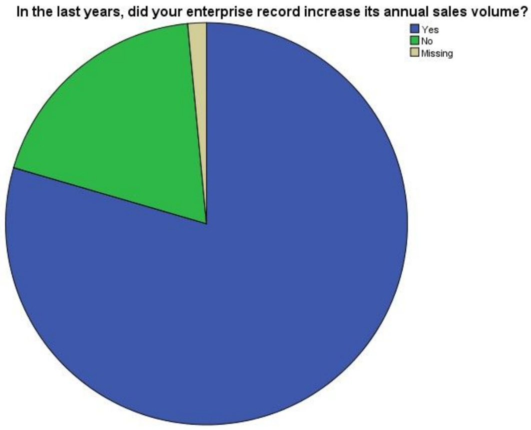


Figure 14: Firms' increase in annual sales volume

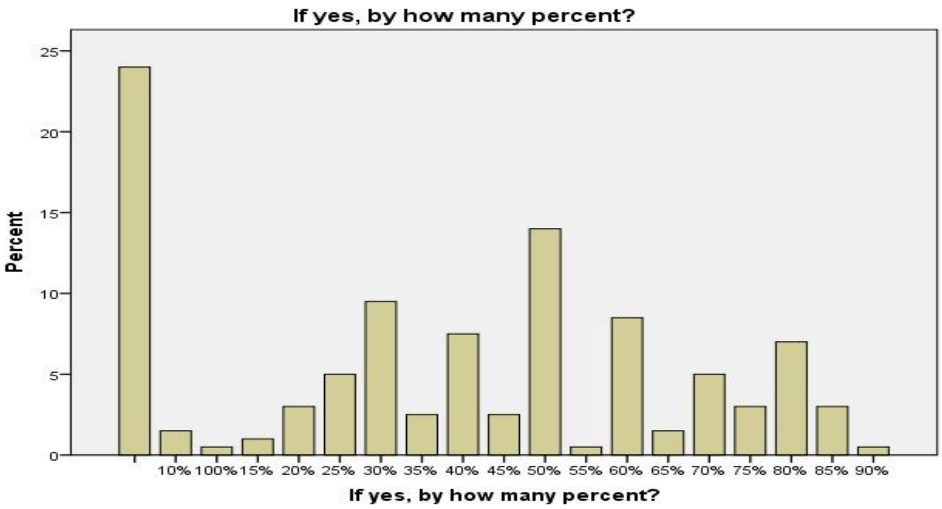


Figure 15: Percentage growth of enterprises in annual sales volume

CONCLUSION

A major reason for the rapid growth in the cluster was knowledge sharing not access to finance. There was serious emphasis on sharing knowledge, skills and ability that each enterprise had to collectively compete. The nature of open collaborative innovation in the cluster was through cooperation to collectively compete as a cluster (with international market).

In the cluster, knowledge acquisition was achieved either through formal methods (university education and trainings) and informal method (apprenticeship system and indigenous knowledge systems). However, apprenticeship system of education was the most used channel of acquiring knowledge in the cluster. Knowledge diffusion was communal in the cluster. especially with the presence of trade associations/union guiding wide dissemination of knowledge in the cluster. This is because of the monitoring role played by trade association/unions such as CAPDAN and COMPTON evidently present in the cluster. Amongst other reasons, knowledge sharing and diffusion influenced scaling-up in the cluster this manifested principally in increase in number of employees within enterprises. Improved access to finance, increase fine gross earning and increase in gross sales Hence, knowledge sharing was seen an instrument of collective advancement (open development).

Implications of the Study

The practice of open collaborative innovation among knowledge-based enterprises/networks has been found to be highly productive in overcoming the barriers to accessing finance in the cluster. It is therefore highly recommended that government, unions, professional bodies, trade associations and self-help organizations buy into this, as knowledge sharing and collaborative problem solving approaches represent the currency in which enterprises in clusters need to trade with. How much an enterprise knows, how fast they can learn something new, and how much knowledge it is willing to volunteer determine the vibrancy of the enterprise not really how much it has.

Acknowledgements

This work was carried out under the auspices of the Open African Innovation Research (Open AIR) network, in partnership with the University of Cape Town (South Africa), the University of Johannesburg (South Africa), the University of Ottawa (Canada), The American University in Cairo (Egypt), Strathmore University (Kenya), and the Nigerian Institute of Advanced Legal Studies (Nigeria).

We acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the International Development Research Centre (IDRC), and the UK Department for International Development (DFID). The views expressed in this work are those of the authors and do not necessarily represent those of the research funders.

References

Adeyeye, A. D., Jegede, O. O., Oluwadare, A. J., & Aremu, F. S. (2016). Micro-level determinants of innovation: analysis of the Nigerian manufacturing sector. Innovation and Development, 6(1), 1-14.

Akinbinu, A.F. (2001): Informal Small Enterprises Clusters: A Case Study of Auto-Mechanic Villages in Ibadan. Nigerian Institute of Social and Economic Research (NISER) Monograph Series No. 5.

Akinbinu, A.F. (2003). Industrial Reorganization for Innovation: Current Knowledge on Small and Medium Enterprises Clusters in Western Nigeria. Nigerian Institute of Social and Economic Research (NISER) Monograph Series No. 87.

Allen, F., Qian, J., & Qian, M. (2005). Law, finance, and economic growth in China. Journal of financial economics, 77(1), 57-116.

Baptista, R. (1996). An empirical study of innovation, entry and diffusion in industrial clusters, unpublished doctoral thesis, London: London Business School.

Baptista, R. and Swann, G.M.P. (1999). A comparison of clustering dynamics in the US and UK computer industries, Journal of Evolutionary Economics, 9(3): 373-399.

Beaudry, C. and Swann, P. (2001), Growth in industrial clusters: A bird's eye view of the United Kingdom, Stanford Institute for Economic Policy Research Discussion Paper No. 00-38, Stanford, CA: Stanford University.

Beaudry, C., Cook, G.A.S., Pandit, N.R. and Swann, G.M.P. (1998), Industrial Districts and Localised Technological Knowledge: The Dynamics of Clustered SME Networking, Research Report 3.3 (Clusters, growth and the age of firms; A study of three industries: Aerospace, Broadcasting and Financial Services) for the European Community DG XII.

Berger, A. N., & Udell, G. F. (1998). The economics of small business finance: The roles of private equity and debt markets in the financial growth cycle. Journal of banking & finance, 22(6-8), 613-673.

Braunerhjelm, P., Acs, Z. J., Audretsch, D. B., & Carlsson, B. (2010). The missing link: knowledge diffusion and entrepreneurship in endogenous growth. Small Business Economics, 34(2), 105-125.

Burger, A. E., & Shaffer, S. A. (2008). Perspectives in Ornithology Application of Tracking and Data-Logging Technology in Research and Conservation of Seabirds. *The Auk*, *125*(2), 253-264.

Burger, J., & Gochfeld, M. (2008). Knowledge about fish consumption advisories: A risk communication failure within a university population. *Science of the Total Environment*, *390*(2), 346-354.

Cavalluzzo, K. S., Cavalluzzo, L. C., & Wolken, J. D. (2002). Competition, small business financing, and discrimination: Evidence from a new survey. The Journal of Business, 75(4), 641-679.

Clarysse, B., Wright, M., & Van de Velde, E. (2011). Entrepreneurial Origin, Technological Knowledge, and the Growth of Spin-Off Companies. Journal of Management Studies, 48(6), 1420-1442.

Cook, G.A.S., Pandit, N.R. and Swann, G.M.P. (1999). The dynamics of industrial clustering in British broadcasting, Loughborough University Business School Working Paper 1999: 11.

Egbetokun, A., Atta-Ankomah, R., Jegede, O., & Lorenz, E. (2016). Firm-level innovation in Africa: overcoming limits and constraints. Innovation and Development. 6 (2)

Etzkowitz, H., de Mello, J. M. C., & Almeida, M. (2005). Towards "meta-innovation" in Brazil: The evolution of the incubator and the emergence of a triple helix. Research policy, 34(4), 411-424.

Firth, M., Lin, C., Liu, P., & Wong, S. M. (2009). Inside the black box: Bank credit allocation in China's private sector. Journal of Banking & Finance, 33(6), 1144-1155.

Fisman, R., & Love, I. (2003a). Trade credit, financial intermediary development, and industry growth. The Journal of finance, 58(1), 353-374.

Fisman, R., & Love, I. (2003b). Financial development and the composition of industrial growth (No. w9583). National Bureau of Economic Research.

Global Competitive Report (2015). World Economic Forum. Insight Report. Available at: http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2014-15.pdf Accessed May 9th, 2018

Henderson, J. V. (2003). Marshall's scale economies. Journal of urban economics, 53(1), 1-28.

Henderson, J.V. (1986). The efficiency of resource usage and city size, Journal of Urban Economics, Vol. 19: 47-70. Available at: http://www.nepza.gov.ng/index.php/about/downloads

Jegede, O. O. (2017a). Chapter 8. Collaborating to innovate: the case of the Nigerian mining industry. Innovation in Developing and Transition Countries, 156.

Jegede, O. O. (2017b) Linking Information Sources, Innovation Outputs and Financial Performance in Nigeria's Mining Sector. Journal of Entrepreneurship and Innovation Management. 6 (2), 73 - 95

Jegede, O. O., Ilori, M. O., Olorunfemi, M. O., & Oluwale, B. A. (2016). On the link between human capital, innovation and performance: evidence from a resource-based economy. International Journal of Learning and Intellectual Capital, 13(1), 27-49.

Lin, H. (2011). Foreign bank entry and firms' access to bank credit: evidence from China. Journal of Banking & Finance, 35(4), 1000-1010.

Malmberg, A., & Maskell, P. (2002). The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering. Environment and Planning A: Economy and Space, 34(3), 429-449.

Mander, J. (Ed.). (2014). The case against the global economy: and for a turn towards localization. Routledge.

Oluwale, B. A., Ilori, M. O., & Oyebisi, T. O. (2013). Clustering and Innovation in the Automechanic Industry in Nigeria. *African Journal of Science, Technology, Innovation and Development*, *5*(5), 411-421.

O'Sullivan, Arthur; Sheffrin, Steven M. (2003). Economics: Principles in Action. Upper Saddle River, New Jersey 07458: Pearson Prentice Hall. p. 472

Oyelaran-Oyeyinka, B. (1997): Nnewi: An Emergent Industrial Cluster in Nigeria. Ibadan: Technopol.

Oyelaran-Oyeyinka, B. (2006). Systems of innovation and underdevelopment: an institutional perspective. Science, Technology and Society, 11(2), 239-269.

Oyelaran-Oyeyinka, B., & Lal, K. (2006). SMEs and new technologies: learning e-business and development. Springer.

Oyeyinka, O. (2017). The State, Institutions, and Policy Support for Clusters. In Industrial Clusters, Institutions and Poverty in Nigeria (pp. 157-177). Springer, Cham.

Pandit, N.R., Cook, G.A.S. and Swann, G.M.P. (2000), A comparison of clustering dynamics in the British broadcasting and financial services industries, European Association for Research in Industrial Economics (EARIE) Annual Conference, 7-10 September 2000, Lausanne, Switzerland.

Pandit, N.R., Cook, G.A.S. and Swann, G.M.P. (2001a). The dynamics of industrial clustering in British financial services, Service Industries Journal, Vol. 4: 33-61.

Pandit, N.R., Cook, G.A.S. and Swann, G.M.P. (2001b), A comparison of clustering dynamics in the British broadcasting and financial services industries, International Journal of the Economics of Business, Vol. 9-2: 195-224.

Peterson, M. A., & Rajan, R. G. (1994). The Benefit of Firm Creditors Relationship: Evidence From Small Business Data. Journal of Finance, 49(1).

Porter, M.E. (1985), Competitive advantage, New York: Free Press.
Porter, M.E. (1998), Clusters and the new economics of competition, Harvard Business Review, November-December: 77-90.
Porter, ME. (1990), Competitive advantage of nations, New York: Free Press.
Ruan, J., & Zhang, X. (2009). Finance and cluster-based industrial development in China. Economic Development and Cultural Change, 58(1), 143-164.
Saxenian, A. (1994). Inside-Out: Regional Networks and Industrial Adaptation in Silicon Valley and Route 128. Regional Networks and Industrial Adaptation. Available at: https://pdfs.semanticscholar.org/c199/4a53f305bd2affd052f72d9cd24b7a7075c2.pdf Accessed May 9th, 2018
Schumpeter, J. A. (1934). The theory of economic development. Oxford University Press, London
Schumpeter, J. A. (1942). Capitalism, Socialism and Democracy, Harper and Row, New York.
Swann G.M.P., Prevezer, M. and Stout, D. eds. (1998). The dynamics of industrial clustering: International comparisons in computing and biotechnology, Oxford: Oxford University Press.
Swann, G.M.P. and Prevezer, M. (1996), A comparison of the dynamics of industrial clustering in computing and biotechnology, Research Policy 25: 1139-1157.
Tregenna, F. (2015). Deindustrialisation, structural change and sustainable economic growth. UNU-MERIT working paper series. #2015-032
Zeng, D. Z. (Ed.). (2008). Knowledge, technology, and cluster-based growth in Africa. World Bank Publications.

Determinants of Innovation Capability in the Informal Settings

[a]Oluseye Oladayo Jegede & [b]Olubukola Esther Jegede

[a]CeSTII, Human Science Research Council, Cape Town, South Africa [b]CGSPS, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract

This study contributes to the growing literature on innovation capability in the informal sector in Nigeria. It explores the role of openness as a facilitator for measuring innovation capability, and proposes openness as a metric for the measurement of innovation capability in the informal sector. This new metric was tested using 200 informal information and communication technology (ICT) enterprises at the Otigba hardware cluster, which is located in the Nigerian commercial capital of Lagos and is regarded as a key ICT hub in West Africa. The main research instrument was a set of questionnaires designed to capture the core objective of the research. All 200 questionnaires were retrieved and found suitable for analysis. The questionnaires elicited information on the socio-demographic characteristics of the enterprises, the attributes of the Otigba cluster, the strength of the enterprises, the strength of the cluster, the extent of innovations within the cluster, and the proximity advantages drawn from clustering. Spearman's correlation and binary logistic regression were used to determine the direction and impact of the various independent variables (determinants of innovation capability) on the dependent variable (the extent of innovation as a proxy for innovation capability). It was found that openness plays a very significant role in access to: information, customers, new domestic markets, tools and technology, suppliers of raw materials, and inputs. However, openness was found to play only a limited role in finished products for the export market. It was also found that much more still needs to be done by the enterprises to build up their internal capabilities, so as to reduce their reliance on external sources of knowledge— notwithstanding the fact that exposure to external capabilities, through cooperation and openness, will remain necessary to complement enterprises' internal capabilities.

Keywords: microenterprises, clusters, informal sector, innovation capability, process innovation, openness, information and communication technology (ICT)

Introduction

Recent findings have shown that most innovations in the informal sector are not research and development (R&D)-based (De Beer et al., 2013; De Beer & Armstrong, 2015; Oyelaran-Oyeyinka & Lal, 2006). However, these innovations are nevertheless technical, since technical knowledge is used in achieving these innovations, even though most of the outputs are not technological in nature (Oyelaran-Oyeyinka, 2006; Oyelaran-Oyeyinka & Lal, 2006). These innovations are products of some kind of knowledge peculiar to informal microenterprises.

Despite the importance of the informal sector to employment and economic growth in developing countries, very little attention has been paid to informal enterprises, especially regarding innovation capability. The first, second and third edition of the Oslo Manual (OECD, 2005), as well as the Bogota Manual (RICYT et al., 2001) have conspicuously omitted microenterprises in conducting national innovation surveys. In view of this conceptual limitation, innovation studies have consistently and narrowly focused on enterprises in the formal sector, thereby blurring the theoretical lens of innovation measurement in Africa. Systematic research on innovation management in informal microenterprises may help re-orient the measurement of innovation in Africa. In practice, the goal of knowledge management is to improve organisational capabilities through better use of the organisation's individual and collective knowledge resources. These resources include skills, capabilities, experience, routines, and norms, as well as technologies. However, attention to knowledge management in the informal sector is very scant in the literature. Research has shown that larger enterprises have recognised that they compete in increasingly knowledge intensive markets. In order to thrive or survive, they are required to rethink the management of their organisational knowledge bases.

Studies carried out in the Otigba cluster so far have evaluated size and capacity (Abiola, 2008; Oyelaran-Oyeyinka, 2006), evolution of the cluster (Oyelaran-Oyeyinka & McCormick, 2007), mode of operation (Abiola, 2008), performance (Oyelaran-Oyeyinka, 2006; Oyelaran-Oyeyinka & McCormick, 2007), production capability (Awoleye, 2015), sustainability (Oyelaran-Oyeyinka, 2006; 2014; 2017), and constraints (OyelaranOyeyinka, 2006) for the industries located there. The literature defines a cluster in terms of geography and product specialisation. To this end, a cluster is defined as a sectoral and geographical concentration of enterprises (Schmitz, 1995). Previous studies (Cohen & Levinthal, 1989, 2000; Cassiman & Veugelers, 2006; Gallego, Rubalcaba, & Suárez, 2013) have identified that firms generally do not innovate in isolation because they rely heavily on knowledge sources external to the firm; which may be drawn from the proximity to one another within a cluster. Proximity fosters informal, face-to-face interaction as an effective means of information exchange among personnel from different enterprises and firm proprietors.

The importance of face-to-face interaction in clusters and industrial districts has been cited in the literature (Cooke, 2002; Keeble & Wilkinson, 2017; Oyelaran-Oyeyinka & McCormick, 2007, Oyelaran-Oyeyinka, 2014; 2017). Firms in dense geographic proximity tend to enjoy certain advantages of agglomeration relative to isolated enterprises (Oyelaran-Oyeyinka, 2006). This happens in at least two different ways. First, demand for their goods and services is enhanced as potential customers come to know about the existence of the cluster. This is especially true for micro- and small enterprises whose markets tend to be local and dependent on direct sales to traders and individual consumers. Second, a cluster's ability to innovate and supply high quality products also benefits from agglomeration. For these reasons, the main advantage of agglomeration derives from the properties of knowledge: that it is largely tacit, uncodified and informal. The growth of clusters is most times anchored on how much the enterprises improved in acquiring, disseminating, and adapting knowledge and technology (both domestic and foreign); building a relatively educated labour force; achieving collective efficiency through joint actions and cooperation, and gaining support from national and local governments, institutes, and, in some cases, international bodies (Zeng, 2008).

Previous studies (Abiola, 2008; Oyelaran-Oyeyinka & McCormick, 2007) on the Otigba market cluster investigated how the cluster was formed, how its enterprises evolved, which elements contributed to the enterprises' success, and how the cluster was sustained. These studies did not, however, explore how external (cluster-related) factors and internal (enterprise-related) factors influenced innovation capability. Hence, this research on which this Working Paper is based sought to fill this gap in the literature.

Innovation Capability

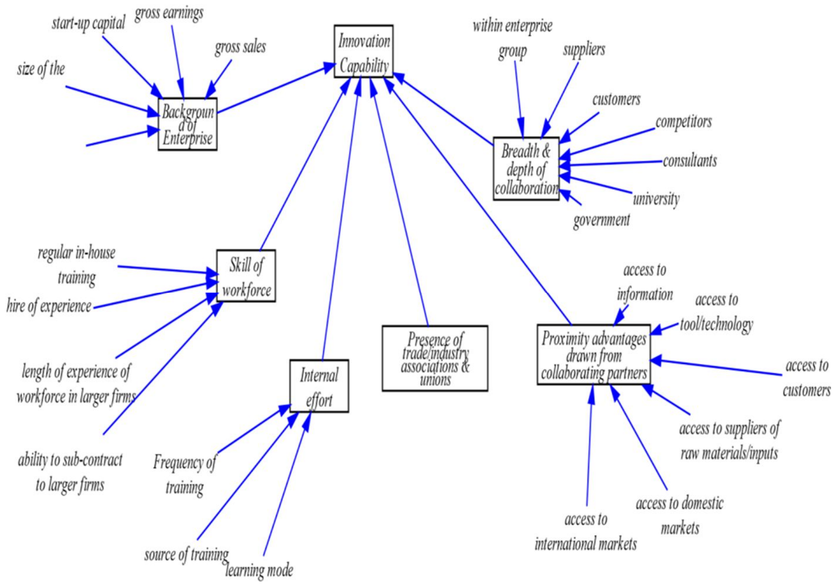
In the broad sense, innovation capability in enterprises can be described as the way in which production processes and technologies are organised and managed to manufacture the desired product/service for that enterprise (Bell & Figueiredo, 2012). It can also be seen as the ability of an enterprise to support the development of new products and services (Albaladejo & Romijn, 2000; Romijn & Albu, 2002). Hence, innovation capability has been defined in the literature from different perspectives. Adler and Shenbar (1990) explored innovation capability from five angles: the ability to develop new products that meet customer needs, the capacity to apply appropriate processes to produce these new products, the ability to adapt product and process technologies to meet future needs, the ability to respond to unexpected opportunities arising from technological change, and competitor activities. Capaldo, Iandoli, Raffa and Zollo (2003) view the innovation capability in six categories: skill of workforce (at the bottom), motivation, finance, human resources, advantages drawn from linkages and technological innovation capability (at the peak). Hence, drawing from existing literature, this study suggests that innovation capability can be drawn either from a source internal to the enterprise or from a source external to the enterprise which may or may not be limited to the cluster (Bell & Albu, 1999). The internal sources could include the firm's enterprise capital, the skill of the manager and that of the employees as well, and training of the workforce, while the external sources can be drawn from interaction with suppliers, customers, competitors, knowledge centres, trade associations, amongst others.

RESEARCH METHODOLOGY

A. Conceptual Framework

The conceptual framework used in this paper is based on concepts well-established in the literature. In the literature, chief among the conceptualisations of determinants of innovation capability are: research and development (R&D) expenditure/intensity; R&D expenditure and intensity (Bhattacharya & Bloch, 2004; Cabello-Medina et al., 2011; Jegede et al., 2015; Mytelka et al., 2004; Raymond & St-Pierre, 2010; Rogers, 2004; VegaJurado et al., 2008) the skill level of employees, firm capital, experience of the manager (Jegede et al., 2016; Kivimäki, 2013; Krause, 2004; Romijn & Albaladejo, 2002) and networks and collaboration (Bougrain & Haudeville, 2002; Freel, 2003; Hadjimanolis, 2000; Jegede et al., 2012a, 2012b; Oyelaran-Oyeyinka & Adebowale, 2012; Sarros et al., 2008). In order to apply, as this study did, an innovation-capability framework in an informal sector setting, the broad conceptual variables just outlined were simplified, in order to respond to the informal sector's peculiarities.

In Figure 1 below, the variable box at the top centre represents innovation capability, while the six other variable boxes connected to it represent six main determinants of innovation capability in informal, knowledge-based microenterprises. These six variables can be broadly categorised into two, namely: sources due to the strength of the enterprise, and sources due to the strength of the cluster/business environment to which they belong. The strength of the enterprise is premised on the background and characteristics of the enterprise, the skill of the employees in the enterprise, and the internal innovation efforts of the enterprise, while the strength of the cluster is premised on the breadth and depth of collaborating partners, proximity advantages drawn from collaborating partners, and the presence of an industry or trade association guiding the affairs of the enterprises in the cluster.



enterprise age of the enterprise

Workforce

Figure 1: Determinants of Innovation Capability in Informal, Knowledge-Based Microenterprises. Developed by author through modifications of Hadjimanolis (2000), Romijn and Albaladejo (2002), and Capaldo et al. (2003).

B. Study Variables and their Measurement

i. Innovation Capability

Process innovation was found to be the most common innovation modality in the Otigba hardware cluster, and hence it was treated, in the data analysis, as a proxy for innovation capability in the cluster. Process innovations were measured in terms of implementation of a new or significantly improved method of production within the reference year, and were recorded on a binary scale of "Yes" (=1) or "No" (=0).

Determinants of innovation capability in the cluster were measured in two broad categories— internal (peculiar to enterprise) factors, and external (peculiar to cluster) factors—as advanced by Bell and Albu (1999), Romijn and Albaladejo (2002), and Jegede et al. (2012b). Internal factors were captured using three broad variables: demographic characteristics of the enterprise, skill of the workforce (Romijn & Albaladejo, 2002), and internal efforts of the enterprise (Romijn & Albaladejo, 2002). External factors were captured using three broad variables: breadth and depth of collaborating partners (Laursen & Salter, 2014), extent of proximity advantages drawn from clustering (Love et al., 2014), and support from trade/industry associations guiding knowledge sharing within the cluster (Jegede et al., 2012b).

ii. Internal (Enterprise-related) Factors

This was measured using three proxy variables: background (strength) of the enterprise, the skills of the enterprise's workforce, and the enterprise's internal training efforts. The measurement of these variables is outlined in Table 1 below.

Table 1: Measurement of Predictor Variables for Internal (Enterprise-related) Factors

Predictor Variable	**Measurement**
(i) Background (strength) of enterprise	
Initial start-up capital	Continuous variable
Age of enterprises	Continuous variable
Size of enterprises	Continuous variable
Financial capital (percentage increase in the enterprise's annual gross earnings in 2016 relative to 2015)	Continuous variable
Production capital (percentage increase in the enterprise's annual gross sales in 2016 relative to 2015)	Continuous variable
(ii) Skill of enterprise's workforce	
Exposure to regular internal training programmes	"Yes" (=1) or "No" (=0)
Employment of employees with extensive prior work experience with larger computer firms	"Yes" (=1) or "No" (=0)
Prior work experience in other larger firms	"1–2 years" (=1), "3–4 years" (=2), "5–6 years"(=3), "7–8 years" (=4)
Ability of enterprise to sub-contract for larger businesses	"Yes" (=1) or "No" (=0)
(iii) Enterprise's internal training effort	
Frequency of in-house training for the enterprises' workforces	"Once a year" (=1), "Quarterly" (=2)
	"Monthly" (=3), and "Weekly" (=4)
Source of training	"Sourced within the enterprise" (=1)
	"Sourced from other enterprises within the cluster" (=2)
	"Sourced from other enterprises outside the cluster" (=3)
	"Sourced from a knowledge institution" (=4)
	"Sourced from abroad" (=5)
Mode of learning among employees	"Learning under experienced personnel" (=1)
	"Assignment of simple task to the new employees" (=2)
	"Assignment of bigger task to the new employees with close supervision" (=3)

The direction of relationship between these internal factors—background (strength) of enterprise, skill of enterprise's workforce, and enterprise's internal training effort—and the extent of process innovation was analysed using Spearman's correlation. For the variables that showed significant positive correlations, binary logistic regression was used to determine the impact of each variable representing internal factors on extent of process innovation (innovation capability) as shown in the equation in Model 1 below:

Model 1 Specification log(odds) = log(y/1-y) = $\mathbf{a + b_1x_1 + ... + b_nx_n + e}$ **……… (i)**
Where*: y = extent of process innovation a = intercept (constant) b = coefficient (constant) e = error term* x_1 to x_n = variables of internal factors

iii. External (Cluster-related) Factors

This was measured using three variables: breadth and depth of collaborating partners, extent of proximity advantages drawn from clustering, and support from trade/industry associations guiding knowledge-sharing within the cluster. The measurement of these variables is outlined in Table 2 below.

Table 2: Measurement of Predictor Variables for External (Cluster-related) Factors

(i) Breadth and depth of the collaborating partners	
other enterprises within your enterprise group	"Never" (=0), "Occasionally" (=1), "Always" (=2)
suppliers of equipment, materials, components or software	"Never" (=0), "Occasionally" (=1), "Always" (=2)
clients or customers	"Never" (=0), "Occasionally" (=1), "Always" (=2)
competitors or other enterprises in your cluster	"Never" (=0), "Occasionally" (=1), "Always" (=2)
consultants, commercial labs or private R&D institutes	"Never" (=0), "Occasionally" (=1), "Always" (=2)
universities or other higher education institutions	"Never" (=0), "Occasionally" (=1), "Always" (=2)
government research institutes	"Never" (=0), "Occasionally" (=1), "Always" (=2)
(ii) Support from trade/industry associations	"Yes" (=1) or "No" (=0)
(iii) Extent of the proximity advantages drawn from clustering	
access to information	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)
access to tools/technology	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)
access to customers	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)
access to suppliers of raw materials and input	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)
access to domestic market	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)
access to international market	"Not significant" (=0), "Slightly significant" (=1), "Very significant" (=2)

The direction of relationship between these external factors—breadth and depth of collaborating partners, support from trade/industry associations, extent of proximity advantages drawn from clustering—and the extent of process innovation was analysed using Spearman's correlation. For the variables that showed significant positive correlations, binary logistic regression was used to determine the impact of each variable representing external factors on the extent of process innovation (innovation capability) as shown in the equation in Model 2 below:

Model 2 Specification $\log(\text{odds}) = \log(y/1\text{-}y) = \mathbf{a + b_1}x_1 \mathbf{+ ... + b_n} x_n \mathbf{+ e}$ **……… (ii)**

Where: *y = extent of process innovation a = intercept (constant) b = coefficient (constant) e = error term* x_1 *to* x_n *= variables of internal factors*

C. Assumptions of the Models

Sample size: the study avoided small sample sizes within large numbers of predictors so as not to reduce its power. Also, categorical predictors with less than five cases in a category were a voided because this can lead to poor model fit.

Multi-collinearity: The study involved a bivariate correlation analysis to check for high intercorrelations between predictors. Any bi-variable correlation values greater than 0.70 indicated high collinearity and were not used in the regression analysis. In addition, collinearity diagnostic tests were also carried out: tolerance value of less than 0.10 indicated high collinearity while variance inflation factor (VIF)-values greater than 10 indicated high collinearity and were not used in the regression analysis.

Outliers: A scatter plot was used to identify any outlier variables in the model, using a standard deviation of 3.3.

D. Research Scope

The research was grounded on the collection of first-hand data, by developing a methodological framework/questionnaire useful for testing standard innovation indicator metrics for the informal sector and administering survey instruments on 200 ICT business units in the Otigba hardware cluster in Lagos, which consists of approximately 4,000 business units.

The sample frame used was the stratified sampling techniques to selected relatively equal number of respondent that were involved in different range of technical services. Those identified were: networking services, production of peripherals, installation of software, branding computer and other equipment, sales of hardware and software of computer, IT services, general IT maintenance and repairs, assemblage of computers and accessories, and sales of peripherals and repair of mobile phones and tablets. Twenty microenterprises were selected from each category to add up to the 200 selected microenterprises. The survey results were used for undertaking quantitative analyses responding to the study's objectives. The information gathered was supplemented with additional information from published sources.

E. Research Instruments and Subjects

The research instrument used was a set of questionnaires administered to the owners and employees of the microenterprises at Otigba hardware cluster. These microenterprises are comprised of businesses having employee size of less than 10, and that were not incorporated nor registered for taxation.

F. Data Analysis and Interpretation

Information from the questionnaire was fed into Statistical Package for Social Science (SPSS) 20.0, and was analysed using both descriptive and inferential statistics responding to the research's core objectives.

FINDINGS AND DISCUSSION

A. Socio-demographic Characteristics of the Enterprises in the Cluster

Figure 2 depicts the main business activities that the enterprises were found to be engaged in. The key activities were found to be hardware and software maintenance (46%), and sales and services (40%). Others were consultancy and trainings (6%), installations (4%), and web development (4%). All these activities represent involve technologies with plentiful and frequent incremental innovations.

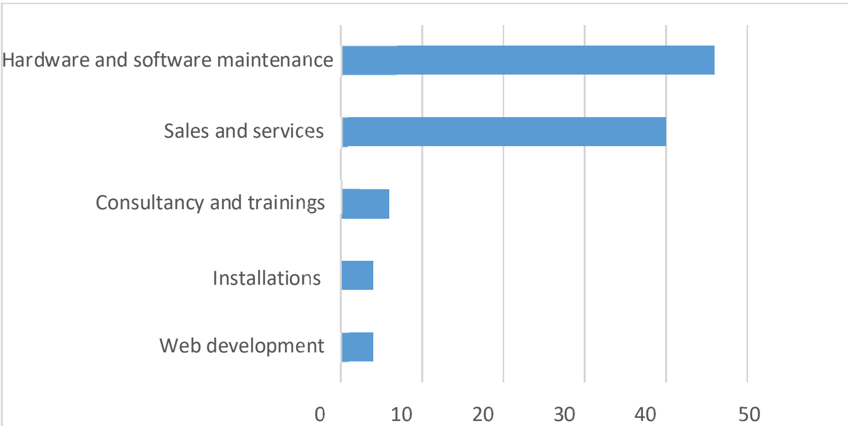


Figure 2: Business Activities in the Cluster

About half (52%) of the enterprises claimed that they had an initial start- up capital in the range of NGN200,000 – 400,000 (see Table 3 below), while about one quarter (22%) of the firms said they had started with NGN100,000 or less. The rest of the firms, about (24%), claimed to have had over NGN4 million as their start-up capital.

Table 3: Initial Start-up Capital for the Business

Amount of capital, in Nigerian Naira (NGN)	Frequency	%
No response	4	2
Less than NGN100,000	44	22
NGN100,000-1,999,999	103	51.5
NGN2,000,000 -3,999,999	8	4
NGN4,000,000 - 5,999,999	20	10
NGN6,000,000 - 7,999,999	5	2.5
NGN8,000,000 - 9,999,999	3	1.5
NGN10,000,000 - 11,999,999	3	1.5
NGN12,000,000 and above	10	5
Totals	200	100

Note: At the time of writing, USD1 is worth approximately NGN360

In the cluster, it was found that most operators preferred to separate family relationships from business as only 10.5% of the businesses studied were family enterprises (see Table 4 below).

Table 4: Percentage of Family Enterprises

	Frequency	%
Yes	21	10.5
No	177	88.5
Sub-totals	**198**	**99**
Missing	2	1
Totals	**200**	**100**

Hence majority of the enterprises have very few of their family members involved in the running of their businesses. Even though the business sampled were informal enterprises, a large majority (90%) of the respondents reported not having any family members in the day-to-day running of their business (Table 5 below). This further buttresses the point that informal businesses are hard to define, as some scholars interchangeably refer to informal businesses and household businesses.

Table 5: Family Members Working for the Firm in the Cluster

No.	Frequency	%
0	180	90
1	4	2
2	11	5.5
3	1	0.5
4	1	0.5
5	3	1.5
Totals	200	100

B. Characteristics of the Cluster

Table 6 below shows the nature of the openness at the Otigba market cluster. The majority of the enterprises in the cluster strongly agreed that while there was "competition within the computer village" (mean = 4.64) "cooperation within the cluster" was fully embraced at the same time. Since open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, the firms looked to advance their technology (De Beer et al., 2014; De Beer & Armstrong, 2015; De Beer, 2017).

Table 6: Nature of Open Innovation in the Cluster

	N.	Min.	Max.	Mean	Std. dev.
There is competition within the computer village	200	1	5	4.64	.576
There is cooperation within the computer village	200	1	5	4.10	.857
There is mutual trust within the computer village	200	1	5	3.43	.894
Valid N (listwise)	200				

Scale: Strongly agree (=5), Agree (=4), Undecided (=3), Disagree (=2), Strongly disagree (=1)

Table 7 below reveals more details regarding the nature of the cluster. All of the firms reported that they usually exchange information with other technicians, share experience with other technicians, engage technicians from other firms, and share tools and equipment with other technicians though none of them had a joint purchase of expensive equipment or importation of inputs. The reason for this disparity could be to avoid the conflict that may come with joint ventures. Also, the cluster placed more emphasis on sharing what they had than on combined effort.

Table 7: Modes of Open Innovation in the Cluster

	N.	Min.	Max.	Mean	Std. Dev.
Exchanging information with other technicians	200	0	4	3.45	0.855
Sharing experience with other technicians	200	0	4	3.20	1.130
Engaging technicians from other firms	199	0	4	3.17	1.172
Sharing tools with other technicians	200	0	4	3.07	1.354
Sharing equipment with other technicians	200	0	4	3.03	1.398
Joint purchase of expensive equipment	197	0	4	0.32	0.644
Joint importation of inputs	194	0	4	0.14	0.529
Valid N (listwise)	193				

Scale: always (=4), usually (=3), occasionally (=2, rarely (=1), not at all (=0)

C. Extent of Innovations by the Enterprises

The enterprises were mainly involved in process innovation (nearly 70% of the enterprises), followed by marketing innovation (nearly 30%), but their product innovation was low (Table 8 below). According to the Oslo Manual (OECD, 2005), process innovations include new or significantly improved methods for the creation and provision of services. This can also involve significant changes in the equipment and software used in service-oriented firms, or in the procedures or techniques that are employed to deliver services. For this research, process innovation was used to generalise for all innovation types, and was therefore used as the proxy for innovation capability.

Table 8: Types of Innovations Enterprises Involved in

	Frequency	%
Product innovation	7	3.5
Process innovation	134	67
Marketing innovation	55	27.5
Other kinds of innovation	1	0.5
Subtotals	**197**	**98.5**
Missing	3	1.5
Totals	**200**	**100**

D. Determinants of Innovation Capability in the Cluster

i. Internal (Enterprise-related) Factors

Of the 10 variables considered as internal determinants of innovation capability, seven were positively correlated with extent of innovation, while three were negatively correlated. Of the seven that were positively correlated, four were strongly positively correlated (Table 9 below). The incidence of in-house training had the highest positive correlation with ability of the enterprises to implement innovations ($r = 0.773$; $p < 0.01$), and similarly for frequency of the trainings (r = 0.535; p < 0.01). This was followed by percentage increase in annual turnover (r = 0.468; p < 0.01) and by percentage increase in annual sales (r = 0.343; p < 0.01).

Table 9: Spearman's Correlation between Enterprise Internal Factors and Process Innovation

	Correlation coefficient
Start-up capital	–0.49
Age of enterprise (year of establishment)	–0.007
Size of work force	0.067
Percentage annual increase in turnover	0.468**
Percentage annual increase in sales	0.343**
Sub-contracting to larger firms	–0.14
Presence of in-house trainings	0.773**
Frequency of trainings	0.535**
Source of the trainings	0.025
Mode of learning (transferring knowledge)	0.144
** Correlation is significant at the 0.01 level (2-tailed).	

The study went further to carry out a binary logistic regression of only the strongly positively correlated values, to determine the impact of each of these variables on innovation capability. Prevalence of process innovation was used to proxy innovation capability, which was the dependent variable. The independent variables included incidence of training, frequency of training, percentage annual increase in turnover and percentage annual increase in sales volume (Model 1, shown earlier). Because incidence of in-house training can be considered as perfectly predicting the outcome (innovation capability), due to its very high collinearity with the innovation capability proxy variable, it was dropped from the equation in Model 1. Hence, only three variables were used in the equation. The Nagelkerke R-square value from Table 10 below implies that the three variables in Model 1 explain 41.1% of the variates in the outcome being predicted or affected by the predictor variables in the model. This is quite acceptable for a binary logistics regression.

Table 10: Model 1 Summary

Step	**–2 log likelihood**	**Cox & Snell Rsquare**	**Nagelkerke Rsquare**
1	25.379[a]	.132	0.411

Note: Estimation terminated at iteration number 8.

Also, the classification table (Table 11 below) shows how accurate the variables were in predicting the outcome: of the outcome was correctly predicted about 94% of the time by Model 1, once again affirming that the model was strong.

Table 11: Classification Table [a] for Model 1

	Observed		Predicted		
			Process innovation		Percentage correct
			0	1	
Step 1	Process innovation	0	1	4	20
		1	2	96	98
	Overall percentage				94.2

Note: Cut value is .500.

Table 12 below gives the actual coefficients that we can use to create the equation in the regression model (Model 1). It also shows the odds ratio associated with each of the variables in the equation. The higher the ratio is above 1, the more likely it is that the enterprise will implement innovations. This implies that with a 1% increase in the annual turnover of an enterprise, the chances of its implementing innovations increases by 120%. Also, with a 1% increase in the sales of the enterprises, their chances of implementing innovation increases by 80%, while with a unit increase in the frequency of training of the employees in the workforce, the enterprises are about 7 times more likely to implement innovations. Hence, using the values shown in Table 12 below, Model 1 can be rewritten as:

$$\textbf{log(odds)} = \textbf{log}(y/1-y) = -4.804 + 0.179\times(\textbf{PIAT}) - 0.123\times(\textbf{PIAS}) + 1.917\times(\textbf{FOT}) + e$$

Where *y = implementation of process innovation, PIAT is percentage increase in annual turnover, PIAS is percentage increase in annual sales, FOT is frequency of training, and e = error term in the equation.*

Table 12: Binary Logistic Regression of Enterprise Internal Factors and Process Innovation

		B.	S.E.	Wald	Df.	Sig.	Exp(B)
Step 1[a]	Percentage increase in annual turnover	.179	.078	5.345	1	.021	1.197
	Percentage increase in annual sales	.123	.060	4.186	1	.041	.884
	Frequency of training	1.917	.670	8.191	1	.004	6.801
	Constant	–4.804	3.104	2.395	1	.122	.008

Regarding the internal determinants of innovation capability, the incidence of in-house training had the highest positive correlation with the ability of the enterprises to implement process innovations, and similarly for frequency of the trainings. This was followed by percentage increases in annual turnover and by percentage increases in annual sales – which is in line with previous studies carried out in other countries (Moodie, 2004; Van Adelsberg & Trolley, 1999).

Recent literature (Harmsen et al., 2000; Peretz et al., 2015) has also underlined the fact that the quantity of output of a firm determines to a great extent the amount of innovation within that firm. The studies found that the size of a firm, the mode of learning, and the source of training also had positive relationships with the implementation of innovation in the enterprises—which is again in accord with several studies that have been carried out, as described in earlier literature such as Adeyeye, Jegede, and Akinwale (2013), Adeyeye, Jegede, Oluwadare and Aremu (2016), Bhattacharya and Bloch (2004), Hadjimanolis (2000), Freel (2003), Jegede, Ilori, Olorunfemi and Oluwale (2016), and Rogers (2004). On the other hand, and in contrast to existing literature (see, for instance, Rogers, 2004), age of firm, start-up capital and being an auxiliary to a larger firm all have a negative correlation with the implementation of innovation as described in this study.

ii. External (Cluster-related) Factors

Of the eight variables considered as external determinants of innovation capability, five were positively correlated with four of these being strongly positively correlated—with the implementation of innovation (Table 13 below). Three variables were negatively correlated with implementation of innovation – with three being strongly negatively correlated. Collaborations within an enterprise or enterprise group ($r = 0.515$; $p < 0.01$), with customers ($r = 0.302$; $p < 0.01$), competitors ($r = 0.273$; $p < 0.01$), and trade associations or unions ($r = 0.240$; $p < 0.01$) were all strongly positively associated with implementation of innovation – once more corroborating several previous studies (Bramwell et al., 2008; Feldman, 1999; Jegede, 2017a; 2017b; Sandee & Rietveld, 2001) (see Table 13). On the other hand, collaborations with R&D laboratories and consultants, universities and knowledge centres, and with government agencies were all strongly negatively correlated with implementation of innovation (Table 13). This indicated that the institutional and government sources of collaboration were not used by the enterprises in implementing their innovations.

Table 13: Spearman's Correlation between Enterprise External Factors and Process Innovation

Type of collaboration	Correlation coefficient
Collaborations within group	0.515**
Collaborations with suppliers	0.143
Collaborations with customers	0.302**
Collaborations with competitor	0.273**
Collaborations with R&D consultants	–0.506**
Collaborations with universities	–0.342**
Collaborations with government	–.0508**
Collaborations with trade association	0.240**

** Correlation is significant at the 0.01 level (2-tailed).

In like manner, the author carried out yet another binary logistic regression of the strongly correlated values to assess the impact of each of the variables on the extent of innovation. Prevalence of process innovation was also used to proxy innovation capability as the dependent variable, while the independent variables included collaborations within an enterprise or enterprise group, collaborations with customers, collaborations with competitor, collaborations with R&D consultants, collaborations with universities, collaborations with government agencies and collaborations with trade associations or unions (Model 2). The Nagelkerke R-square value from Table 14 below implies that the seven variables in Model 2 explain 31.5% of the variates in the outcome being predicted or affected by the predictor variables in the model – again quite acceptable for a binary logistics regression. Also, the classification table on Table 15 below shows how good the variables were in predicting the outcome: about 81% of the outcome was rightly predicted by Model 2, once again affirming that the model was good (Table 15).

Table 14: Model 2 Summary

Step	–2 log likelihood	Cox & Snell R-Square	Nagelkerke RSquare
1	116.302[a]	0.188	0.315

Note: Estimation terminated at iteration number 20.

Table 15: Classification Table for Model 2

	Observed		Predicted		
			Process innovation		Percentage correct
			0	1	
Step 1	Process Innovation	0	5	23	17.9
		1	8	131	94.2
	Overall percentage				81.4

Note: Cut value is .500.

This implies that, for a unit increase in the depth of collaboration within an enterprise or enterprise group, the chances of the enterprise implementing innovations increases by a factor of 3. With a unit increase in the depth of collaboration with customers, the enterprises are about 116 million times more likely to implement innovations. Also, a unit increase in the depth of collaboration with competitors increases the enterprises' chance of implementing innovation by 110%. And as the enterprises join the trade association or union they are 3 times likely to implement innovations. Hence, Model 2 can be re-written as:

$$\log(\text{odds}) = \log(y/1\text{-}y) = -57.587 + 1.044 \times (CWEG) + 18.573 \times (CWCu) + 0.128 \times (CWCo) + 1.086 \times (CTAU) + e \text{ .... (ii)}$$

Where *y = implementation of process innovation, CWEG is collaborations within the enterprise group, CWCu is collaborations with customers, CWCo is collaborations with competitors, CTAU is collaborations with trade association or unions and e = error term in the equation.*

Table 16 below gives the actual coefficients that we can use to create the equation in the regression model (Model 2). It also shows the odds ratio associated with each of the variables in the equation. The higher the ratio is above 1, the more likely it is that the enterprise will implement innovations.

Table 16: Binary Logistic Regression of Enterprise External Factors and Process Innovation

Step 1[a]	B	S.E.	Wald	df	Sig.	Exp(B)
Within enterprise	1.044	.396	6.949	1	0.008	2.841
Customers	18.573	15282.763	.000	1	0.999	116465172.514
Competitor	.128	.433	.088	1	0.767	1.137
Association	1.086	.502	4.681	1	0.030	2.963
Constant	–57.587	45848.288	.000	1	0.999	.000

Note: Variable(s) entered on Step 1: within enterprise, customers, competitor, association

iii. Proximity Advantages from Openness in the Cluster

As seen earlier, in Table 7, it is evident that openness plays a very significant role in access to information, customers, new domestic markets, tools and technology, suppliers of raw materials and inputs. However, it plays only a limited role on finished products for the export market. This implies that the cluster still needs to expand its territory in terms of market range for its products. This may be achieved through continuous improvement on the products from the cluster. Regarding cluster determinants of innovation capability, several previous studies (Adebowale & Oyelaran-Oyeyinka, 2013; Dodgson, 2018; Jegede et al., 2012c; Jegede 2017a; 2017b; Kazadi et al., 2016; Lundvall et al., 2009; Romijn & Albaldejo, 2002) have highlighted the importance of the number of stakeholders within clusters that firms may network or collaborate with for innovation. Proofs exist in favour of customers, suppliers, trade associations, higher education and research institutions, among others, as helpful sources of information for the firms' innovation activities. Collaborations within enterprises or enterprise groups, with customer, competitors, and trade association or unions were all strongly positively associated with implementation of innovation. On the other hand, collaborations with R&D laboratories and consultants, universities and knowledge centres and with government agencies were all strongly negatively correlated with implementing innovation. This indicated that institutional and government sources of collaboration were not used by the enterprises in implementing their innovations. Suffice it to say that, although the enterprises did not take advantage of the knowledge output from institutional sources, they did leverage the information readily available from their market sources and, most importantly, from their industry and trade associations which more or less operate as private institutions.

CONCLUSION AND RECOMMENDATIONS

This survey showed that the microenterprises in the Otigba hardware cluster—which are primarily involved in engineering and repairs, sales, installation, and maintenance services—are very dynamic. They practice open innovation that allows them to supplement internal ideas with external ideas, as well as exploring both internal and external paths to market, as they aim to advance their technology and productivity. Hence, though there is visible competition within the cluster, while at same time strong cooperation within the cluster is fully embraced by the enterprises.

It was found that although product, market and organisational innovations were also present, process innovation was at the core of innovations in the cluster. Hence, the enterprises' innovation capability was mainly for the implementation of process innovations—which principally involve significant changes in the equipment and software used in offering their services, as well as significant changes in the procedures or techniques employed to deliver services.

The chief internal determinants of innovation capability in the enterprises were the incidence and frequency of training, and business growth (captured in the increment in annual gross earnings and sales). The principal external causes of innovation capability of enterprises in the cluster were the intensity of cooperation with an enterprise or the enterprise's network or group; receiving feedback from customers; spillovers from competitors; and joining trade/industry associations where up-to-date information was being shared.

It was evident that openness plays a very significant role in access to information, to customers, to new domestic markets, to tools and technology, and to suppliers of raw materials and inputs. However, it plays only a limited role on finished products for the export market as this is directly determined by enterprises internal capabilities, i.e., the skill of the workforce and how trained the workforce is. External sources of knowledge are important to complement internal capabilities. Internal capabilities will determine absorptive capacity, and will provide the foundation on which external knowledge can rest.

At the same time, it is apparent in the findings that a lot more is still required for the enterprises to build up their internal capabilities and reduce reliance on external sources of knowledge. (Most of the variables for internal factors did not have as much significant positive impact on innovation capability as the external factors.) The findings from the study showed that external capabilities through cooperation and openness are necessary to complement enterprises' internal capabilities (mainly internal training programmes). Finally, all of the respondent enterprises who benefitted from proximity in the cluster were involved in at least one form of innovation.

Acknowledgements

This work was carried out under the auspices of the Open African Innovation Research (Open AIR) network, in partnership with the University of Cape Town (South Africa), the University of Johannesburg (South Africa), the University of Ottawa (Canada), The American University in Cairo (Egypt), Strathmore University (Kenya), and the Nigerian Institute of Advanced Legal Studies (Nigeria).

We acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the International Development Research Centre (IDRC), and the UK Department for International Development (DFID). The views expressed in this work are those of the authors and do not necessarily represent those of the research funders.

We appreciate the comments received from Prof. Jeremy de Beer of the University of Ottawa and Prof. Erika Kraemer-Mbula of the University of Johannesburg, through the internal review processes of the Open AIR network. We also acknowledge the supervision provided by Prof. Kraemer-Mbula, in her capacity as Open AIR theme leader for research into informal-sector innovation, during the conceptualisation of the proposal, drafting of the research instrument, and implementation of the project.

References

Abiola, B. O. (2006). *Knowledge, technology and growth: The case study of Otigba computer village cluster in Nigeria*. Unpublished paper. Washington, DC: Knowledge for Development Programme, World Bank.

Adebowale, B. O. A., & Oyelaran-Oyeyinka, B. (2012). Determinants of productivity and inter-firm collaboration in Nigerian clusters. *International Journal of Technology and Globalisation, 6*(3), 188–205.

Adeyeye, A. D., Jegede, O. O., & Akinwale, O. Y. (2013). The impact of technology innovation and R&D on firms' performance: An analysis of Nigeria's service sector. *International Journal of Technology Learning, Innovation and Development*, *6*(4), 374–395. http://doi.org/10.1504/IJTLID.2013.060873

Adeyeye, A. D., Jegede, O. O., Oluwadare, A. J. & Aremu, F. S. (2016). Micro-level determinants of innovation in firms: Evidence from manufacturing sector in Nigeria. *Innovation and Development, 6*(1), 1–14. https://doi.org/10.1080/2157930X.2015.1047110

Adler, P., & Shenbar, A. (1990). Adapting your technological base: The organizational challenge. *Sloan Management Review*, *32*(1), 25–37.

Albaladejo, M., & Romijn, H. (2000). *Determinants of innovation capability in small UK firms: An empirical analysis*. Netherlands: Eindhoven Centre for Innovation Studies.

Awoleye, O. M. (2015). *Assessment of production and innovation capability in selected ICT clusters in Nigeria*. Unpublished PhD Thesis, Faculty of Technology, Obafemi Awolowo University, IleIfe, Nigeria.

Bell, M., & Albu, M. (1999). Knowledge systems and technological dynamism in industrial clusters in developing countries. *World Development, 27*(9), 1715–1734. http://doi.org/10.1016/S0305-750X(99)00073-X

Bell, M., & Figueiredo, P. N. (2012). Innovation capability building and learning mechanisms in latecomer firms: Recent empirical contributions and implications for research. *Canadian Journal of Development Studies, 33*(1), 14–40. http://doi.org/10.1080/02255189.2012.677168

Bhattacharya, M., & Bloch, H. (2004). Determinants of innovation. *Small Business Economics*, *22*(2), 155–162.

Bougrain, F., & Haudeville, B. (2002). Innovation, collaboration and SMEs internal research capacities. *Research Policy*, *31*(5), 735–747. http://doi.org/10.1016/S00487333(01)00144-5

Bramwell, A., Nelles, J., & Wolfe, D. A. (2008). Knowledge, innovation and institutions: Global and local dimensions of the ICT cluster in Waterloo, Canada. *Regional Studies, 42*(1), 101–116. http://doi.org/10.1080/00343400701543231 Cabello-Medina, C., Carmona-Lavado, A., & Cuevas-Rodríguez, G. (2011). Organisation of R&D departments as determinants of innovation: Testing alternative explanations. *Technology Analysis & Strategic Management*, *23*(4), 383–400. http://doi.org/10.1080/09537325.2011.558396

Capaldo, G., Iandoli, L., Raffa, M., & Zollo, G. (2003). The evaluation of innovation capabilities in small software firms: A methodological approach. *Small Business Economics*, *21*(4), 343– 354.

Cassiman, B., & Veugelers, R. (2006). In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Management Science, 52*(1), 68–82. http://doi.org/10.1287/mnsc.1050.0470

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: The two faces of R & D. *The Economic Journal, 99*(397), 569–596. doi: 10.2307/2233763

Cohen, W. M., & Levinthal, D. A. (2000). Absorptive capacity: A new perspective on learning and innovation. In R. L. Cross, Jr, & S. B. Israelit (Eds.), *Strategic learning in a knowledge economy* (pp. 39–67). London: Routledge.

Cooke, P. (2002). *Knowledge economies: Clusters, learning and cooperative advantage*. London: Routledge.

De Beer, J. (2017). *Open innovation in development: Integrating theory and practice across open science, open education, and open data*. Open AIR Working Paper No. 3. Cape Town and Ottawa: Open African Innovation Research (Open AIR).

De Beer, J., & Armstrong, C. (2015). Open innovation and knowledge appropriation in African micro and small enterprises (MSEs). *The African Journal of Information and Communication (AJIC)*, *16*, 60–71. https://doi.org/10.23962//10539/19315

De Beer, J. Sowa, I., & Holman, K. (2014). Frameworks for analysing African innovation: Entrepreneurship, the informal economy and intellectual property. In J. de Beer, C. Armstrong, C. Oguamanam, & T. Schonwetter (Eds.), *Innovation and intellectual property: Collaborative dynamics in Africa* (pp. 32–58). Cape Town: UCT Press.

De Beer, J., Kun, F., & Wunsch-Vincent, S. (2013). *The informal economy, innovation and intellectual property: Concepts, metrics and policy considerations*. WIPO Economic Research Working Papers 10. Geneva: World Intellectual Property Organisation, Economics and Statistics Division.

Dodgson, M. (2018). Technological collaboration in industry: Strategy, policy and internationalization in innovation. London: Routledge.

Feldman, M. P. (1999). The new economics of innovation, spillovers and agglomeration: A review of empirical studies. *Economics of Innovation and New Technology, 8*(1– 2), 5–25.
http://doi.org/10.1080/10438599900000002

Freel, M. (2003). Sectoral patterns of small firm innovation, networking and proximity. *Research Policy, 32*(5), 751–770. http://doi.org/10.1016/S0048-7333(02)00084-7

Gallego, J., Rubalcaba, L., & Suárez, C. (2013). Knowledge for innovation in Europe: The role of external knowledge on firms' cooperation strategies. *Journal of Business Research, 66*(10), 2034–2041. http://doi.org/10.1016/j.jbusres.2013.02.029

Hadjimanolis, A., & Dickson, K. (2000). Innovation strategies of SMEs in Cyprus, a small developing country. *International Small Business Journal*, *18*(4), 62–79.

Harmsen, H., Grunert, K. G., & Declerck, F. (2000). Why did we make that cheese? An empirically based framework for understanding what drives innovation activity. *R&D Management*, *30*(2), 151–166.

Ibero-American Network of Science and Technology Indicators (RICYT), Organisation of American States, (OAS), CYTED Program, & COLCIENCIAS/OCYT. (2001).
Bogota manual: Standardisation of indicators of technological innovation in Latin American and Caribbean Countries.
Retrieved from http://www.ricyt.org/manuales/doc_view/149-bogotamanual

Jegede O. O., Egbetokun, A. A., & Siyanbola W. O. (2012a). Assessment of technological innovations in the indigenous oil and gas servicing firms in Nigeria. *African Journal of Science, Technology, Innovation and Development*, *4*(2), 69– 91.

Jegede, O. O., Ilori, M. O., Sonibare, J. A., Oluwale, B. A. & Siyanbola, W. O. (2012b). Factors influencing innovation and competitiveness in the service sector in Nigeria: A sub-sectoral approach. *Journal of Management, 2*(3), 69–79. doi: 10.5923/j.mm.20120203.03

Jegede O. O., Aderemi H. O., Jesuleye O. A., & Siyanbola W. O. (2012c). Status of technological capacity building in the indigenous oilfield servicing firms in Nigeria vis-à-vis innovation capability. *Greener Journal of Science, Engineering and Technology Research*, *2*(1), 11–16.

Jegede, O. O., Ilori, M. O., Olorunfemi, M. O., & Oluwale, B. A. (2015). Innovating in a resourcebased economy: Role of R&D and non-R&D activities. In E. Betiku, B. S.
Ogunsina, & A. M. Jubril (Eds.), *Proceedings of the faculty of technology conference*, Obafemi Awolowo University, Ile-Ife, Nigeria, 21–22 September. Retrieved from http://www.oautekconf.org/proceedings/39-Jegede%20et%20al.pdf

Jegede, O. O., Ilori, M. O., Olorunfemi, M. O., & Oluwale, B. A. (2016). On the link between human capital, innovation and performance: Evidence from a resourcebased economy. *International Journal of Learning and Intellectual Capital*, *13*(1), 27–46. http://doi.org/10.1504/IJLIC.2016.074344

Jegede, O. O. (2017a). Collaborating to innovate: The case of the Nigerian mining industry. In A. Tsvetkova, J. Schmutzler, M. Suarez, & A. Faggian (Eds.), *Innovation in developing and transition countries* (pp. 156–170). Cheltenham, UK: Edward Elgar.

Jegede, O. O. (2017b). Linking information sources, innovation outputs and performance in Nigeria's Mining Sector. *Journal of Entrepreneurship and Innovation Management, 6*(2), 73– 95.

Kazadi, K., Lievens, A., & Mahr, D. (2016). Stakeholder co-creation during the innovation process: Identifying capabilities for knowledge creation among multiple stakeholders. *Journal of Business Research, 69*(2), 525–540. http://doi.org/10.1016/j.jbusres.2015.05.009

Keeble, D., & Wilkinson, F. (2017). *High-technology clusters, networking and collective learning in Europe*. London: Routledge.

Kivimäki, R. (2013). Work Organisation and Innovation-Case Study: Care Home X, Finland. Ithaca, NY: ILR School, Cornell University.

Krause, D. E. (2004). Influence-based leadership as a determinant of the inclination to innovate and of innovation-related behaviors: An empirical investigation. *The Leadership Quarterly, 15*(1), 79–102.

Laursen, K., & Salter, A. J. (2014). The paradox of openness: Appropriability, external search and collaboration. *Research Policy, 43*(5), 867–878. http://doi.org/10.1016/j.respol.2013.10.004

Love, J. H., Roper, S., & Vahter, P. (2014). Learning from openness: The dynamics of breadth in external innovation linkages. *Strategic Management Journal, 35*(11), 1703–1716. http://doi.org/10.1002/smj.2170

Lundvall, B. Å., Joseph, K. J., Chaminade, C., & Vang, J. (Eds.). (2009). *Handbook of innovation systems and developing countries: building domestic capabilities in a global setting*. Cheltenham, UK: Edward Elgar.

Moodie, G. (2004). Optimising tertiary education for innovating Australia. *Growth*, *53*, 92– 108.

Mytelka, L. K., Goedhuys, M., Arundel, A., & Gachino, G. (2004). *Designing a policyrelevant innovation survey for NEPAD*. United Nations University Institute for New Technologies (UNU-INTECH). Maastricht.

Organisation for Economic Co-operation and Development (OECD). (2005). *Oslo manual: The measurement of scientific and technological activities: Proposed guidelines for collecting and interpreting technological innovation data*. Paris.

OECD. (2015). *Frascati manual 2015: Guidelines for collecting and reporting data on research and experimental development*, *the measurement of scientific, technological and innovation activities*. Paris. http://dx.doi.org/10.1787/9789264239012-en.

Oyelaran-Oyeyinka, B. (2014). Industrialization pathways to human development: Industrial clusters, institutions and multidimensional poverty in Nigeria. In World Bank (Ed.), *Harnessing Africa's growth for faster poverty reduction: Proceedings of the First Annual Bank Conference on Africa* (pp. 23–24). Washington, DC: World Bank.

Oyelaran-Oyeyinka, B. (2017). Learning to compete in African industry: Institutions and technology in development. London: Routledge.

Oyelaran-Oyeyinka, B., & Adebowale, B. A. (2012). University-industry collaboration as a determinant of innovation in Nigeria. *Institutions and Economies*, *4*(1), 21-46.

Oyelaran-Oyeyinka, B., & Lal, K. (2006). Learning new technologies by small and medium enterprises in developing countries. *Technovation*, *6*(2), 220–231. http://doi.org/10.1016/j.technovation.2004.07.015

Oyelaran-Oyeyinka, B. (2006). *Learning hi-tech and knowledge in local systems: The Otigba computer hardware cluster in Nigeria*. UNU Working Paper Series 2006007.

Oyelaran-Oyeyinka, B., & McCormick, D. (2007). Industrial clusters and innovation systems in Africa. United Nations University Press.

Oyeyinka, O. (2017). *Industrial clusters, institutions, and poverty in Nigeria. Industrial clusters, institutions and poverty in Nigeria* (pp. 1–26). London: Springer.

Peretz, H., Levi, A., & Fried, Y. (2015). Organizational diversity programs across cultures: Effects on absenteeism, turnover, performance and innovation. *International Journal of Human Resource Management*, *26*(6), 875–903.

Raymond, L., & St-Pierre, J. (2010). R&D as a determinant of innovation in manufacturing SMEs: An attempt at empirical clarification. *Technovation, 30*(1), 48–56. http://doi.org/10.1016/j.technovation.2009.05.005

Rogers, M. (2004). Networks, firm size and innovation. *Small Business Economics*, *22*(2), 141–153.

Romijn, H. & Albaladejo, M. (2002). Determinants of innovation capability in small electronics and software firms in southeast England. *Research Policy*, *31*, 1053–1067. http://doi.org/10.1016/S0048-7333(01)00176-7

Romijn, H., & Albu, M. (2002). Innovation, networking and proximity: Lessons from small high technology firms in the UK. *Regional Studies, 36*(1), 81–86. http://doi.org/10.1080/00343400120099889

Sandee, H., & Rietveld, P. (2001). Upgrading traditional technologies in small-scale industry clusters: Collaboration and innovation adoption in Indonesia. *Journal of Development Studies*, *37*(4), 150–172. http://doi.org/10.1080/00220380412331322081

Sarros, J. C., Cooper, B. K., & Santora, J. C. (2008). Building a climate for innovation through transformational leadership and organizational culture. *Journal of Leadership & Organizational Studies*, *15*(2), 145–158. doi/abs/10.1177/1548051808324100

Schmitz, H. (1995). Collective efficiency: Growth path for small-scale industry. *The Journal of Development Studies*, *31*(4), 529–566.

Van Adelsberg, D., & Trolley, E. A. (1999). *Running training like a business: Delivering unmistakable value*. Oakland, CA: Barrett-Koehler Publishers.

Vega-Jurado, J., Gutiérrez-Gracia, A., Fernández-de-Lucio, I., & Manjarrés-Henríquez, L. (2008). The effect of external and internal factors on firms' product innovation. *Research Policy*, *37*(4), 616–632. doi: 10.1016/j.respol.2008.01.001

Zeng, D. Z. (2008). *Knowledge, technology, and cluster-based growth in Africa*. WBI Development Studies. Washington, DC: World Bank. doi: 10.1596/978-0-82137306-4

Innovating for Broadband: The Case of Television White Space Networks in Sub-Saharan Africa

Mjumo Mzyece[1], Luzango P. Mfupe[2], and Fisseha Mekuria[2]

[1]University of the Witwatersrand – Wits Business School (WBS)

PO Box 98, Johannesburg 2050, South Africa

[e-mail: Mjumo.Mzyece@wits.ac.za]

[2]Council for Scientific and Industrial Research (CSIR) – Meraka Institute

PO Box 395, Pretoria 0001, South Africa

[e-mail: {LMfupe, FMekuria} @csir.co.za]

Abstract

Television white space (TVWS) networks based on geo-location spectrum databases (GLSDs) present an excellent opportunity to provide affordable broadband to underserved rural communities in Sub-Saharan Africa. In this paper, we explore potential pathways to full-scale commercial deployment and diffusion of TVWS/GLSD technology in Sub-Saharan Africa from an innovation perspective. This is our key research contribution since previous works have focused on individual components of innovation in relation to TVWS/GLSD technology in Sub-Saharan Africa and elsewhere. In contrast, we explore the entire innovation process, from invention to commercialisation to diffusion. The case of South Africa is considered, in comparison with several other countries and sub-regions in Sub-Saharan Africa. We explain the technology behind TVWS networks and GLSDs, and the current state of TVWS and GLSD pilots, trials and commercial deployments in Sub-Saharan Africa. We then outline the broadband penetration and policy environment context. We examine the case in terms of four innovation paradigms, namely, inclusive innovation, open innovation, systems of innovation, and diffusion of innovation. We proceed to analyse existing and potential responses in terms of innovation policy and industrial policy. We assess the implementation status and conclude by summarising the paper, drawing key lessons and insights from the preceding discourse, and making recommendations for policy makers and practitioners.

Keywords: Appropriate Technology, Broadband, Innovation, Internet, Mobile, Television White Spaces, TVWS, Wireless.

INTRODUCTION

Studies of the impact of broadband estimate that a 10% increase in broadband penetration can raise economic growth by up to 1.4%; that doubling broadband speed can increase Gross Domestic Product (GDP) by as much as 0.3%; and that these effects are more pronounced in lower income countries than in higher income countries (ITU, 2016). Consequently, a number of governments in Sub-Saharan Africa, including South Africa (DTPS, 2013), have prioritised the rollout of broadband to their citizens.

Due to the global migration of television (TV) transmission from analogue to digital broadcast, a large portion of the very high frequency (VHF) and ultra high frequency (UHF) radio frequency (RF) spectrum bands will be freed up and become available for other uses on a geographical basis. Furthermore, these TV frequencies have favourable propagation characteristics, making them ideal for reaching otherwise economically unviable markets, such as sparsely populated rural areas. Television white space (TVWS) networks therefore present an excellent opportunity to provide affordable rural broadband connectivity in African countries (Masonta *et al.*, 2017). To that end, the Independent Communications Authority of South Africa (ICASA), the country's ICT regulator, recently finalised its regulations on the use of television white spaces (ICASA, 2018a). The challenge of diffusing this new dynamic spectrum sharing technology, its supporting regulations and its enabling policies throughout South Africa and other African countries is of paramount importance. This will help African countries create the necessary environment and market potential for the new unlicensed network technology and for the development of relevant societal broadband Internet services.

Geo-location spectrum databases (GLSDs) are the preferred technique for enabling spectrum sharing between primary users and secondary users, or white space devices (WSDs), in the VHF and UHF TV bands. The technological feasibility of a world-class GLSD solution for the African context has been successfully demonstrated (Mfupe *et al.*, 2014; Mekuria *et al.*, 2016).

In this paper, we explore potential pathways to full-scale commercial deployment and diffusion of TVWS/GLSD technology in Sub-Saharan Africa *from an innovation perspective* – this is our key research contribution. We note that: "Innovation is more than a new idea or an invention. An innovation requires *implementation*, either by being put into active use or by being made available for use by other parties, firms, individuals or organisations. The economic and social impacts of inventions and ideas depend on the diffusion and uptake of related innovations." (OECD/Eurostat, 2018: 44)

Whereas previous works have focused on *individual* aspects of this definition of innovation in relation to TVWS/GLSD technology in Sub-Saharan Africa and elsewhere, in this work we deal with *all* the aspects of innovation in an integrated manner. More specifically, we investigate how to move this new technology from invention to innovation, and from innovation to industrialisation, and how to drive the creation of related local small, medium and micro enterprises (SMMEs), and the establishment of an associated industrial base. In particular, the case of South Africa is considered, in comparison with several other countries and sub-regions in Sub-Saharan Africa.

In the following section, Section 2, we explain the technology behind TVWS networks and GLSDs, and the current state of TVWS and GLSD pilots, trials and commercial deployments in Sub-Saharan Africa. We then provide an analysis of the broadband penetration and policy environment context in Section 3. In Section 4, we examine the case in terms of four innovation paradigms, namely, inclusive innovation, open innovation, systems of innovation, and diffusion of innovation. We proceed to analyse existing and potential responses in terms of innovation policy and industrial policy in Section 5. We review the implementation status in South Africa and Sub-Saharan Africa in Section 6. We conclude, in Section 7, by summarising the paper, drawing key lessons and insights from the preceding discourse, and making recommendations for policy makers and practitioners.

TELEVISION WHITE SPACE (TVWS) NETWORKS AND GEO-LOCATION SPECTRUM DATABASES (GLSDs)

Motivation

There is an ever-increasing demand for RF spectrum to accommodate the massive growth in bandwidth requirements for wireless, mobile and nomadic access to the Internet and, secondly, underutilised spectrum can be repurposed to meet the need for rural affordable broadband access in the forthcoming 5th generation (5G) wireless ICT ecosystem. These two critical factors are driving the surge in research, development and, to a lesser extent, innovation activities in dynamic spectrum access (DSA). There are important technological and policy issues that must be addressed to realise holistic innovation and commercial development based on smart spectrum sharing (S3) technology for emerging economy countries. DSA and S3 technologies, as well as service frameworks for dynamic spectrum broadband networks, must contain software and features which will promote both network deployment and innovative policies to enable affordable broadband in underserved areas. A further function of DSA and S3 technologies is to create a pool of much-needed and underutilised spectrum channels and techniques for use in future wireless 5G Networks. It is thus necessary to develop innovative business models to address the various use cases made possible through smart spectrum sharing.

The main drivers and market potential for developing TVWS and GLSD technologies include the following:

- Migration from analogue TV to digital TV broadcasting standards and the need for efficient utilisation of spectrum resources, and to enable affordable broadband Internet connectivity.
- Meeting the 2020 Vision for broadband for all (DTPS, 2013) – technologies for enabling the design of low-cost broadband networks.
- Becoming a reliable design house for spectrum databases in South Africa, regional Southern African Development Community (SADC) states and other African emerging economy countries.
- Creating a comprehensive tool for shared spectrum broadband network planning and provision.
- Providing an inexpensive platform for the deployment of dynamic spectrum regulatory policy frameworks.
- Additional services such as: (a) wireless broadband infrastructure availability data and spectrum databases, and (b) spectrum monitoring tools, for wireless Internet service providers (WISPs), telecom regulators and government organs.

TVWS networks

Figure 1 depicts a typical TVWS broadband network. The network consists of a TVWS base station (BS) at the high tower with a sectorised antenna, connecting through a white space radio, to customer premises equipment (CPE) with TVWS transceivers at the service stations (located at rural schools, health clinics and public safety facilities, and agri-centres). The network backhaul is a high-bandwidth optical fibre link to the Internet and the GLSD for accessing available spectrum and network parameters. Other roles players that are connected via the Internet and GLSD include the regulator (ICASA), device manufacturers (DM), WISPs and Industry.

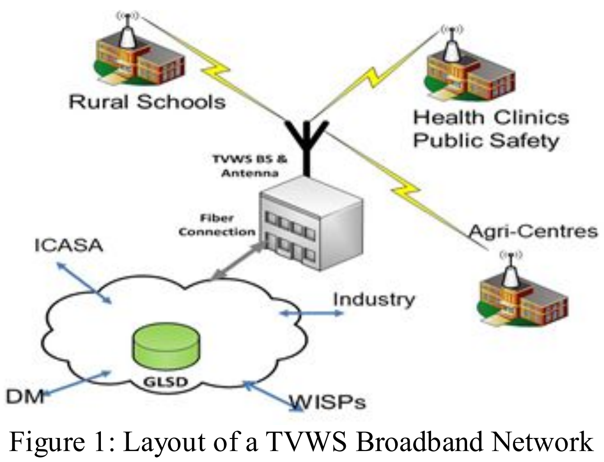


Figure 1: Layout of a TVWS Broadband Network

The role of GLSDs in the TVWS ecosystem

In order to ensure dynamic and efficient utilisation of the RF spectrum, the current trend among spectrum regulators and the wireless industry is to establish an ecosystem of key stakeholders in the TVWS value chain as shown in Figure 2.

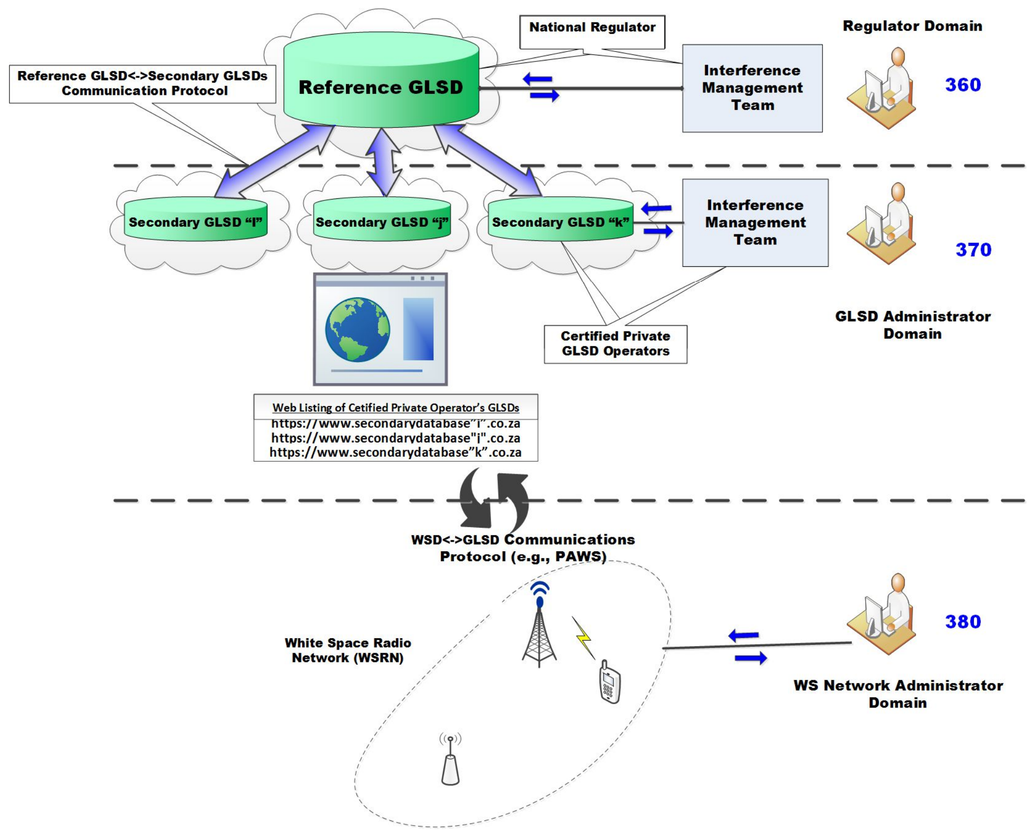


Figure 2: Typical TVWS ecosystem comprising: (360) the Reference geo-location spectrum database (R-GLSD) operated by the regulator, (370) Secondary GLSDs (S-GLSDs) operated by commercial entities and, (380) the TVWS wireless network operated by WISPs. (Source: Mfupe, 2016)

GLSDs are an enabling technology for the first phase in the cognitive radio network (CRN) evolution. The two major functionalities of CRNs are cognitive capability and re-configurability. Cognitive capability is the ability of a CRN device to sense the unused (white space) spectrum information from its ambient radio environment. However, GLSDs are currently the preferred means to implement spectrum sharing networks and guide dynamic spectrum access regulations by leading regulators due to their higher reliability compared with other options such as spectrum sensing and beaconing.

GLSDs enable interference mitigation and quality spectrum sharing between WSDs and licensed TV broadcasters in the VHF and UHF bands. GLSDs have two primary roles. First, to translate WS spectrum usage regulations taken as an input from the national spectrum regulatory authorities. Secondly, GLSDs provide a static technical mechanism for enabling WSDs to access TVWS spectrum without causing any harmful interference to the incumbent TV stations.

There are two dominant GLSD design approaches preferred by leading Western regulatory bodies (Mfupe *et al.*, 2014):

- The *Vectorised Approach*, a deterministic based approach favoured by both the Federal Communications Commission (FCC) in the United States and Innovation, Science and Economic Development (ISED) Canada (formerly Industry Canada).
- The *Pixelated Approach*, a statistical based approach proposed by the European Conference of Postal and Telecommunications Administrations (CEPT) and the UK's Office of Communications (Ofcom).

It is important to note that in most cases these two approaches produce almost identical results on spectrum availability. For the purposes of this paper, the pixelated approach will be assumed in combination with the ITU's method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 to 3000 MHz (ITU, 2009).

Pilots, trials and commercial deployments

There is no single authoritative, comprehensive repository of up-to-date information on TVWS and GLSD pilots, trials and commercial deployments in Africa, or anywhere else for that matter. Instead, the required information is scattered across multiple sources, such as the Dynamic Spectrum Alliance website[1], which lack one or more of the necessary elements of authority, comprehensiveness or up-to-dateness. Figure 3 presents our understanding of the current and historical status of TVWS or GLSD pilots and trials across Africa, based on our own analysis of multiple sources. To the best of our knowledge, while Africa is relatively well-represented globally in terms of TVWS or GLSD pilots and trials (13 countries across all major regions of Africa), up to now there has been no full-scale commercial deployment of TVWS/GLSD technology anywhere in the continent. It is this gap in full-scale commercial deployment of TVWS/GLSD technology that this paper addresses.

Figure 3: African countries where either TVWS or GLSD has been piloted or trialled (Source: Authors' own analysis)

[1] http://dynamicspectrumalliance.org/pilots/

Figure 4 shows a screenshot from the longest-standing of Africa's pilots and trials of TVWS/GLSD technology, the Geo-Location Spectrum Database at CSIR Meraka Institute in South Africa, with which two of the authors are directly affiliated.

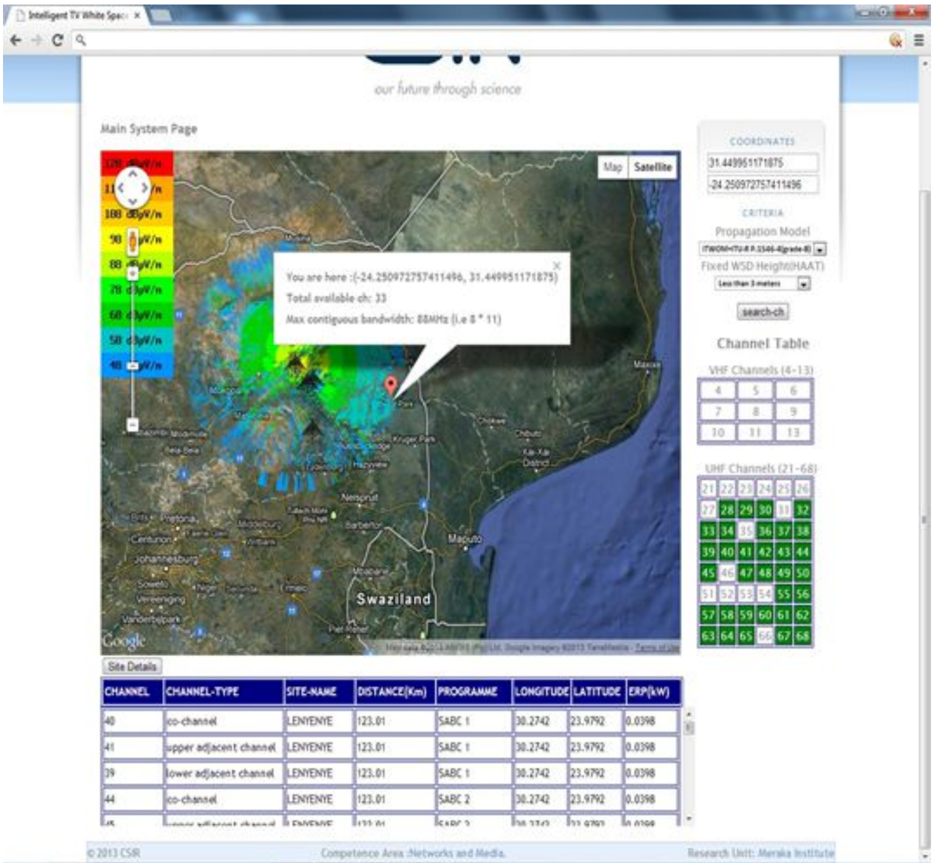


Figure 4: Results from CSIR Meraka Institute's GLSD (Source: http://whitespaces.meraka.csir.co.za/)

CONTEXTUAL ANALYSIS

Broadband penetration

Figure 5 shows active mobile-broadband subscription penetration rates across the world, where broadband is defined as a speed of at least 256 kb/s. Globally, active mobile-broadband subscriptions have exhibited strong growth over the past seven years, increasing from 11.5 per 100 inhabitants in 2010 to 56.4 in 2017 (ITU, 2017). For comparison, the active *fixed*-broadband subscription penetration rates in 2017 were 13.1 per 100 inhabitants for the global average versus 0.4 for Africa (ITU, 2017). South Africa's 2017 statistics are 70 per 100 inhabitants for active mobile-broadband subscriptions, and 3.1 per 100 inhabitants for active fixed-broadband subscriptions[2]. Africa has the lowest regional broadband penetration rates both for mobile-broadband and fixed-broadband subscriptions, far below the global averages. South Africa's mobile-broadband penetration rate is well above the global average and, in that sense, it is a positive outlier on the African continent. However, broadband affordability remains a significant challenge in most Sub Saharan African countries, including South Africa (Broadband Commission, 2018).

[2] https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

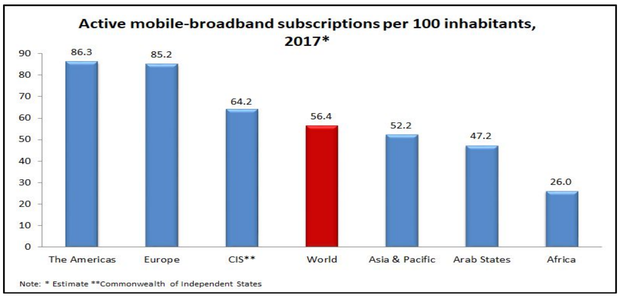


Figure 5: Global mobile broadband penetration rates (https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx)

Policy environment

Of the 54 African countries, 45, about 83%, have a national broadband policy, a higher proportion than the global average of 81% (Broadband Commission, 2018). However, as noted in Section 3.1, Africa lags behind the rest of the world in *implementation* of broadband policy as shown the poor penetration rates. Broadband availability and affordability continue to be serious challenges in Africa. Turning to the specific instance of full-scale commercial deployment and diffusion of broadband based on TVWS/GLSD technology in South Africa, the country has a highly complex and fragmented policy environment. There are at least five South African government departments that have some direct bearing on the issue:

- The Department of Communications (DoC), which oversees ICASA, the ICT regulator;
- The Department of Telecommunications and Postal Services (DTPS), which is responsible for South Africa's broadband policy (DTPS, 2013) as well as its national integrated ICT policy (DTPS, 2016);
- The Department of Science and Technology (DST), which funds high-tech research and development in areas like TVWS/GLSD and is responsible for South Africa's National System of Innovation (NSI) (DST, 2018);
- The Department of Higher Education and Training (DHET) which directs tertiary education and skills development and training; and
- The Department of Trade and Industry (DTI) which formulates industrial policy and localisation policy.

One could argue, quite plausibly, that, besides these five, there are many other relevant government departments. For example, just at national level: the Department of Planning, Monitoring and Evaluation (DPME) which manages the National Planning Commission (NPC) and the National Development Plan (NDP); the Department of Rural Development and Land Reform (DRDLR) whose mandate is to uplift rural communities; and the Department of National Treasury which administers the nation's finances. Our analysis would become even more complicated if we tried to take into account all relevant departments and agencies across all three spheres of South African government: national, provincial, and local. Therefore, as a starting point, we will limit our discussion to the above five national departments. Even restricting our attention to just these five national departments, we observe numerous overlaps and interdependencies involved with many elements of implementing TVWS/GLSD-based broadband commercially. For instance, successfully implementing just the GLSD itself requires: regulatory policy to enable TVWS (DoC); broadband policy to stimulate demand (DTPS); research and development on GLSD technologies (DST and DHET); skills development and training in engineering and computer science (DST and DHET); and industrialisation and localisation initiatives for the TVWS/GLSD sector (DTI).

INNOVATION PARADIGMS

In this section, we examine our case in terms of four innovation paradigms: inclusive innovation, open innovation, systems of innovation, and diffusion of innovation.

Inclusive Innovation

Inclusive innovation is "the inclusion within some aspect of innovation of groups who are currently marginalised" according to a 6-level "ladder of inclusive innovation": intention, consumption, impact, process, structural, post-structural (Heeks *et al.*, 2014). In our case, the marginalised group are rural communities and, arguably, inclusion levels 1 to 4 (intention, consumption, impact, process) have been achieved. Structural inclusion (innovation created within a structure that is itself inclusive) and post-structural inclusion (innovation created within a frame of knowledge and discourse that is itself inclusive) constitute work in progress.

Open Innovation

Open innovation has two distinct definitions in the innovation studies literature. One definition, "open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesbrough, 2015), focuses on how ideas flow across organisational boundaries and are used by firms to create commercial value. Business models are essential to this definition. A second definition is "*open user innovation* … [whereby] economically important innovations are developed by users and other agents who divide up the tasks and costs of innovation development and then *freely* reveal their results" (von Hippel, 2014). This definition emphasises user-centred innovation driven by end users and user organisations, as opposed to producer-centred innovation. Both forms are potentially useful in our scenario and should be utilised in the journey towards full-scale commercialisation of TVWS/GLSD technology in Sub-Saharan Africa.

Systems of Innovation

The concept of a system of innovation is essential to understanding the characteristics and performance of innovation: "Although to some the word [system] connotes something that is consciously designed and built, this is far from the orientation here. Rather the concept is of a set of institutions whose interactions determine the innovative performance, in the [economic] sense above, of national firms. There is no presumption that the system was, in some sense, consciously designed, or even that the set of institutions involved works together smoothly and coherently. Rather, the "systems" concept is that of a set of institutional actors that, together, plays the major role in influencing innovative performance." (Nelson, 1993)

The set of institutional actors whose interactions will determine the practical achievement of the innovative potential of TVWS/GLSD technology includes, among others, R&D institutions like the CSIR, universities, government departments, SMMEs, private sector financiers, and civil society and community organisations.

Diffusion of Innovation

Diffusion is integral to innovation because it is not only the process by which new technologies spread throughout a population, but it also an essential part of the innovation process itself since the original innovation is invariably enhanced through the imitation, learning, feedback, adaptation and modification that occurs as the new technology spreads (Hall, 2004). The rate of diffusion of new technologies is influenced by four main groups of factors: *factors that affect the benefits received* (e.g. degree of improvement over previous technologies, network effects, technological standards); *factors that affect the costs of adoption* (e.g. price, complementary investments in training and equipment, absorptive capacity); *factors related to the industry or social* *environment* (e.g. regulation, market structure, cultural attitudes); and *factors due to information and uncertainty issues* (e.g. suitability for potential adopter's situation, longevity and trajectory of new technology, reversibility and resaleability). In our case, complete diffusion corresponds to full industrialisation of TVWS/GLSD technology. The key diffusion determinants that have been influenced positively thus far are network effects and technological standards by creating and promoting common technology in South Africa and other African countries; tackling information and uncertainty through technical trials and pilots; and the adoption of clear technical regulations. These determinants should be strengthened, while addressing the remaining determinants.

POLICY RESPONSES

In this section, we consider appropriate responses from innovation policy and industrial policy perspectives.

Innovation policy

Innovation policies are policies that have an important impact on innovation, and are of three main varieties (Edler and Fagerberg, 2017):

- *Mission-oriented policies* aimed at providing practical new solutions to specific challenges on the political agenda;
- *Invention-oriented policies* which focus narrowly on the R&D/invention phase, leaving exploitation and diffusion to the market;
- *System-level policies* which focus on features and improvements at the innovation system level.

In our case, up to now, we have been heavily focused on mission-oriented policies (affordable rural broadband) and invention-oriented policies (research on TVWS and GLSDs). More attention and effort should be directed towards system-level policies. Table 1 presents a catalogue of policy instruments that can be applied to our scenario. For instance, we can stimulate both supply and demand for TVWS/GLSD by using standards, regulation and technology foresight (policy instruments 13-15).

Table 1: Taxonomy of innovation policy instruments (Edler and Fagerberg, 2017)

	Overall orientation		Goals						
Innovation policy instruments	Supply	Demand	Increase R&D	Skills	Access to expertise	Improve systemic capability, comple-mentarity	Enhance demand for inno-vation	Improve frame-work	Improve discourse
1 Fiscal incentives for R&D	•••		•••	•○○					
2 Direct support to firm R&D and innovation	•••		•••						
3 Policies for training and skills	•••			•••					
4 Entrepreneurship policy	•••				•••				
5 Technical services and advice	•••				•••				
6 Cluster policy	•••					•••			
7 Policies to support collaboration	•••		•○○		•○○	•••			
8 Innovation network policies	•••					•••			
9 Private demand for innovation		•••					•••		
10 Public procurement policies		•••	••○				•••		
11 Pre-commercial procurement	•○○	•••	••○				•••		
12 Innovation inducement prizes	••○	••○	••○				••○		
13 Standards	••○	••○					•○○	•••	
14 Regulation	••○	••○					•○○	•••	
15 Technology foresight	••○	••○							•••

Notes: ••• = major relevance, ••○ = moderate relevance, and •○○ = minor relevance to the overall orientation and stated innovation policy goals of the listed innovation policy instruments.

Industrial policy

Industrial policy relates to building out the TVWS/GLSD industrial base by economic and technological catch-up (Lee, 2013), and by exploiting Africa's unique characteristics and opportunities, as was done so successfully in the African mobile communications industry (Ibrahim, 2012). It is important to note that this requires a strong element of emergent policy – akin to emergent strategy (Mintzberg and Waters, 1985) – and therefore policy makers and practitioners must remain flexible and results-oriented in their approach. The limits of what we might term "deliberate policy formulations" and the value of emergent policy are evident in South Korean and Taiwanese economic history: "This book often uses Korean and Taiwanese firms and industries as examples of successful catch-up, leaving us with an intriguing question: did the policy makers in these countries have the criterion of short cycle time firmly in mind as they planned and conducted industrial policy? While the answer to this question is no, they were in fact always asking themselves, "what's next?" They looked keenly at which industries and businesses were likely to emerge in the immediate future and thought carefully about how to enter the emerging ones. Without specifically planning to do so, in effect the policy makers were always pursing the short-cycle industries as these were often the ones that relied less on existing technologies." (Lee, 2013: xviii)

IMPLEMENTATION STATUS

Implementation status in South Africa

R&D on TVWS networks has been going on in South Africa for close to a decade, an effort to which the authors have contributed over the years (ICASA, 2015). Despite this decade's worth of R&D, it was only in March 2018 that the TVWS regulations were promulgated (ICASA, 2018a), and in October 2018 that the process of establishing a national Reference GLSD (see Figure 2) was initiated (ICASA, 2018b). This is an important step forward which must be enhanced by additional regulatory innovation. Other aspects of the innovation system around TVWS/GLSD technology, such as other government departments, SMMEs, private sector financiers, and civil society and community organisations have yet to be mobilised.

Implementation status in Sub-Saharan Africa

At innovation system level, other countries in Sub-Saharan Africa are substantially behind South Africa in TVWS/GLSD technology, although there are excellent instances of innovation in some other countries (Nyasulu, 2018).

CONCLUSIONS

Summary

This paper describes an innovative spectrum sharing technology designed to significantly improve the effective utilisation of national radio frequency (RF) spectrum resources. The technology uses television white space (TVWS) broadband networks based on geo-location spectrum databases (GLSDs) to enable efficient RF spectrum sharing. It has been deployed on several experimental test-beds in South Africa and other African countries. This technology has the potential to support affordable broadband networks, particularly to address the demand for broadband connectivity in underserved rural communities. This technology is potentially of revolutionary benefit to the emerging economies of Africa. However, African telecom regulators are still lagging behind the rest of the world in enacting the necessary dynamic spectrum regulations required to enable the TVWS broadband Internet industry and associated services to flourish and provide the necessary socio-economic benefit. Spectrum sharing is also a technology being considered for future wireless 5G wireless network standards.

Hence this technology is future secure and expected to have extremely high market potential.

Key lessons and insights

The key lessons and insights emerging from this paper are as follows:

- *Complete innovation process.* To reap the full benefits of innovation, African countries must implement and practise all elements of the entire innovation process: invention (R&D), commercialisation, and diffusion. In particular, the critical importance of diffusion, and the factors that influence it, has been underappreciated. It is important to realise that innovation is *not* a linear or sequential process and that all three elements will, in some sense, be in a constant state of flux as the innovation itself is being developed and deployed.
- *Systems of innovation.* Successful innovation requires fully functioning systems of innovation at national, regional and organisational levels.
- *Local knowledge and capabilities.* Developing strong knowledge of local characteristics and innovation opportunities, and creating strong local technological and commercial capabilities, is key to the development of technology-based sectors such as TVWS/GLSD. Good examples include the African mobile industry and the Asian tiger economies.

Recommendations for policy makers and practitioners

Our main recommendations for policy makers and practitioners are as follows:

- *System orchestration (policy makers).* Focus on orchestrating – identifying, integrating and coordinating – the key actors in the innovation system. At a granular level, this involves formulating and implementing effective system-level innovation polices that will stimulate both supply and demand for innovation. The key challenge in any system of institutional actors is how to align intentions, interests and incentives. Policy makers should become skilled in designing incentives, in the form of regulations, market mechanisms, and so forth, in such a way as to positively influence the behaviour of the various actors and enhance the performance of the innovation system as a whole.
- *Emergent innovation and industrial policy (policy makers).* Due to the complexity of modern societies and economies, it is impossible for policy makers to control or foresee all the consequences or nth-order effects of their decisions. Consequently, successful innovation policy and industrial policy requires flexibility and an unremitting focus on results.
- *Commercialisation (practitioners).* Practitioners should be keenly aware of the need to commercialise their ideas in the form of viable business models. This applies equally to researchers, entrepreneurs and intrapreneurs alike. Without a viable business model, no new technology is sustainable in the long term.
- *Aspiration (practitioners).* Raise the level of aspiration beyond mere consumption, adoption or imitation to the level of production and creation. Practitioners whose aspirations and ambitions remain low cannot expect to survive, let alone succeed, in this highly competitive, rapidly evolving global economy.
- *Education and circulation (policy makers and practitioners).* Help build understanding and linkages by educating each other about their respective worlds and encouraging the circulation of people between the various institutional parts of the innovation system. Most policy makers have little first-hand – or even second-hand – understanding of the true objectives, concerns and motivations of practitioners. And, of course, the same is true of practitioners in

relation to policy makers. And yet the work of both sets of actors is vital to the success of the innovation enterprise.

References

Broadband Commission. 2018. "The State of Broadband 2018: Broadband Catalyzing Sustainable Development". Available at: https://www.broadbandcommission.org/publications/Pages/SOB-2018.aspx

Chesbrough, H. 2015. "Open Innovation: Striving for Innovation Success in the 21st Century", *BBVA OpenMind*, Available at: https://www.bbvaopenmind.com/en/articles/open-innovation-striving-for-innovation-success-in-the-21-st-century/

DST. 2018. "Draft White Paper on Science, Technology and Innovation". Available at: https://www.dst.gov.za/images/2018/DST-WHITE-PAPER-2108-WEB.pdf

DTPS. 2013. "South Africa Connect: South Africa's Broadband Policy". Available at: https://www.dtps.gov.za/index.php?option=com_content&view=article&id=134&Itemid=268

DTPS. 2016. "National Integrated ICT Policy". Available at: https://www.dtps.gov.za/images/phocagallery/Popular_Topic_Pictures/National_Integrated_ICT_Policy_White.pdf

Edler, J. and Fagerberg, J. 2017. "Innovation policy: what, why, and how", *Oxford Review of Economic Policy*, 33(1): 2-23.

Hall, B. H. 2004. "Innovation and Diffusion", Working Paper 10212, NBER Working Paper Series, Available at: https://www.nber.org/papers/w10212

Heeks, R., Foster, C. and Nugroho, Y. 2014. "New models of inclusive innovation for development", *Innovation and Development*, 4(2): 175-185.

Ibrahim, M. 2012. "Celtel's Founder on Building a Business on the World's Poorest Continent", *Harvard Business Review*, 01 October.

ICASA. 2015. "Discussion Paper on the Draft Framework for Dynamic and Opportunistic Spectrum Management". Notice 1001 of 2015.

ICASA. 2018a (March). "Regulations on the use of Television White Spaces". Available at: https://www.icasa.org.za/uploads/files/Regulations-on-the-use-of-Television-White-Spaces-2018.pdf

ICASA. 2018b (October). "Reference Geo-Location Spectrum Database (R-GLSD)". ICASA 09/2018 Request for Proposals. Available at: https://www.icasa.org.za/tenders/icasa-09-2018-geo-location-spectrum-database

ITU. 2009. "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz". Recommendation ITU-R P.1546-4. Available at: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1546-4-200910-S!!PDF-E.pdf

ITU. 2016. "Working Together to Connect the World by 2020". Available at: http://www.broadbandcommission.org/Documents/publications/davos-discussion-paper-jan2016.pdf

ITU. 2017. "Measuring the Information Society Report". Available at: https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017.aspx

Lee, K. 2013. *Schumpeterian Analysis of Economic Catch-up: Knowledge, Path-Creation, and the Middle Income Trap*, Cambridge: Cambridge University Press.

Mfupe, L. 2016. "Techno-policy evaluation of dynamic spectrum access management frameworks", Doctoral Thesis, Tshwane University of Technology.

Masonta, M. T., Kliks, A. and Mzyece, M. 2017. "Unlocking the potential of unoccupied spectrum in developing countries: Southern African Development Community – case study", *Development Southern Africa*, 34(2): 224-244.

Mekuria, F., Mfupe, L. P. and Montsi, L. G. (inventors). 2016. CSIR Council for Scientific and Industrial Research (assignee). A method and system: back-tracking forward-looking (BTFL) dynamic channel allocation mechanism for white space radio networks. UK Patent GB2522927B.

Mfupe, L., Mekuria, F. and Mzyece, M. 2014. "Geo-location White Space Spectrum Databases: Models and Design of South Africa's First Dynamic Spectrum Access Coexistence Manager. *KSII Transactions on Internet and Information Systems*, 8(11): 3810-3836.

Mintzberg, H. and Waters, J. A. 1985. "Of strategies, deliberate and emergent", *Strategic Management Journal*, 6(3): 257-272.

Nelson, R. R. (ed.). 1993. *National Innovation Systems: A Comparative Study*, Oxford: Oxford University Press.

Nyasulu, T., Crawford, D. H. and Mikeka, C. 2018. "Malawi's TV white space regulations: a review and comparison with FCC and Ofcom regulations", in Proceedings of the 2018 IEEE Wireless Communications and Networking Conference (WCNC), Barcelona, Spain.

OECD/Eurostat. 2018. Oslo Manual 2018. Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition. Available at: https://doi.org/10.1787/9789264304604-en

von Hippel, E. 2014. Open User Innovation. *The Encyclopedia of Human-Computer Interaction, 2nd Ed.* Available at: https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/open-user-innovation

Development of Summer Outreach STEM Program: Case-Study Smart Lighting

Peter Bofah[1], Mohamed Chouikha[2]
pbofah@howard.edu
[1,2] *Department of Electrical and Computer Engineering*
Howard University, Washington, DC 20059

Abstract

We present high school summer outreach program in science, technology, engineering and mathematics (STEM) areas using Smart Lighting Program as a case study. The continuous improvement or advanced standards of the citizens of any nation depends on continuous research and innovations. The US enjoys the global leadership role in developing and implementing cutting edge research. However, there are few underrepresented minority groups of researchers and educators in STEM. The contribution of a diverse population of scientists and engineers is necessary to meet the world's needs. There is a talented underrepresented group that needs to be tapped and trained for research and improved technology. Under-represented high school students are invited to participate in summer outreach STEM program with the hope that they will pursue college education in STEM areas to improve their employability. We introduce STEM through lectures and hands on activities. The program includes daily activities coupled with field trips and presentations. Smart Lighting activities involve application of light-emitting diodes (LEDs) and solar power. The participants are introduced to instrumentation and use of mobile studio and Analog discovery. These are portable labs using a PC as the instrumentation, with dc power supplies and function generators that connect to the hardware (bread board with mounted circuitry). We do assessment for future improvement of future STEM programs. We receive positive response from the assessments.

Keywords: employability, outreach, discovery, assessment.

INTRODUCTION

Howard University has been one of the Educational Outreach Partners for the Smart Lighting Program which is led by Rensselaer Polytechnic Institute (RPI) and funded by the National Science Foundation (NSF). Howard University's Electrical and Computer Engineering Department has been hosting the smart Lighting Summer program for the past several years. One of the goals of this program is to introduce a wide range of engineering concepts to local High School students and encourage them to later major in Science and Engineering. This is a 4-week program offered in July. Participating students are selected from mostly Washington, DC metro (DC, Virginia, Maryland) area high schools from 10 - 12 graders.

During the Summer program, students' learning activities are divided into several modules that are each taught by faculty and mentors. These modules include lectures that provide the theoretical background information about electrical and computer engineering concepts as well as hands on labs that give students practical views and experiences on some engineering systems. This program is divided into three modules.

Module I, introduction engineering design principles (Robert Bowman). This guide outlined series of actions and tasks that could lead to a successful analysis, design, and implementation of an engineering project, a list of common engineering terms and their definitions as well as assigned a Solar Powered Aerial cable car project.

Module II: Introduction to engineering concepts, electrical engineering concepts, areas of concentration, and devices such as conductors, semiconductors, insulators, and circuit components such as resistors, capacitors, inductors, diodes and many more. He also gave students hand on projects about AM/FM radios, traffic Light systems, communications (report writing, oral penetrations) and others.

Module III: engineering systems, devices and concepts which included electric circuits, in ways that made them understand easily some of these very complex concepts. Valuable feedback to students when they were building their electric circuits, introduction to Python programming presentation about weekly information learned. A mentor (graduate) student leads the students to conduct several labs activities. In addition to the three modules, we have invited guest lectures/speakers from industry (such as NASA) to participate in the program.

SMART LIGHTING INSTITUTE

The main purpose of the Smart Lighting program is to introduce high school students to pursue engineering education in future that will improve minority skills in their employability as well as make contributions to research. Presently, minority contributions in the STEM areas are rather low. Other similar programs are available on campus. The program introduces the students to general engineering education through lectures and hands on. They learn about electrical terms, quantities and how to use instruments to collecting data. They learn how to use the Analog Discovery which is a personal instrumentation that contains function generator with leads that connect to bread boar and then to the computer. It has dc power supplies as well as other signals. The computer is used as scope to measure voltages, currents and waveforms.

A. Lectures

The program consists of 3 main modules plus guest lectures form industry. Each instructor (with mentors) with different backgrounds conduct the assigned module.

Module I

Introduction to engineering design principles and related assigned projects that Robert Bowman). Frequently used vocabulary and key terms in science and engineering are first outlined and defined, as follows:

Terms outline:

- Hypothesis- an educated guess or prediction to make
- Independent variable- controlled by the experimenter, maybe a measure of a parameter to determine the outcome
- Dependent variable- variations because of independent variables observed or measured to collect data.
- Constant parameters- remain the same
- Quantitative observations- use of numbers to describe objects such as mass, volume
- Qualitative observations- use of words to describe objects appearance, color, texture
- Inferences - an attempt to interpret observations
- Questions- answers to the experiment.

After the above vocabulary and key terms are introduced, the instructor discusses the engineering design project guide that includes a set of steps to be followed in order to successfully complete an engineering analysis and design project. Outlined below:

- Getting started, gathering data, generating ideas, implementing solution
- Engineering design process, define the problem, design notebook

- Background research, specifications
- Brainstorm, multiple solutions choose optimal design
- Implementing a solution- development work, prototyping, test and redesign

After discussing the above necessary background for a successful completion of design project, students are assigned to solar-powered aerial cable car project in activities section.

Module II

Lectures involve circuit theory, introduction to semiconductors with emphasis on LEDs and applications, hands on labs, instrumentation are. Students learn how to use the analog discovery, a persona; instrumentation with built function generator and dc power supplies +/- 5 V. It works for analog and digital labs, concepts of conductors, semiconductors, insulators, AM radios, traffic light system. Figure 2, the functions and characteristics of circuits elements such as resistors (color code), capacitors, inductors, diode, soldering techniques.

AM/FM: Lectures to students in the area of communications. Fundamental concepts of Amplitude Modulation, how a message signal can be modulated by a carrier signal to produce an AM signal on the transmitter side. On the receiver side, demodulate is explained how to recover the AM signal. Students are also shown two videos about how Amplitude Modulation and Demodulation work. After learning about the basic fundamentals of AM/FM systems, students are given an AM/FM radio kit with block diagram shown in Figure 3, an instruction manual containing the parts list needed for construction, and then asked to build the radio by soldering.

Module III

Provides students a wide range of activities such as Python Programming, circuit constructions, power point presentations, report writing. The lab activities include building circuits with topics about resistors, Ohm's Law and voltage divider, signal generators and waveforms, capacitors and time constant, inductors and resonance and 3D-Printer. The Python programming includes topics about Functions, variables, If Statements and many more.

b. Activities

Each module has lectures are coupled with hands on activities (Science Buddies).

(i) Solar-Powered Cable car

This experiment uses a cable car that utilizes a solar panel to power it. The Aerial Solar Cable Car experiment encourages students to learn about how a solar panel works, the cable car works and what causes it to move based on design principles they pull from user profiles. This activity also encourages students to iterate on their designs and practice using different ideas and data. This exercise is a great way to push students to build, test and iterate while keeping their designs founded in engineering education. This activity also encourages critical thinking by asking students to synthesize their user's profile to find their needs. Students must also demonstrate strength in the face of challenges or frustrations. Specifications: Solar panel output 1.1 V, 75 mA, size: 11mm x110mmx180mm, unit wt 2.9 oz, solar cell life 2 years normal use, Motor Dc, power consumption 1.2 Vx10mA, Tools needed: diagonal cutter,, screw driver, scissors.

Materials: Each group (size 4-8, total 40 students) receives transport cable, automatic round trip return stoppers, solar panel and 30 plastic parts to assemble will be provided. Students will receive parts to build the item a solar powered aerial cable car shown in Figure 1.

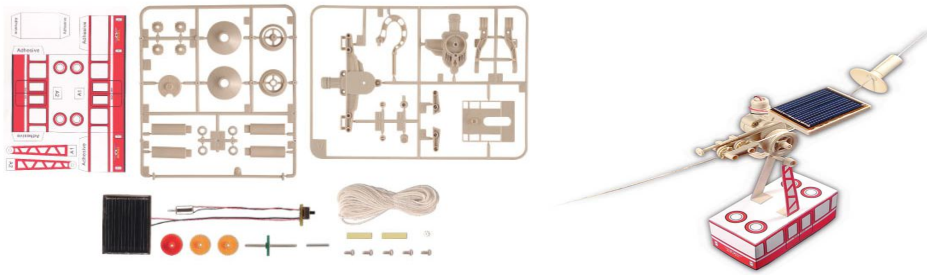


Figure 1. Solar powered aerial cable car parts and view

List of materials per team needed and a detailed step-by-step experimental procedure to complete the project's measurements and data gathering are outlined as follows: Parts- Solar cell, cable car, string, 2 poles, marker, stopwatch, pole/shadow, protractor, chalk.

Procedure:

- First, assemble the Aerial Cable Car., Next, arrange two poles on a level grassy area.
- Place the poles at least 54 inches apart from each other, attach the end of a string to each pole. Measure the poles at a 105 degree angle, if possible. Place the cable on the string.
- Place the string under the plastic wheel and up and around the pulley.
- Position the solar panel flat. Time the cable car at least 4 different hours.
- Examples: 12:30, 1:30, 2:30 and 3:30pm on a sunny day, or pick your own.
- The cable car is expected to go back and forth on the string at least six times each trial.
- There will be at least two trials per hour. Record the time for each trial with a stopwatch.
- Record the average time for the two trials per hour. Place a pole in the ground at the same angle to the poles with a string. Measure the angle of the shadow of the pole at each hour with a protractor. Use Chalk to draw a line where the protractor is placed. The angle is then recorded**.**

Each student writes a final project design report it is completed.

Report writing outline: The project report will just entail pulling together the information you have already collected into one document according to: acknowledgments and bibliography, a detailed description of your procedure, data analysis and discussion, results and conclusions. The report format include these sections:

- Outline—to include the following:
  - Cover sheet and Title of project
  - Abstract (Project Summary) - this is an abbreviated version of your report.
  - Table of contents
  - List of questions, variables, and hypothesis
  - Background research – What you did before starting the experiment
  - Material list
  - Science Project Logbook (your experiment journal)
- Experimental Procedure
- Data analysis and discussion- This section is a summary of what you found out in your experiment, observations, data table, and graph(s).
- Conclusions and Ideas for future research

- Acknowledgements – thank anyone who helped you with your science project
- Bibliography – combine with the above.

Students work on this project in several phases; they first assemble the Solar Powered Arial Cable Car and then got outside several times during the day in order to take some measurements such as the speed of the car, the shadow angle with respect to the sun position on the sky.

(ii) Traffic Light Project

After discussing a traffic light system's elements and functions, the students are provided the traffic light kit below. They are asked to read the instructions and assemble all components on the board by soldering and conduct testing.

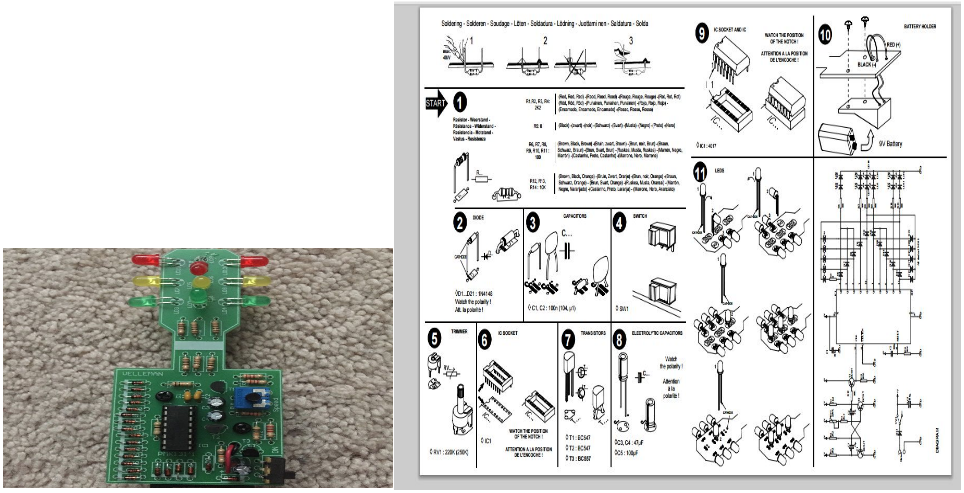


Figure 2: Traffic light kit, parts and instruction manual

In order to construct the traffic light system, students use the information provided in Figure 2. It shows each of the components and a sequence of steps that must be taken for assembly.

(iii) AM/FM Radio Project

After learning about the basic fundamentals of AM/FM communication systems, students are given an AM/FM radio kit with block diagram shown in Figure 3, an instruction manual containing the part list in Figure 2.4, the circuit board and all parts needed for construction, and then asked to build the radio by soldering each component onto the circuit board.

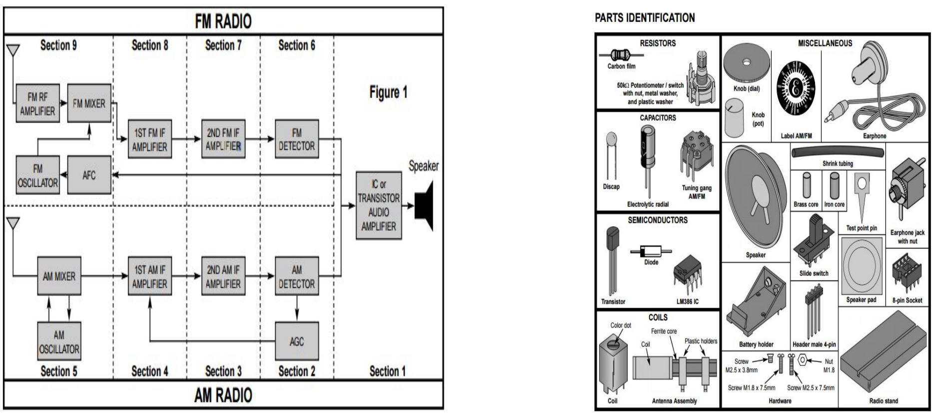


Figure 3: AM/FM radio system, block diagram and parts

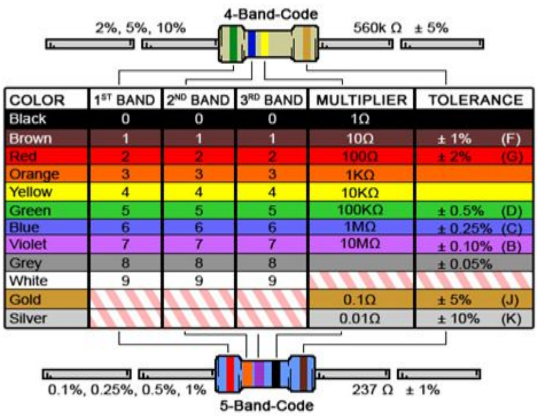
(c) Lab Hands On Activities

Students are introduced to several lab activities and safety where they learn about electric circuit components, such as resistors, capacitors, inductors, diodes, LEDs. They build and test several circuits using breadboards and the Analog Discovery.

Sample activities

(i) Activity 1: Resistors

In the first lab activity, students are introduced to the resistor circuit element. They learned about its physical characteristics, how to read a resistor value using its color code, and then measure its value using the Multimeter instrument. Each student is given several resistors and asked to compute the resistor value based on the color code, and then compared it to the value obtained from the Multimeter reading. An example of resistor color code is shown below:



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Figure 4: Resistor color code

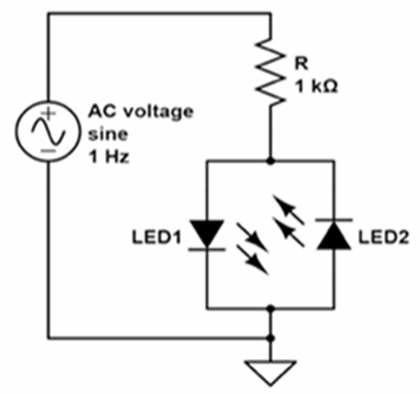


Figure 5. Ac voltage and flashing LEDs

This Lab is extended to Ohm's Law and voltage divider labs verification

(ii) Lab Activity 2: Signal Generators and Waveforms and Analog discovery

During this lab experiment, students are introduced to the Diligent Analog Discovery instrument. They learn about its internal functions such as Oscilloscope, Arbitrary Waveform Generator, DC voltage generator, Network Analyzer, and others. After learning about the Analog Discovery (AD) instrument, students are asked to use a solder less breadboard and to construct the circuit in Figure 5 using 1 Kilo Ohm resistor and two Light Emitting Diodes (LED). The Analog Discovery is used to generate the sinusoidal input voltage with a frequency that is changed from 1 Hz to 60 Hz with an increment of 5 Hz. Students observe the behavior of each LED (off and on) with different time delay at variable frequencies of the input signal. Also, students used the measurement function built-in the AD to measure input and output voltage characteristics such as amplitudes, frequencies, periods, the input across the voltage source, and LEDs devices.

(iii) Lab Activity 3: Capacitors and Time Constant

Students are asked to build on a solderless breadboard the circuit in figure xxx using 1 K-Ohm resistor and a capacitor with value 1 microfarad as shown in Figure 6 with results. The input voltage source is square wave generated from the Analog Discovery with an amplitude of 500 mV and an offset of 500 mV.

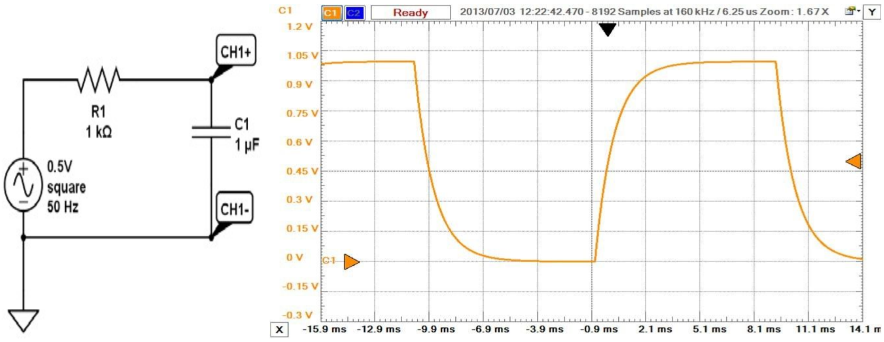


Figure 6 Capacitor Circuit- charge discharge with square wave input

Students are instructed to observe the output waveform across the capacitor using the oscilloscope and to observe that the capacitor is charging and discharge as shown in figure 6. The calculated and measured time constant are also compared.

(d) 3D - Printer Activity

Students are introduced to the 3D-Printer in Figure 7. It can be used to print 3D-objects of difference sizes and forms. The printer comes assembled, the only installation done is about the control software package called Cura.

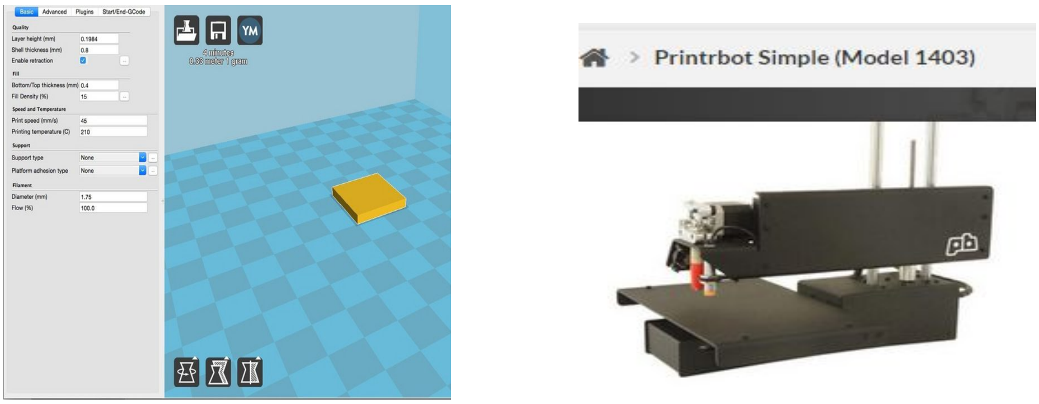


Figure 7: Printer software interface and 3D- Printer

The software is downloaded to the computer connected to the 3d-Printer and several configuration parameters are set. The Interface allows the user to interact with the 3D-Printer in order to load models, set parameters, and print 3D-Objects. Students print 3D-Objects.

(e) Python Programming

Students learn Python programming and its applications. The activities cover a wide range of Python programming topics: such as: Python If Statements, Variables, Functions, and Loops. A summary follows:

Introduction to Python (Python IDLE)

The Python 2.7 program is designed to be a simple way to begin writing code (Dr, N. Harrington).

Downloading Python: 1. Follow this link to download: bit.ly/pythonLE27, 2. Run the file and continue until the folder is downloaded, 3. Open the Python 2.7 folder, and open IDLE (Python GUI). 4. Browse through the Python 2.7 or search for IDLE via **Starting to Code (python Program). Setting Variables:** In any programming language, data can be stored in different data types. Variables can be modified and printed. Data types **Strings** and **integers**. **Python If Statements:** An If

Statement is the way programmers ask the computer questions. If Statements are true/false questions that the computer can evaluate. The truth or falsity of a statement determines which steps the computer takes next in a program. If Statements have a particular design. The trigger for an If Statement is the word *if* (no caps). **User Input:** Programmers can make the computer ask for user input. **Python Functions:** is a reusable block of code that serves as a template for one or more actions. We have already used the print() function and the input() function. Create your own functions. **Variables: 2** types of variables. **Strings** are groups of characters, and **Integers** are numbers without decimals. Python automatically decides whether something is a String or an Integer. **Input function:** [variable name] = input ([Message you want the computer to ask]). Note: You do not type the answer to the question inside the input function! You type the answer after running the program. Example: age = input("Please enter your age: "). **Python Loops:** is a short (one or two line) segment of code that allows the programmer to repeat lines of code until a certain condition is met. Loops encase the code that needs to be repeated. **While Loops:** The While loop looks and works similarly to the If Statement. Loops can easily be integrated into existing programs to make a program that lasts longer and has more utility. **While Loops and Functions:** Lines of code that begin with a hashtag are called **comments** and are not run by the code. Programmers add comments to organize and label different parts of longer programs, numbers and print their sum. **While Loops and Input:** is asking the user whether they would like to run the program again. This combines the input function and the while loop.

CONCLUSION

Howard University Electrical and Computer Engineering Department hosts the Smart Lighting program each summer where students from local High School are introduced to a wide range of engineering concepts and activities. Learning activities are divided into several modules. In these modules, students are involved in several activities that include lectures and labs using Analog Discovery, a personal instrumentation.. They learn about the engineering design process, AM/ FM radio systems, traffic light systems, Python programming, circuit building and testing, and other engineering concepts and devices. We do pre and post survey assessment of the program. Both results show participants enthusiasm and their desire to pursue STEM areas in their college education. The program is improved on yearly bases based on the students' surveys outcomes.

Acknowledgements

Our due thanks to the National Science Foundation (NSF) for supporting the Smart Lighting Summer Institute. Thanks also to participating students, faculty, mentors and invited guest lecturers for making the program a success.

References

Science Buddies, 'http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps.shtml'

Robert Bowman, *Electrical Engineering Practicum*, http://www.trunity.net/purchaseaccess/10024/

Dr. Andrew N. Harrington, Computer Science Department, Loyola University Chicago http://anh.cs.luc.edu/python/hands-on/3.1/handsonHtml/index.html

Python Program, 'https://www.python.org/downloads/'

Processing 55 Program, 'https://processing.org/'

Training Early Childhood Educators in Africa Using E-Learning Technology

Conrad Brian Law[1] and Gwendolyn Amina Jones Law[2]

[1]Applied Learning Solutions LLC, 10905 Livingston Road, Ft Washington, MD 20744
Ph: 866-599-4330, Fx: 301-203-7628, cblaw@appliedlearningsolutions.com

[2]Childcare Management Solutions, 10905 Livingston Road, Ft Washington, MD 20744
Ph: 866-599-4330, Fx: 301-203-7628, amina@cms4training.com

Abstract

The effort to make pre-primary education accessible to children from birth to five in Africa has been ongoing since before research revealed the importance of brain development in infants. A child's brain develops rapidly during the first five years of life, especially the first three years. It is a time of rapid cognitive, linguistic, social, emotional and motor development. Their first teachers have an important impact on their future development. Governments and international organizations quickly adopted policies to address the issue but many early childcare teachers in Africa have no formal training. An appropriate use of technology to address this problem is to provide instructor-facilitated, self-directed, online training using a learning management system (LMS). By integrating pre-recorded video lectures, instructor graded assignments, forum discussions and downloadable resources delivered through mobile phones and other smart devices, training can take place. In areas that do not have schools, it would be useful to include entrepreneurial, administrative and other types of training using e-learning technology. Providing instructor-facilitated online training using mobile devices can increase the number of trained teachers and the quality and effectiveness of their interactions with young children. This paper summarizes the tools and techniques that can be used as a result of our experience and research in technology and early care.

Keywords: Early childhood education, learning management system, distance learning, pre-primary, teacher training, brain development, Nigerian Pre-Primary Education.

INTRODUCTION

Recent research has revealed that brain development in infants affects the cognitive, language, perceptual, socio-emotional and motor development faculties they will need for academic success and future achievements. As a result of these developments, early childhood education policies have been initiated to better prepare young children for school. In many African countries teachers of children from birth to five years of age have received very little formal training. The early years is now widely accepted as the most important period where brain development becomes the foundation young children depend upon for future development. Ninety percent of a child’s brain development takes place before the child reaches the age of five (Figure I).

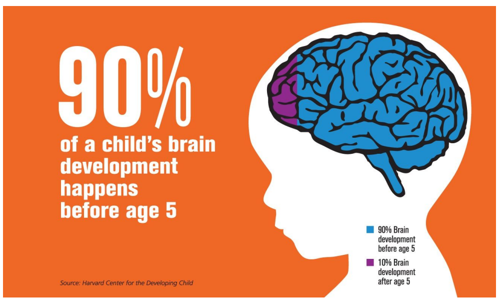


Figure I. Human Brain Development

The development of the brain is impacted by many factors, including a child's relationships, experiences and environment. Early childhood teachers influence the quality of those experiences. Teachers that are well trained understand how to develop the sensory pathways, language and higher cognitive functions through play and other activities (Sun, Rao and Pearson 2015).

Most of our knowledge about online training and early childhood development stem from over thirty years of experience training teachers and parents, over one hundred thousand enrolments in our courses and conferences, thirty plus years in technology and networking with other professionals at conferences and universities from around the world. We have designed, developed and implemented online training for more than eight years in a variety of industries. It is the summation of our experience and primary research that forms the foundation of this paper.

The Instructional Technology Council (ITCNetwork.org) is the leading organization of colleges and universities in the United States that offer online degree programs. As a member of the organization I participated in their e-learning conferences. Most of the member colleges did not offer continuing education (non-degree) online courses. The infrastructure for e-learning was expensive and required a lot of support. They decided the best use of the technology was with their degree programs and tenured professors. Most of the schools used Black Board as their learning management system which was very expensive to purchase and support. It was resource prohibitive to offer online non-degree courses and support the part time instructors that taught them.

During the World Forum in Early Care and Education conference held in San Juan, Puerto Rico in 2014, discussions and presentations confirmed that in many parts of the world, including Nigeria, Ghana and other countries, teachers that work with young children in pre-primary classrooms have little or no formal training in Early Childhood Education (ECE). Presentations during the conference discussed the limited resources to train Early Childhood teachers.

Governments now realize the need for pre-primary education but the resources needed to effectively train the teachers are still lacking. In Nigeria, there is a shortage of teachers but more than half of all teachers for children birth to five have no formal training at all (Sooter 2013). The ratio for teachers to children in Nigeria are from birth to two (1 to 10) and from three to five (1 to 25) (Salami 2016).

At the 2015 E-learning Africa Conference in Addis Ababa, Ethiopia, one of the major questions was, "Does Africa need more online training for degrees or should online training be used for continuing education and professional development?" Most of the attendees and dignitaries were from colleges and universities throughout Africa. By the end of the conference, most had decided that degrees were most important.

Distance Education is the discipline that covers the entire realm of learning at a distance. It started sometime after the invention of the Printing Press when the first correspondence course was delivered. Now when we speak of Distance Education or Distance Learning as it is sometimes called there are technological implications. This type of distance education is called E-Learning or Online training. What is E-Learning or Online Training? There are generally three general perceptions of E-Learning.

For colleges and universities e-learning usually means an instructor-facilitated class using a course management system (CMS) or learning management system (LMS). Platforms like Blackboard, MOODLE, CANVAS, Web-CT and Angel are very popular. Many institutes of higher education use these tools as an extension of the classroom. They provide links to files that support the course; the syllabus, documents, audios, videos, and quizzes. How they are used is directly related to the technology skills of the instructor and the level of support provided by the institution. Most colleges and universities use this technology primarily for their degree programs. They usually offer continuing education courses through third party vendors such as Ed2Go and LERN. Those organizations host the courses but offer the training through colleges, universities, organizations and government agencies.

Outside of academia, most e-learning consists of self-directed presentations with embedded quizzes that don't penalize you if you get the answers wrong. It may be followed by a test and you might be able to get someone to answer your questions by email. This type of training is most useful for learning basic concepts. Students and instructors do not get to engage with each other.

The third is organizations that promote live video presentations as training. These live online presentations or webinars take the place of the classroom lecture. Usually you can return to a recording of the presentation if you happened to miss it, but you lose your opportunity for limited interaction with the presenter, if one is available. These presentations generally lack the assessment required to measure learning.

There are limited benefits to each type of e-learning, but when their characteristics are combined with additional tools and technologies, online training can become much more effective than classroom training. During a classroom lecture a student may receive a list of resources including documents and videos they should review. In an online course those resources are directly accessible. The group activities and discussions that are conducted in the classroom are also available online through forums and group assignments. Redundant resources can be made available online to support the learning styles of every individual. All of these tools are available in learning management systems. The true promise of online training is a virtual learning environment (VLE) where activities equivalent to what takes place in the classroom, are conducted online. The Certified Online Instructor (COI) credential offered by LERN.org, is a platform independent certificate program that teaches participants how to develop effective online content. It focuses on how to construct online activities and assessments that are equivalent to those that take place in the classroom.

We have designed instructor-led online courses for childcare professionals since 2010 but our courses could not work well in Africa for a variety of reasons. By addressing those issues we will be able to develop effective online courses to conduct teacher and administrative training for early childhood educators. We started with long pre-recorded lecture videos that consumed a lot of Internet resources utilizing the Flash video format. Over time Flash technologies have been replaced by HTML5 and videos have been recorded in smaller segments. Also, todays e-learning tools are smart device aware and compliant.

E-Learning in Professional Development

The use of online training in the workplace is generally limited to self-directed training. This type of training is useful for learning basic concepts in areas such as computer security, ethics and customer service skills. However, to teach someone how to protect their computer from viruses, how to enforce ethics and professionalism and how to provide excellent customer service to your customers cannot be taught effectively using self-directed online training alone.

There are tremendous opportunities for online training to be used to increase the knowledge, skills, abilities and effectiveness of early childhood teachers but efforts to use distance learning in this way has been limited. The concepts of On-The-Job and Just-In-Time training begin to take on new meaning when you can provide flexible training techniques to learn new job skills. Instructor-facilitated online training changes how organizations measure employee effectiveness.

Though most colleges and universities offer continuing education and workforce development training, they only use instructor-facilitated online training for their more expensive degree programs. The expense of supporting a course management system, instructors, instructional designers, administrators and help desk staff is prohibitive. Government agencies, corporations, small businesses, non-profits and individuals can all benefit from instructor-facilitated online training courses.

The Learning Pyramid

The more involved students are in the learning process the better retention can be expected. In traditional face-to-face classes most time is spent in lecture with the teacher. The instructor is the "Sage on the Stage". This traditional lecture presentation activity reduces the amount of time and resources spent on audio visuals, demonstrations, discussions, practice and student presentations which contribute higher levels of learning retention. In the distance learning environment, the instructor is the "Guide on the Side". It is the collaborative activities and resources that engage the student. The student must take responsibility for participating in their learning activities. It is the instructor's responsibility to make sure that the students complete the activities.

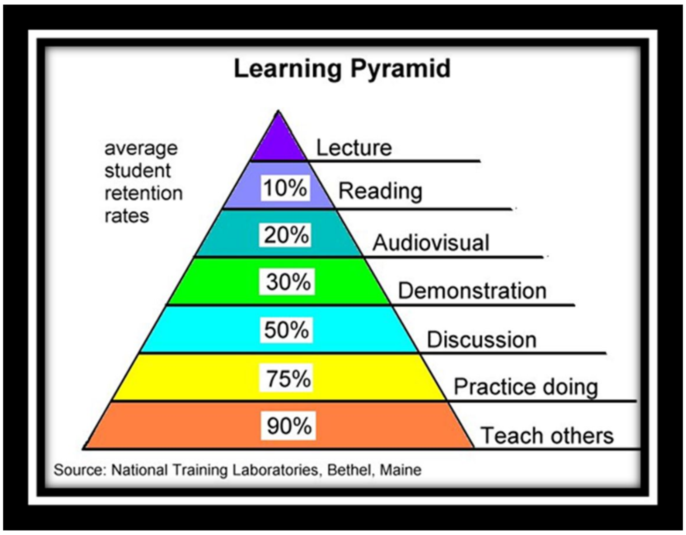


Figure II. The Learning Pyramid.

The Learning Pyramid is a model that estimates the rates at which students retain information based on learning activities. Though lectures are the most common type of learning activity they are not particularly effective. A student can expect to learn more from reading an article or chapter in a book than by having an instructor talk about it. It is said that a picture is worth a thousand words. Students can retain more from a chart, sound bite or video than they can from a lecture or reading an article. Along these same lines demonstrations, discussions, practice and teaching others can offer higher levels of retention for students than lectures alone. In a classroom a combination of these learning activities are often employed, in an online course all of them can utilized in such a way that students can learn outside of the classroom and on their own (Figure II).

Online training should include redundant resources so that students have use the learning styles they are most comfortable with. One popular theory, the VARK model, identifies four primary types of learners: visual, auditory, reading/writing, and kinaesthetic. The instructor can use a pre-recorded lecture, YouTube video, an article and a group discussion using a forum to teach a single concept or topic (Table I).

Table I. E-Learning Equivalents to Classroom Instruction

Classroom	Online
Lecture	Live webinar, video, pre-recorded lecture
Reading	Web document (html, .doc, .pdf)
Audio Visual	Podcast (audio, video) charts, graphs, resources
Demonstration	Case Study (text, video, audio) Quizzes
Discussion	Forum, Blog, chat
Practice Doing	Simulation, exercise, assignment, activity
Teach Others	Live webinar, lead a discussion, write an article

There are many types of activities that have been conducted in the traditional classroom by effective teachers. Often the primary delivery is through lecture. However, many teachers have a limited amount of time to teach their students. Also students have a limited amount of time to be taught. The quality and effectiveness of the resources and activities available to students is just as important if not more important than the lecturer. Online course resources are readily available to the students and the expectations for the students should be higher than the participation requirements in the classroom.

Most of the criticism about online training consists of the lack of interaction between the students and the instructor and the ineffectiveness of T/F, multiple choice quizzes. These are easily addressed by using forums which are threaded discussions between the instructor and students or even groups of students. It creates an environment where dialogue take place. Though it is asynchronous, responses are posted in an hierarchical structure that allows a participant to catch up and join in at any time. The use of Assignments is effective because it allows the teacher to interact individually with each student as the short answer or short essay assignments are graded. Another criticism of quizzes is that it makes it easy for students to guess answers without reviewing course materials or sharing the questions with other students. However, if you have a ten question quiz using a bank of twenty-five questions and have the questions selected for each student at random, it minimizes the impact of cheating. You can also password protect each quiz to ensure that students complete reading or other activities tracked by the learning management system.

Table II. Types of Instruction

Instruction Type	Description
Face-to-Face	(classroom lecture / Instructor-Led)
Self-Directed / Self-Paced	(student proceeds at own pace)
Instructor-Facilitated	(web-based using Forums and Assignments)
Blended / Hybrid	(combination of face-to-face and online)
Webinar	(live online presentation)

Today, web-based training tools are the most effective way to deliver training at a distance. With mobile broadband networks audio, video and text are easily accessible. With the participation of an instructor to keep students engaged and on track, there are opportunities to provide effective training. In locations where Internet access is limited there are tools and techniques that can be used to reduce the reliance on the Internet. These include downloadable resources that students can review offline. Blended training is a combination of classroom and online training where students meet in a traditional classroom setting periodically, then perform much of their work and submit assignments online. In remote areas with limited teacher educators and limited Internet access this type of instruction is especially effective. In some areas teacher education training is also conducted through radio lessons.

Materials and Methods

MOODLE Learning Management System (LMS)

The MOODLE LMS is an open source virtual learning environment that is used by colleges and universities throughout the world. This feature rich learning management system encourages collaboration between teachers and students. The latest version of MOODLE is 3.5.2. It is mobile compliant and there is a mobile app designed specifically to let students complete their entire course from a smart phone or other mobile device. It also provides students with the ability to download segments of the course for offline review. When the student reconnects to the Internet assignments and activities are uploaded to the learning management system.

In 2009 we established the Early Care Institute. It is a MOODLE online training site that we established to provide instructor-facilitated training to early care providers in Maryland, Virginia and the District of Columbia in the United States. We have provided training for thousands of students in a variety of topics. Childcare Management Solutions is approved to provide training to early care administrators and staff for each Core of Knowledge Area at the advanced level. Each state establishes their own policies, procedures and requirements for teacher training organizations and training organizations get approved to offer courses in the classroom and online (Figure III).

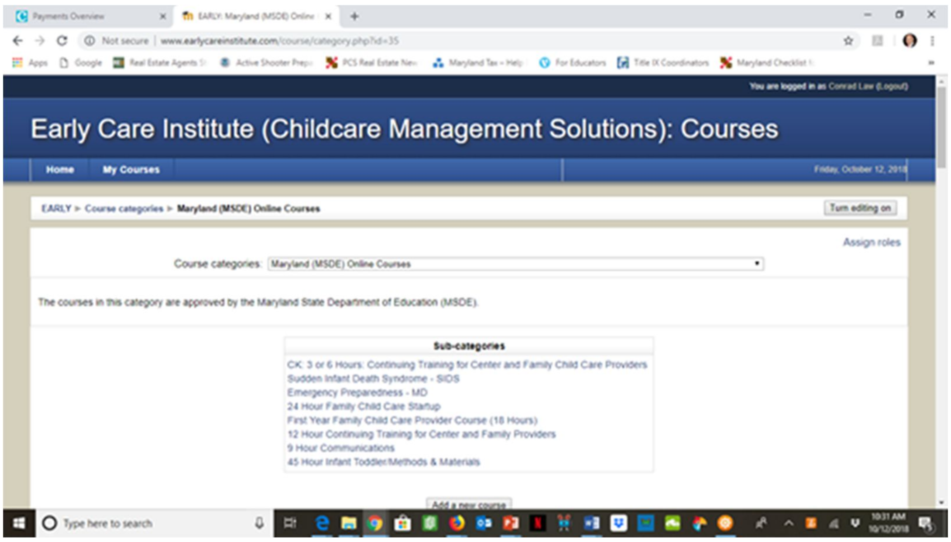


Figure III. Early Care Institute (MOODLE Site)

Videos

The HTML5 specification introduced the video element for the purpose of playing videos, partially replacing the object element. HTML5 video is intended by its creators to become the new standard way to show video on the web, instead of the previous de facto standard of using the proprietary Adobe Flash plugin. The HTML5 video element allow device independent use of properly formatted videos. MOODLE supports the integration of videos from services such as YouTube and Vimeo. For videos used for online training in Africa the segments should be short segments by topic. They should also provide students with the option of downloading the video for offline viewing.

Mobile Devices

Smart phones are more widely used in Africa then computers and much less expensive. Smartphone connections are expected to surpass 725 million by 2020, up from 226 million in 2015. Much of this activity is driven by the expansion of mobile broadband services and smartphones that cost less than $50 US (Dahir 2016). MOODLE is a mobile compliant application that recognizes when a smart phone or tablet is being used. It will allow students to download resources and activities to the device for later access to minimize data costs and to complete the complete course on the mobile device (Figure IV).

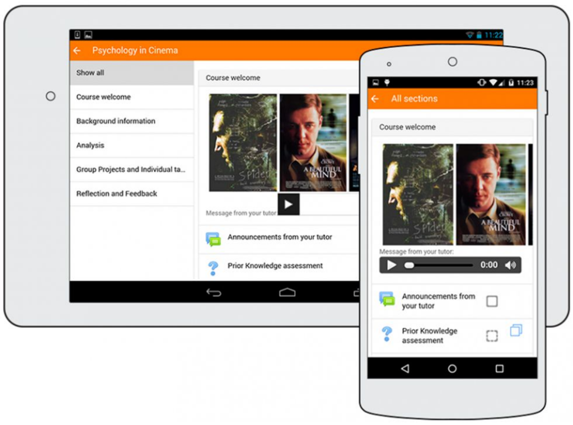


Figure IV. MOODLE Mobile App

Moodle Mobile is the official mobile app for Moodle.

- Browse the content of your courses, even when offline
- Receive instant notifications of messages and other events
- Quickly find and contact other people in your courses
- Track your progress, mark tasks as complete and browse your learning plans
- Attempt quizzes, post in forums and edit wiki pages
- Upload images, audio, videos and other files from your mobile device
- View your course grades

MOODLE is an Open Source learning management system designed to provide educators, administrators and learners with a single robust, secure and integrated system to create personalised learning environments. It is used by tens of millions of people worldwide. It can also be extended with over 500 plugins for assignments, quizzes, grading, certification, and social and collaborative learning. Here are just a few of the standard features (Table III).

Table III. MOODLE Activities and Resources

Module Name	Description
Assignment	Enable teachers to grade and give comments on uploaded files and assignments created on and off line
Attendance	Allows teachers to keep detailed records on attendance and participation
Chat	Allows participants to have a real-time synchronous discussion
Choice	A teacher asks a question and specifies a choice of multiple responses
Database	Enables participants to create, maintain and search a bank of record entries
Feedback	For creating and conducting surveys to collect feedback. Similar to Questionnaire, but allows for anonymous feedback.
Forum	Allows participants to have online discussions to complement class
Glossary	Enables participants to create and maintain a list of definitions, like a dictionary
Lesson	For delivering content in flexible ways
Questionnaire	Allows the teacher to design survey questions for students, such as mid-term evaluations
Quiz	Allows the teacher to design and set quiz tests, which may be automatically marked and feedback and/or to show correct answers
Scheduler	Allows participants to sign up for time slots created by the teacher
SCORM	Enables SCORM packages to be included as course content, sometimes SCORM modules are available from textbook publishers
Survey	Tool for gathering data from students to help teachers learn about their class and reflect on their own teaching using pre-loaded surveys
Wiki	A collection of web pages that anyone can add to or edit
Workshop	Enables peer assessment
Gradebook	Allows teacher to collect and calculate grades, with the option of allowing students to see their only grade calculations for the course
Completion	Tracking that allows a teacher to set criteria that marks an activity 'complete'.

Course Content

Established Early Childhood Education (ECE) curriculum for teacher training is widely available and accomplishes the primary goal of providing training for classroom teachers, but there is also a unique opportunity to provide training in other topic areas. Training for administrators and for individuals interested in starting a new school can be provided online. Nigeria's Basic Curriculum provision of the National Policy on Pre-Primary Educations suggests to achieve their objectives that a variety of steps be taken (Sooter 2013):

1. Encourage private efforts to provide pre-primary education
2. Make the training a specialty

3. Ensure that local languages are incorporated into the training, including textbooks and resources
4. Ensure that the main method of teaching be through play and be reflected in the curriculum for teacher training

These basic curriculum materials already exist. By modifying the materials for online and converting them into local languages, existing teachers can be trained and new teachers can be recruited and trained.

RESULTS AND DISCUSSION

Technology Solutions

Online training can increase the number of trained teachers that are available to work with children from birth to five in Nigeria and other countries in Africa. Using mobile devices and content designed to work effectively in environments with limited Internet access will increase the number of teachers that are trained to work with young children.

CONCLUSION

Evidence shows that birth to five education has a critical impact on a child's educational ability later in life. Trained teachers are needed to work with young children. Effective E-Learning can be a cost effective tool to increase the skills of existing teachers and to train new teachers. As mobile broadband networks and smartphone usage expands, online training will be a logical choice to provide the training needed by teachers of young children. The use of online training tools for early childhood teacher training places much of the responsibility for learning on the student. It also makes the training materials more accessible to the student, they can learn at a time and in ways that are most convenient and effective for them. Instructors also benefit because their schedule becomes more flexible and their burden of being responsible for training is shared with the student as it should be. Instead of utilizing classroom training which is very limited in rural areas, learning resources can be made available to the teachers of young children more effectively.

It's time to start using online training tools in the workplace and at home to make employees more productive, businesses more effective and students more engaged. Using distance learning technologies provides an opportunity to stretch the training budget and make better use of resources.

Acknowledgements

The authors would like to acknowledge Rhoda Odigboh of The Learning Craft and The Teacher's Network in Nigeria, West Africa for assisting with this project. Any opinion, findings and conclusions or recommendations expressed in this material is that of the authors and The Teacher's Network does not accept any liability in this regard.

References

Akinrotimi, A.A., Olowe, P.K. 2016. 'Challenges in Implementation of Early Childhood Education in Nigeria: The Way Forward', Journal of Education and Practice, Vol. 7, No. 7, 33-38.

Dahir, A.L., 2016 'Smartphone use has doubled in Africa in two years' Available at https://qz.com/africa/748354/smartphone-use-has-more-than-doubled-in-africa-in-two-years/

Harvard Center on the Developing Child. 2007. “The Science of Early Childhood Development.” Retrieved from www.developingchild.harvard.edu.

Obiweluozor, N. 2015. ‘Early Childhood Education in Nigeria, Policy Implementation: Critique and a Way Forward’, *African Journal of Teacher Education*.

Salami, Ishola Akindele. 2016. ‘Nigerian Early Childhood Education Policies and Practices For Sustainability’, *European Journal of Research and Reflection in Educational Sciences*, Vol. 4 No. 5: 71-85.

Smart Future, 2016 ‘Smartphone Connections in Africa Will Triple by 2020: New GSMA Study’, Available at http://www.corporate-digest.com/index.php/smartphone-connections-in-africa-will-triple-by-2020-new-gsma-study.

Sooter, T. 2013. ‘Early Childhood Education in Nigeria: Issues and Problem’, *Journal of Education and Social Research*, Vol. 3 (5) August 2013.

Sun, J., Rao, N., Pearson, E. 2015. ‘Policies and Strategies to Enhance the Quality of Early Childhood Educators’. Paper commissioned for the EFA *Global Monitoring Report 2015*, Education for All 2000-2015.

IoT Sensors Using Intel's UP² Board

Asmamaw Mersha (Sophomore)
Bowie State University, MD
e-mail: asmking12@gmail.com

Abstract

This project is done using Intel UP² Grove IoT Development Kit that provides guidelines how IoT sensors can be configured using UP² board. The purpose of this project is to show how to read data from sensors and use the monitor to interact with the UP² board. It assesses how IoT sensors function to control our environment such as detecting how bright or dark light. The project mainly tests three sensors. The first sensor is Grove LCD that shows outputs on the LCD display using UPM library. The second sensor is rotary angle sensor that rotates up to 300 degrees to control the sensor output. The third sensor is Grove Light Sensor which uses a light dependent sensor (GL5528 photoresistor) to detect the intensity of light in the environment. The project is done with the assistance of Dr. Jesse Bemley. Because of budget and time restraints, the project is limited to Intel UP² Board Grove IoT Development Kit. I have also used online articles throughout the research. The project will help as an introductory point for those who are interested on the area to do further research. The project is organized into three major parts. While the first part gives the general introduction about the whole project, the second part provides details about how to configure UP² Board. The last part of the project covers how different sensors sense environment and displays output. It also incorporates bibliography.

Keywords: IoT Sensor, UP² Board, Grove Pi+ Board, Arduino Create, blink application

INTRODUCTION

This project is to configure IoT sensors using UP Squared (UP²) Board intel's IoT Development Kit. It briefly provides guidelines for users how IoT sensors work with UP² board. The **IoT (Internet of Things)** is the network of physical objects or devices, vehicles, buildings, and other items embedded with electronics, software, sensors, and network connectivity that enables these objects to collect and exchange data. This kit includes various materials that are needed for the Kit to function properly. As it is shown on figure one below, the kit comprises UP² board, Grove Pi Board, Micro USB Cable, UP² Board Power Cable, Ethernet cable and internet access, and host computer connected to the internet.

Figure One: UP Squared IoT Grove Development Kit materials

While the UP² board (located at the bottom on figure two) is the most powerful maker board ever in Intel, Grove Pi Board (a rectangular shape with many ports located at the top of UP squared board on figure two below) does not need for soldering or breadboards. You can just plug in your Grove sensors and start programming directly. Grove is an easy to use collection of more than 100 inexpensive plug-and-play modules that sense and control the physical world. The UP Squared IoT Grove Development Kit offers pre-installed Ubuntu 16.04 and Arduino Create, which includes over 400 sensor libraries.

By connecting Grove Sensors to Raspberry Pi, it empowers your Pi in the physical world. With hundreds of sensors to choose from Grove families, the possibilities for interaction are endless.

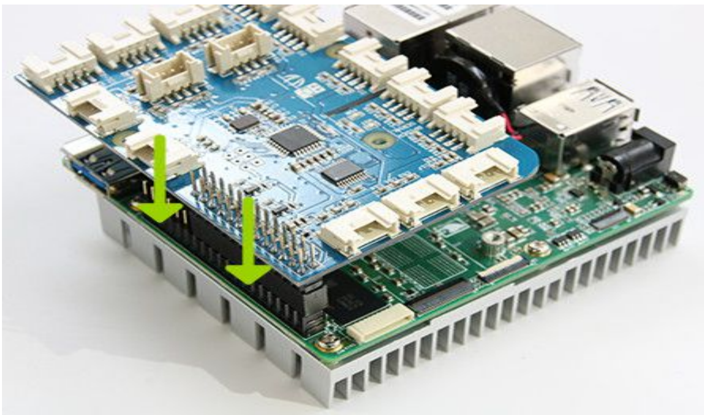


Figure Two: Up Squared board with Grove Pi+ board

Building UP Squared (UP²) Board

UP Squared board (UP²) is the world's fastest x86 maker board based on latest Intel platforms Apollo Lake. UP is the bridge between your hobby and your future business. UP² board is the most powerful maker board ever in Intel. "Features of the UP Squared Board are multiple USB 3.0 ports, double Gigabit Ethernet, and HDMI making it ideal for solutions in Internet of Things" ("UP Squared Boards - AAEON | Mouser Europe", 2018).

In order to configure IoT sensors on UP² board, we are going to have three major steps. Each step will have various sub-steps and instructions. These major steps are to make Board connections, connect to Arduino Create, and run the blink application. All of these step's instructions will be elaborated throughout this paper.

Make Board Connections

To make the board connection you need Grove Pi+ board, micro UP² board, and Ethernet for the system that connects the board to internet connection. The figure Three below shows a diagram of Arduino Create with UP² board IoT sensors.

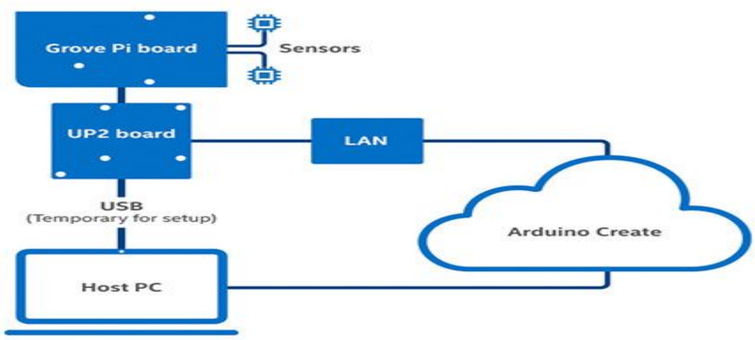


Figure Three: A diagram for Arduino Create with UP Squared Board.

This is how the board connection looks like after completing all connections. Making board connections on the UP squared board follows three major guidelines as the following.

a) Install the Grove Pi+ board. To install the Grove Pi board, locate the small white arrow on the UP^2 board. Look for small white arrow (triangle shaped) at the tip of the UP^2 board right next to the gold screw. Then, locate the connector 1 on the UP^2 board and connector pins on the Grove Pi+ board. Once you locate both the connector1 and pin on the Grove Pi+ board, line up pin 1 on Grove Pi+ board and connector 1 on UP^2 board. Then, carefully press down the Grove Pi+ board to the UP^2 board. Make sure all the pins on the Grove Pi+ board slide neatly into the connectors on the UP^2 board. Do not bend any of the pins on the Grove Pi+ board which will damage all the system not to function properly.

b) plug the Micro USB Cable into the UP^2 board. Identify the Micro USB 3.0 port on the UP^2 board and plug the Micro USB cable in to the UP^2 board. Since there is dual Micro USB 3.0 port on the UP^2 board, plug the Micro USB cable into the left side of the USB port. Then, connect the Micro USB cable to your host computer so that it can transfer any data or information to the host computer. Connect the Ethernet Cable to the UP^2 board and to your Router.

Note: the Ethernet cable must be plugged first before powering on your board so that your board can get an IP address.

c) Power up your board. After completing all other connections, the next step is to plug in your UP squared Board to the power supply and plug the power supply into an electrical outlet. If you completed the connection correctly, you will see the orange LED light blinking at the top of your Ethernet port and power LED light on the left side of your power supply jack. While the orange LED light implies your UP squared Board Ethernet connection, the green power LED light shows the UP squared Board is ultimately connected to power supply. In addition, you can either press the small white button next to the blue LED or simply unplug the power cable.

Connect to Arduino Create

"Arduino Create is an integrated online platform that enables Makers to write code, access content, configure boards, and share projects" ("Arduino - Create", 2018). Arduino is an open source computer hardware and software company, project, and user community. It designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical and digital world.

Through Arduino Create, you can access **Arduino Web Editor** that allows you to write code and upload sketches to any Arduino board Intel based platforms from your web browser after installing a simple plug-in. Since it is hosted online, it will always be **up-to-date** with the latest features and will always support any new board of the Arduino system. The Arduino Web Editor is supported on Windows, Linux, Mac and Chrome OS. In order to configure Arduino Create, follow the following three sub-steps.

Configure the UP Squared Board

On your host computer, go to https://create.arduino.cc/getting-started/up2. Then click **Login**. When you click Login, it will ask you to sign in or sign up for Arduino Create. If you do not have account, follow the onscreen instruction to sign up. You have to activate your account and log into the site using your new password and user name. You will be asked to install Arduino plugin if this is your first-time using Arduino Create. To install Arduino plugin, follow the onscreen instruction. If you get an error message saying "We are not able to detect the installed plug in", locate the Arduino plugin icon and **Right click** on the icon , then select **Open plugin**. After you create Arduino account and logged in into Arduino create, you will be asked to upload the Arduino Connector to your UP² board. Then click **Upload**.

Verify your Board's Connection

After you complete the plugin, you will be asked to double check if your board is properly connected so the connector can be installed. Make sure all connections are properly connected including power supply and network. After installing the plugin, verify if it is still powered on and click **Next.**

Upload the Arduino Connector to your Board

Once you verified your board is properly connected, upload the Arduino connector to UP² board. You will be asked to upload the Arduino Connector to your UP² board. Then Click **Upload.** In order for your board connect to Arduino Create, the process will take about **3** minutes as shown on figure four below.

Figure Four: UP Squared Board connecting to Arduino Create

Hence, make sure to wait at least 3 minutes for the connection process. After 3 minutes, you will see the message "Congratulations! You are all set". If your board cannot connect with in 3 minutes, check your connections such as Ethernet, power, micro USB, and others. If your board is not still connected to Arduino Create, apply the following troubleshooting guidelines:

- **Restar**t your UP Squared board
- Minimize all windows to see if you have missed a pop-up message "**Do you want to install a driver**" or other forms of pop-up messages.
- Make a **hard refresh** on the Arduino web pages.
- Refer to a **troubleshooting guide** on Arduino pages or you tube.

Name your Board

Once your board is connected with Arduino Create, give your board a name, such as up1, up2, or up3 as shown below (see figure five below).

Figure Five: Creating a Device Name

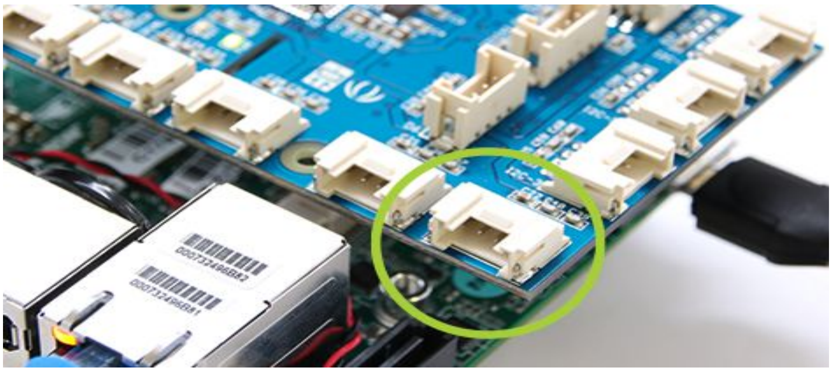
At this point you are ready to do your very first program using Arduino Create software. As your board is connected with Arduino Create software using internet, you can start doing your project on it.

Run the Blink Application

In this topic you will run a blink application using your UP Squared Board and Arduino Create application. You will run a sample Blink Application by connecting LED into your board. You will also upload the sketch using Arduino Create and write a software code that run the Blink Application.

Connect an LED

Before you connect an LED light, get the Grove Green LED and locate **D4** on the Grove pi board (circled in Green on figure six below). Use a Grove Cable to connect the LED to **D4**. The LED have two pins, a longer and shorter. While the longer pin is carrying a positive charge, the shorter pin is carrying a negative charge. Therefore, make sure you connect the longer wire to the positive terminal.



Note: you can leave the board on when plugging in the LED.

Figure Six: Connect an LED

Open the Sample Blink Application

In order to do the sample Blink application, open the Arduino Web Editor page from Arduino Create page and open the Blink Examples. Once you open the Arduino Web Editor, go to Examples > FROM LIBRARIES > UP Squared GROVE IOT DEV KIT > Blink (see figure six above).

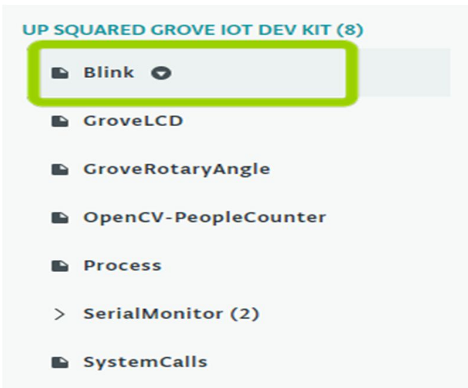


Figure Seven: Web Editor Sample

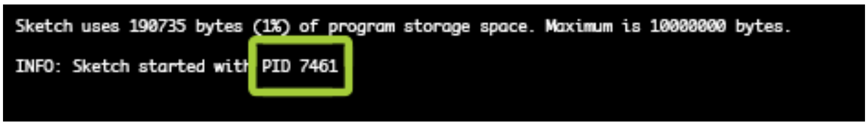
Upload your Sketch Using Arduino Create

Open Arduino Create page to upload the sketch using Arduino Create. Then, from the drop-down menu, choose your board **via Cloud** as it is indicated on figure below. Then click **Upload** (the right arrow sign on figure eight) to upload and run the sketch. When you click Upload button, you are uploading and running the sketch on your target device. However, if you want to compile your sketch without uploading and running it, click the **Verify** button to the left side of the **Upload** button as it is shown on figure eight below.

Figure Eight: Upload your Sketch Using Arduino Create

Your Sketch is Running

At this moment it is time to confirm that your sketch is running. In order to confirm this process, you will get a process ID (PID) at the bottom of the screen as indicated below.



Note: the sketch ID / PID number will be any number generated automatically when you run the sketch.

Now you should see the LED is flashing. Since the LED is less bright and flash slowly, go closer to it and you will see the LED flashing slowly. If your LED is not flashing, follow the next guidelines to troubleshoot the LED:

- Check if you have connected the LED to the right connector on your Grove Pi board **D4**
- Check if your board is still connected.
- Check if the LED is plugged correctly
- Make sure you selected **via cloud** board
- Re-try it again.

Sensors

A **sensor** is a device which detects or measures a physical property and records, indicates, or otherwise responds to it. It is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output. A sensor is a type of transducer; sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple generates a known voltage (the output) in response to its temperature (the environment). There are different types of sensors for different purposes. The following are some of the examples of sensor.

Grove LCD Display

LCD (liquid-crystal display) is a flat-panel display or other electronic visual display that uses the light-modulating properties of liquid crystals. Liquid crystals do not emit light directly. The figure below shows a diagram of Grove LCD display connected to UP Squared board.

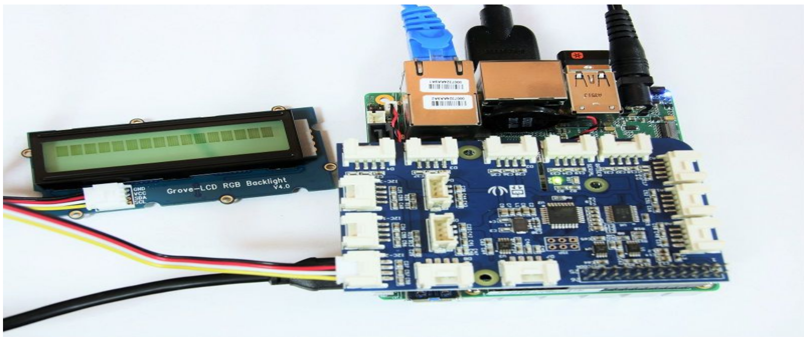


Figure Nine: Grove LCD display connected with UP Squared Board

In order for any UPM (Useful Packages and Modules) library to work, you need to include the header file corresponding to that particular sensor in your sketch. If you browse the Libraries in Arduino Create* and include the UPM library, all the UPM sensor libraries will be included, and you probably only need one or two out of the several hundred.

Grove Rotary Angle Sensor

The rotary angle sensor produces analog output between 0 and Vcc (5V DC with Seeeduino) on its D1 connector. The angular range is 300 degrees with a linear change in value. The resistance value is 10k ohms which is perfect for Arduino use. It is also called a “potentiometer”.

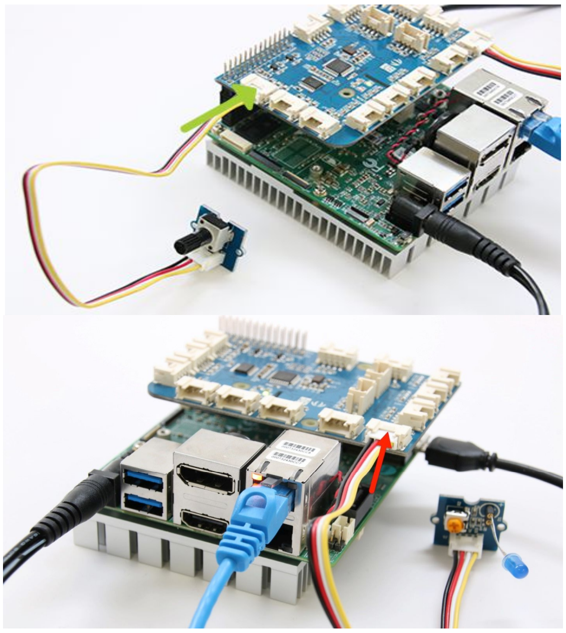


Figure 10: Grove Rotary Angle Sensor

As it is shown above on figure, first connect the hardware. You have to plug in the Grove LED to "D4" on the Grove Pi board. Then, plug the Grove Rotary Angle Sensor into "A0". Second, get the code. Use the existed code, open the example in the Arduino Create IDE, navigate to Examples > FROM LIBRARIES > UP SQUARED GROVE IOT DEV KIT > Grove Rotary Angle.

Grove Light Sensor

The Light Sensor is one of the two sensors that give your robot vision (the Ultrasonic Sensor is the other). The Light Sensor enables your robot to distinguish between light and dark. It can read the light intensity in a room and measure the light intensity of colored surfaces. Grove Light Sensor uses a light dependent sensor (GL5528 photoresistor) to detect the intensity of light in the environment. The resistance of photoresistor decreases when the intensity of light increases. The output signal from this module will be HIGH in bright light and LOW in the dark.

The Grove light sensor works as the following. First, plug the Grove light sensor into port A0 on the Gro pi board. Then get the code from the Arduino Create IDE under Examples > FROM LIBRARIES > UP SQUARED GROVE IOT DEV KIT > Grove Light Sensor. Before running the code, open the Monitor in the IDE. Once you run it, you should see the value of the sensor input in the Monitor.

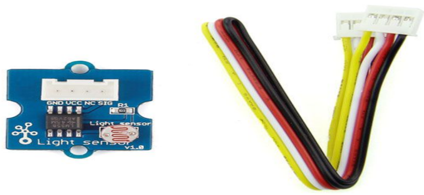


Figure 11: Grove Light Sensor

Bibliography

1. UP Squared Grove IoT Development Kit Getting Started Guide. (2017)
2. Arduino - Create. (2018). Retrieved from https://www.arduino.cc/en/Main/Create
3. UP Squared Boards - AAEON | Mouser Europe. (2018). Retrieved from https://www.mouser.com/new/aaeon-up/aaeon-up2-squared-boards/
4. Arduino - Create. (2018). Retrieved from https://www.arduino.cc/en/Main/Create