The Impact of ICTs Diffusion on MDGs and Baroclinic Digital Learning Environments in East and Southern Africa

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Abstract: **:***Information and communication technologies (ICTs) impact all the MDGs, especially in eradicating extreme poverty and hunger. The correlation between ICTs and high economic growth and education has not been well researched in most African countries. A learner is often inundated with massive volumes and different kinds of knowledge to learn from, i.e. learning vortices that are chaotic. Chaos theory is the qualitative study of unstable, aperiodic behaviour in deterministic, non-linear, dynamical systems, and from which the behaviour of the system is understood by reconstructing its attractor and gaining qualitative insight. The Zimbabwe Open University (ZOU) online platform has digital learning objects that increase opportunities for teaching and learning, supports ubiquitous learning and provides intuitive ways for identifying learning collaborators, learning contents and learning services in the right place at the right time. The specific objectives of the research are:*

(a) To assess the impact of ICTs on MDGs
(b) To ascertain the ICT impact on economic growth, innovations and education in East and Southern Africa
(c) To explore the emerging trends in E-learning from ICTs for development
(d) To apply Chaos Theory to design a digital learning environment with fully functional interactive e-learning facilities at Zimbabwe Open University.
(e) To recommend a development model or a framework for economic growth for these African countries.

The methodology used was largely qualitative on technology capacity needs assessment that covered 6 countries, and also quantitative on GDP and Infodensity covering 18 countries in East and Southern Africa.GDP and Infodensity data was collected for 18 African countries to ascertain the link between ICTs diffusion and GDP density per country. The case study for the establishment of the ZOU Online platform is presented and discussed to show the baroclinic and birfucation nature of the chaotic system, in order to design a completely functional digital learning environment. The mean for the 18 East and Southern African countries with respect to main telephone density is 3.8%, mobile subscribers is 27.87%, and internet use is at 4.87%. Capacity needs assessment included both the human capital development and social capital aspects in order to achieve sustainable information and communication technology capacity development. Human capital development is central to capacity needs. There is a strong correlation between ICT diffusion and high economic growth, evidenced by high mobile density. The mobile phone has become a good measure of wealth for an average African, and can be used in education. The solution to poverty and under-development in these African countries is, therefore, knowledge and economic empowerment. The recommended sustainable technology development with an African model is proposed. Chaos Theory offers tremendous opportunities for handling the complexity associated with the design of a fully interactive e-learning environment available online. The paper proved the correlation and potential application of Chaos Theory to the design model for digital learning environments. In the ZOU Online learning environment, it was established that learning objects can increase course interactivity, give students additional opportunities to interact with a variety of learning content, provide opportunities

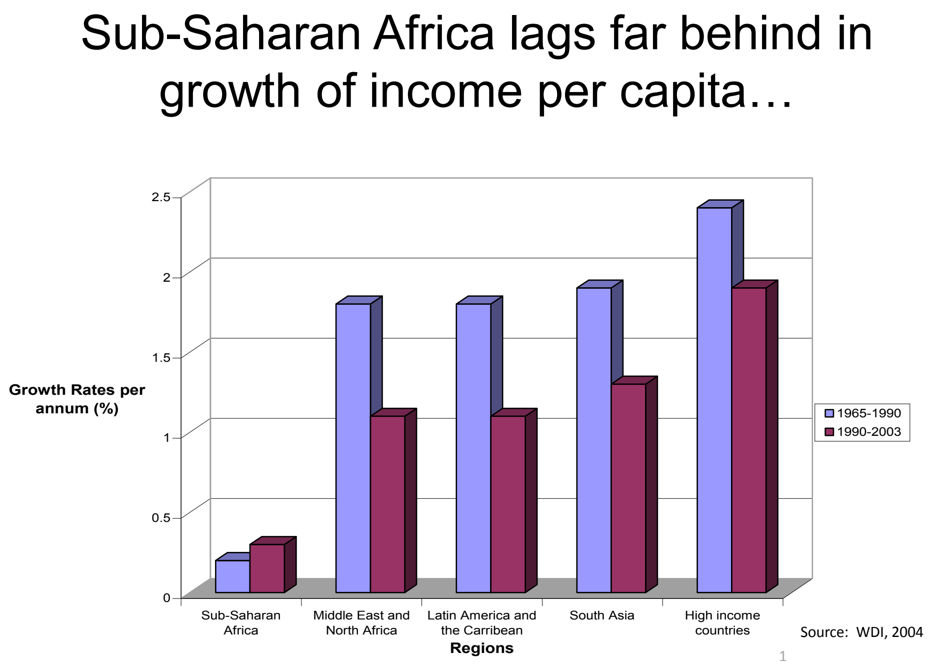
for active learning, enrichment, and remediation, and offer practice with the content which students need to master.

INTRODUCTION

The Millenium Development Goals (MDGs) are stated as follows:

1. To eradicate absolute poverty and hunger
2. To provide primary education for all
3. To promote gender equality and women empowerment.
4. To reduce infant mortality
5. To provide quality maternal health service
6. To combat AIDS, malaria and other diseases.
7. To conserve and make the environment sustainable.
8. To promote solidarity among the international community for development.

Goal 1 (eradicate extreme poverty and hunger) directly affects Goals 2 to 7, and requires Goal 8 (develop a global partnership for development). According to World Development Indicators (2004), Sub-Saharan Africa (SSA) lags far behind in growth of income per capita with levels of 0.2% and 0.3% for the periods 1965-1990 and 1990-2003, respectively, as illustrated below. Furthermore with respect to primary education (Goal 2), most of Africa is still off track with 61% of the 48 SSA seriously off track.



The major problem of under-development characterised by the huge challenge to achieve the MDGs is on knowledge empowerment supported by Information and Communication Technologies (ICTs). The emergence and convergence of information and communication technologies (ICTs) has remained at the centre of global socio-economic transformations. As noted by the World Bank (2003), the effective use of technology is dependent not only on the technology but also on factors that are independent of the technology. ICTs increase productivity through:

- Better communication and networking at lower cost

- Digitalisation of production and distribution
- New trade opportunities through e-commerce
- Access to knowledge
- Increased competition

The productive capacity of a country is determined by the quantity and quality of its factors of production. *Infodensity* is the sum of all ICT stocks, mainly as capital and labour. For example, simple tools are used together with skilled ICT labour in the processing of agricultural output, and computers together with relatively unskilled labour are used to produce telecommunications services. At the end of the numerous production processes, part of the outputs will be in the form of ICT outputs, which will be absorbed as consumables and will be added back to the capital stock (Sciadas, 2003). The pattern for diffusion and adoption of ICT innovations in East and Southern Africa is the main object of this research. Potential applications to e-learning are explored.

ICT consumption involves the use of ICT capital and skills, both of which are becoming increasingly complex as consumption expands from staples to complex technological goods and services. According to UNCTAD (2006), 1% increase in Infodensity resulted on average in 0.3% increase in per capita GDP. The increase in infodensity over time is illustrated below in Figure 2:

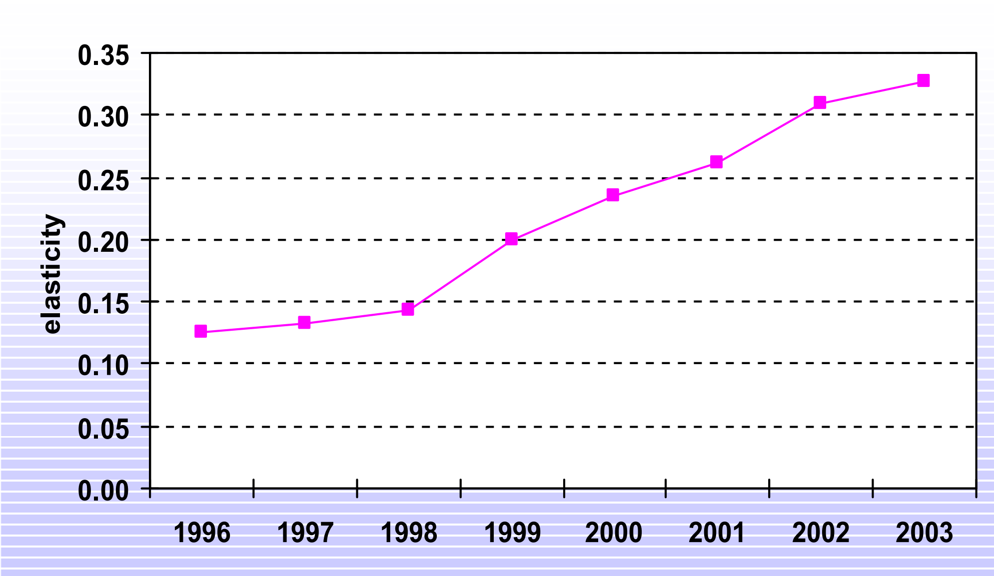


Figure 2: Infodensity and increase in per capita GDP (Source: UNCTAD, 2006)

Baliamoune-Lutz (2003) conducted research using data from developing countries and examined the links between ICT diffusion and per capita income, trade and financial indicators, education, and freedom indicators. internet hosts, internet users, personal computers and mobile phones represent indicators of ICT. The Gompertz model of technology diffusion was used to study ICT dissemination. The results showed that income and government trade policies influence ICT diffusion. However, freedom indices may or may not affect ICT diffusion. In addition, using neoclassical growth models, some studies have shown that IT investment has greatly contributed to economic growth in the United States and in Finland (Baliamoune-Lutz, 2003). While there is a substantial literature on the possible determinants of globalization, very little research work has been devoted to understanding the determinants of ICT diffusion, particularly in developing countries, especially in e-learning.

Introduction of new technologies often follows a similar technology maturity lifecycle, which describes the technological maturity of a product. An innovation is an idea, behaviour, or object that is perceived as new by its audience. Diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas (Rogers,2003, page 5). Innovations diffuse through a social system explained by the diffusion of innovation theory (Rogers, 2003). Diffusion of innovation is a theory that analyzes as well as explains the adaptation of a new innovation. The purpose of this theory to the research is to provide a conceptual paradigm for understanding the process of diffusion and social change associated with ICTs. With this understanding, we take "*adoption*" as the stage in which a technology is selected for use by an individual or an organization. Similarly, "*Innovation*" is used with the gradation of a new or "innovative" technology being adopted. Introducing a new innovation in a social system, such as those associated with the use of ICTs, should consider the characteristics of the target population, those of the innovation, and the stages of adoption. An innovation initially moves slowly through a societal group, but as the number of individuals trying the innovation increases, the diffusion of the new idea moves at a faster rate.

Rogers (2003) posits that people have different levels of readiness for adopting new innovations and that the characteristics of a product affect overall adoption. Rogers classified individuals into five groups: innovators, early adopters, early majority, late majority, and laggards. In terms of the S curve, innovators occupy 2.5%, early adopters 13.5%, early majority 34%, late majority 34%, and laggards 16%. African countries are largely end consumers of technology and fall among the late majority (34%) and laggards (16%) with respect to ICT innovations. This has a great impact on e-learning. This is illustrated by the chart shown below as Figure 3:

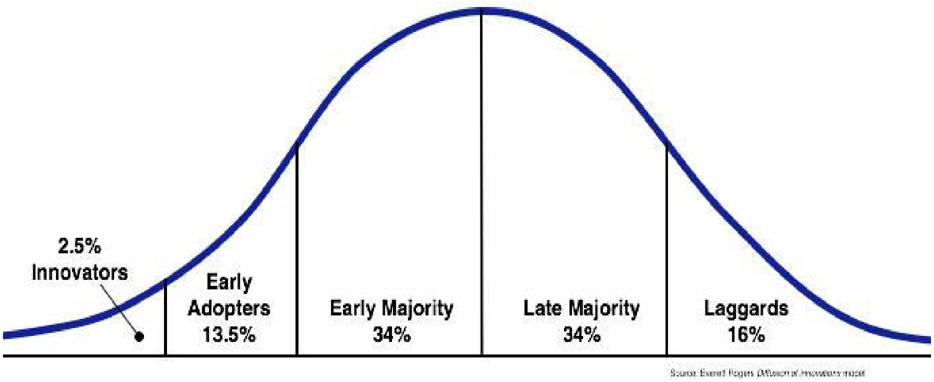


Figure 3: Rogers' Bell Curve

Rogers (1995) presented the following four adoption/diffusion theories:

1. ***Innovation Decision Process theory***

This is where potential adopters of a technology progress over time through five stages in the diffusion process and where the focus is on the user or adopter:

(a) *Knowledge* – learning about the innovation;
(b) *Persuasion* **–** persuasion on the value of the innovation;
(c) *Decision* **–** making decisions to adopt it;
(d) *Implementation* **–** implementation of the innovation; and
(e) *Confirmation* **-** the decision is then reaffirmed or rejected.

2. ***Individual Innovativeness theory***

An innovation is adopted earlier in the continuum of adoption/diffusion by individuals who are risk takers.

3. ***Rate of Adoption theory***

Diffusion takes place over time with innovations going through a slow, gradual growth period, followed by dramatic and rapid growth, and then a gradual stabilization and finally a decline.

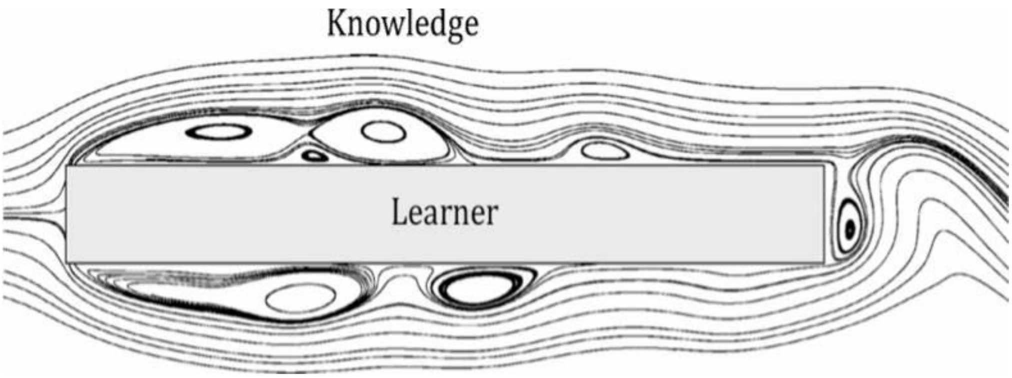
4. ***Perceived Attributes theory***

An innovation is judged by the following five attributes:

(a) *Trialability* - that it can be tried out;
(b) *Observability* - that results can be observed;
(c) *Relative advantage* - that it has an advantage over other innovations or the present circumstance;
(d) *Complexity* - that it is not overly complex to learn or use; and
(e) *Compatibility* - that it fits in or is compatible with the circumstances into which it will be adopted.

Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, observability, and less complexity will be adopted more rapidly than other innovations (Rogers, 1995). E-learning has benefited tremendously from ICTs innovations. A learner is often overwhelmed with massive volumes and different kinds of knowledge to learn from, i.e. learning vortices that are chaotic. These sources of knowledge or learning objects are characterised by vortices acquired from different subjects and courses, as shown in Figure 4 below, especially in a ubiquitous setup:

Figure 4: Learning vortices (objects) in a Chaotic Learning Environment



Chaos theory is the qualitative study of unstable, aperiodic behaviour in deterministic, non-linear, dynamical systems. It often seeks to understand the behaviour of a system by reconstructing its attractor, and knowing this attractor gives us qualitative understanding. This includes theoretical hypotheses that assert relationships of qualitative similarity between its abstract models and the actual systems it studies. Dynamics is used more as a source of qualitative insight than for making quantitative predictions. Dynamics of a fluid is described by its velocity field **V**. Vorticity is defined as the curl of velocity $\mathbf{W}(=\nabla \times \mathbf{V})$. At low velocities vortices are generally observed when a fluid is subject to rotation, the most common example being the kitchen sink vortex, while at high velocities, rotation is inherent in the fluid. They are known to occur in various forms such as lines, rings, etc. (Murugesh S. & Lakshmanan M., 2005).

E-learning is learning that is supported or enhanced through the application of Information and Communications Technology (ICT), and has become an important pillar in open and distance learning. E-Learning can cover a spectrum of activities from supported learning to blended learning and to learning that is delivered entirely online. Designing a digital learning environment is often very complex, especially when one considers the ubiquitous context where learners seem to be everywhere at the same time and using different access devices and technologies (The Free Dictionary, 2008). According to Yang (2006), the main purpose of ubiquitous learning is to provide intuitive ways for identifying learning collaborators, learning contents and learning services in the right place at the right time. The object of this paper is to apply Chaos Theory to design a digital learning environment with fully functional interactive e-learning facilities at Zimbabwe Open University (ZOU). The ZOU online learning platform uses three types of tools:

- Content tools for the delivery of electronic learning content
- Communication tools, e.g. e-mail, discussion lists and bulletin boards, and
- Management tools or systems for the effective management of the teaching and learning process.

Like all progressive communities and in view of the above theories, the Zimbabwe Open University recognises and reflects the following possible education paradigms in its open and distance learning (ODL) model:

1. *Constructivism* – generate and learn from own experiences, i.e. relevancy of working experience
2. *Constructionism* - that individual learners construct mental models to understand the world around them
3. *Collaborative Learning* – students learn from one another.
4. *Creativity Stimulation* – use of creative thinking in challenging situations
5. *Protagonist* – the main character in a movies, drama or story never dies, i.e. the Spouse/student cant forget to come back home.
6. *Formal and informal spaces* are used in ODL.

The key African problem on development is characterised by a world contribution to knowledge of only 0.03%, average tertiary enrolment ratio for school leavers of only 4% and university fields of study largely dominated by social sciences/humanities with 47%, education 22%, agriculture 3%, sciences 9% and health sciences 9% (UNESCO, 2010). It is the object of this paper to assess the impact of ICTs on MDGs and examine the relationship between ICT diffusion and adoption against a set of macroeconomic and policy variables in East and Southern Africa for the period 2000-2010. The paper is purposed to assess the impact of ICTs on economic growth from the perspective of diffusion and adoption. It is important to assess the adoption and diffusion of ICTs in key sectors of the economies of Southern and East African countries, and to collate basic information about the actual and potential applications of ICTs in order to have a clear understanding of the specific policy environments and sustainable capacity requirements. The focus should now be on people, organizations and processes rather than on the technologies themselves. If this is not done, ICTs will not be useful for rural development, unless there is participatory communication and training methodologies.

The major developmental problem being faced by East and Southern African countries, which is the subject of focus for this paper, is multi-faceted and includes the following symptoms:

- Many donor-driven initiatives that excluded both policy-formulation frameworks and sustainable capacity building have not brought meaningful development in these African countries.
- Government policies, donor interest and community development needs are totally divergent with respect to priority areas for development.
- Africa needs to break the under-development, poverty and illiterate cycles in the long term and exploit the blessed resources available to create wealth. Extensive investment in technology and human capital development as a vehicle to exploit the vast mineral and natural resources has not been given sufficient attention.
- Poverty reduction requires a sustainable solution that increases production capacity at individual, institutional, community and national levels. The impact of ICTs on MDGs and generally economic growth needs a detailed assessment.

Some researchers argue that the transfer of ICTs to developing countries may not contribute to economic development the same way it did in industrial countries, and that it may be best to localize technology and focus on its use in education (Baliamoune-Lutz, 2003) and sustainable development of economic growth. The correlation between ICT use and economic growth is interrogated and the issue of the direction of causality is investigated. The specific objectives of the research are:

1. To assess the impact of ICTs on MDGs
2. To ascertain the ICT impact on economic growth, innovations and education in East and Southern Africa
3. To explore the emerging trends in E-learning from ICTs for development
4. To apply Chaos Theory to design a digital learning environment with fully functional interactive e-learning facilities at Zimbabwe Open University.
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According to the International Telecommunication Union study (ITU, 2010), the relevance and impact of ICTs to the MDGs is tabulated below: (http://www.itu.int/ITU-D/ict/publications/wtdr_03/material/ICTs _MDGs.pdf).

MDGs	**Impact of ICTs**
MDG 1: Eradicate extreme poverty and hunger	• ICTs provide increased access to market information and reduce transaction costs for poor farmers and traders. ICTs create employment and increase wealth. Tele-work allows gainful work from home. • ICTs increase skills and productivity resulting in increased incomes.
MDG 2 : Achieve universal primary education	• ICTs increase supply of trained teachers though ICT-enhanced distance training. Distance learning helps in educational and literacy programmes in

	rural and remote areas.
MDG 3 : Promote gender equality and empower women	• ICTs deliver educational and literacy programmes specifically targeted to poor girls and women. Studies show females outnumber males in E-learning programmes. ICTs also empower women to steelwork from home.
MDG 4,5,6 : Health (Child mortality, maternal health – reduce by 2/3 and 3/4, HIV AIDS, malaria, etc. - Halt and reverse)	• ICTs increase access of rural care-givers to specialist support and remote diagnosis. • ICTs enhance delivery of basic and in-service training for health workers. • ICTs increase monitoring and information-sharing on disease and famine.
MDG 7 : Ensure environmental stability	• Remote sensing technologies and communication networks permit more effective monitoring, resource management, and mitigation of environmental risks. Steelwork obviates the need to travel, saves energy and reduces pollution.
MDG 8: Global partnership for development	• ICTs are extensively used in communication and nurturing of collaborative partnerships. • The regional collaboration strategy supported by ICTs covers: o Humanware /social issues o Software Oriented Technologies o Hardware Oriented Technologies o E-mail styles and problems o Multimedia mail o Shared Applications

Therefore ICTs impact on all the MDGs in different ways. The fast track to the achievement of MDGs lies greatly in the ability to effectively manage the diffusion and adoption of ICTs for development.

ICTs play a role mainly as communications technologies rather than as information-processing or production technologies. Access to information and knowledge is considered a key enabler in poverty reduction. In Wresch's (1996) view, there are four information problems frequently faced by the poor: geographic isolation, lack of communication channels, language problems, and lack of computer systems and relevant e-skills. The ICT revolution, at institutional and SADC regional collaboration levels, requires extensive investments into people (labour) and capital for the infrastructure and equipment. With the advent and convergence of ICTs, the world has entered a new era which will witness deep cultural and social changes, and global communication systems which are more interactive and participatory in operation. This new dynamic invites us to cope with still unfamiliar ways of riding the waves in a sea of change (Sciadas, 2003). Advances in communication technologies have enabled many countries to improve the lives of their citizens through improved health, education and public service systems, and economies (Kekana, 2002). Work done by Heeks (1999) in Botswana, shows that investment for Internet access was significant in terms of initial financial outlay, running costs, time and skills. There are tremendous opportunities in ICTs in accelerating broad-based growth and sustainable development, and for reducing poverty (Gillwald and Stork., 2007). A knowledge economy requires:

- widespread access to communication networks;
- the existence of an educated labour-force and consumers (human capital); and
- the availability of institutions that promote knowledge creation and dissemination.

A study conducted by Moradi and Kebryaee (2010) explored the impacts of ICT investment on economic growth in a cross section of 48 Islamic countries over the period 1995-2005. Panel data analysis was carried out to examine the factors affecting economic growth where the standard Solow growth model was extended to take into account the technological progress, embodied in the form of ICT investment and human capital in order to take the speed of convergence into consideration. ICT investment was found to have a stronger influence on economic growth in the sub-sample of 24 countries that have relatively a higher ICT Opportunity Index. Moreover, non-ICT investment was found to positively affect on economic growth. However neither openness nor population growth seems to have significant impact on economic growth although the speed of convergence in both sub-samples was about the same (Moradi and Kebryaee, 2010).

A global set of indicators *(infostate)* showing how the availability of ICTs and access to networks can be a misleading indicator if it neglects people's skills, and if ICT networks and skills combined *(infodensity)* are not matched by a measurement of what individuals, business and countries actually do with such technologies (*info-use*), is worth further interrogation in this study. This approach offers important perspectives into the central role that e-policies and knowledge have started to play in determining how countries will fare in the global competition to benefit from the information revolution and move away from poverty (Sciadas, 2003). Although century-old wireline telecommunications networks are a cause of the Divide, the gaps are more pronounced in newer technologies, which include the internet, computers and cell phones. Skills, as measured by education indicators, also contribute significantly to the divide, and this is more the case as we move from generic to more specific measurements.

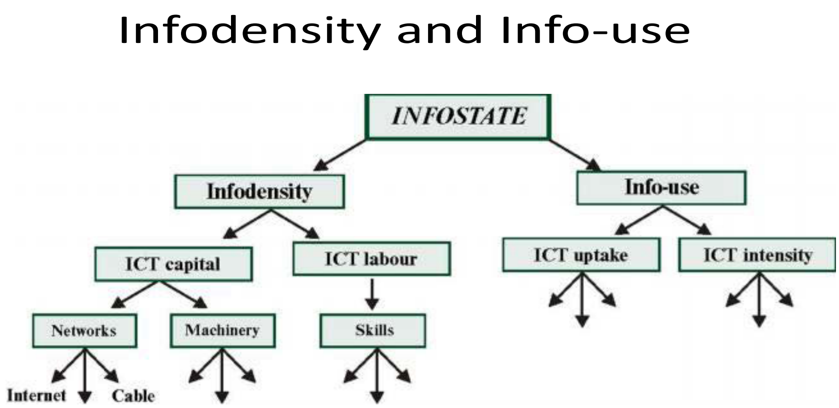


Figure 5: Infodensity versus Info-use

A close correlation exists between Infostates and per capita GDP. Initial study reveals that for every point increase in infodensity, per capita GDP increases anywhere between $136 and $164 (Sciadas, 2003). There are notable exceptions though. Countries with similar GDPs can have very different infostates and vice versa. This speaks to the importance of national e-policies and e-strategies, implying that their design and implementation matter. The interrelationships between info-state, info-density and info use are illustrated by the diagram shown as Figure 5 (after Sciadas, 2003; 10).

As a result of the convergence of information, telecommunications, broadcasting and computers, the Information and Communication Technologies (ICTs) sector now embraces a large range of industries and services. Generally, investment in the development of the ICT infrastructure will result in improved economic efficiency and competitiveness; more efficient and effective education; healthcare and public administration; opportunities to exploit low factor costs in international markets; opportunities to increase social capital; and opportunities to bypass failing domestic institutions. The African ICT environment and infrastructure faces tremendous challenges, as evidenced by a synopsis conducted for ICT indicators for Africa (Kabanda G., 2008), which shows that:

- Africa has the lowest growth in teledensity of any developing region in the world.
- Has 12% of world population, but 3% of World's main telephone landlines.
- Average level of income is the lowest, but the cost of installing telephone landline is the highest due to the huge costs of civil works involved stretching over very long distances or in areas with a large geographical dispersion.
- Highest profit per telephone landline and long waiting period for telephone lines.
- Internet connectivity is 1.5% of the world-wide connectivity.

The number of mobile subscriptions worldwide is now exceeding five billion, i.e. more people today have access to a cell phone than to a clean toilet. The surge in cell phones in Africa is transforming the continent, as some 94% of urban Africans are near a GSM signal. Farmers in Niger use cell phones to find out which market is giving the best price; and people in Kenya pay their bills and send money home using M-Pesa (http://blogs.worldbank.org/africacan/category/topics/information-and-communication-technologies). **M-PESA** (M for mobile, *pesa* is Swahili for money) is the product name of a mobile-phone based money transfer service whose initial concept and design was Kenyan and was later developed by Sagentia for Vodafone (Vodafone. (2007, February 13). *Safaricom and Vodafone launch M-PESA, a new mobile payment service.* Retrieved January 29, 2009,from http://www.vodafone.com/start/media_relations/news/group_press_releases/2007/safaricom_and_vodafone.html).

The study by Wafula-Kwake and Ocholla (2007) explored whether ICT use is feasible in the rural areas of South Africa and Kenya by using largely survey research method. The survey involved interviewing 400 women aged between 16-60 from both Kenya and South Africa. A meagre average of 5.4% of the respondents in South Africa use modern technologies such as the computer/internet, where more than half (57.5%) of the respondents faced problems ranging from affordability to distance from the nearest learning centre and time to study. Reasons for yielding educational information ranged from personal welfare and better living standards, to study assignments, counselling, further studies and job opportunities. The study concluded that radio broadcasts are still highly prevalent as a source of information (80%). The use of TV is relatively low (41%), while 16% respondents also use film to access educational information, with a similar number of respondents (13%) that uses the cell-phone and telephone. In comparison to other sectors, the educational sector has the highest number of respondents using the computer/internet (11%).

CHAOS THEORY

Chaotic Systems

The behaviour of a disordered system could be due to random noise or low-dimensional deterministic but chaotic dynamics. This theory that describes and justifies the procedure for the reconstruction of a system's dynamics draws heavily on differential topology. The time series described by

$$y(t) = \sin(t) + \sin(\sqrt{2}t)$$

gives a signal that is composed of two modes, and the apparent disorder arises because the periods of the modes are incommensurate, i.e. their ratio is irrational. This is referred to as quasi-periodicity.

The logistic map $x_{n+1} = \lambda x_n(1-x_n)$ generates a string of values of X_n given a starting value X_o. The time series is disordered, even though the governing equation is very simple. This is an example of a chaotic system, one that is governed by a low-dimensional set of equations but that has a broad-band spectrum. The logistic map is one of the simplest and most mathematically tractable examples of a chaotic system.

The Lorenz system gives an approximation to the Navier-Stokes equation for a convection system, one of the first sets of differential equations found to show a chaotic behaviour. The system consists of three non-linear first-order ordinary differential equations:

$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = \rho x - y - xz$$
$$\dot{z} = -\beta z + xy$$

There are three degrees of freedom for the Lorenz system, showing that the system evolution takes place on a well-defined subset of three-dimensional space (an "attractor") (Gershenfeld, 1988). ***An** attractor* is a set of points or states in state space to which trajectories within some volume of state space converge asymptotically over time (Kauffman S.A., 1993). However, it is important to distinguish between random noise and deterministic chaos. Deterministic chaos occurs in a low-dimensional space, while random noise does not.

Time Delay and analyzing the Dynamics

Information theory can be used to quantify the relation between the time delay and the amount of information available from a measurement, as is the case in message communication in signalling systems. Historically information theory was developed by Claude E. Shannon to find fundamental limits on compressing and reliably storing and communicating data. The information entropy of a system that has a meter to indicate n different values $v_1, v_2, .., v_n$ with observed probabilities $P(v_1), P(v_2), ..., P(v_n)$, is defined by:

$$\mathbf{I} = - \sum_i P(v_i) \log_2 P(v_i)$$

The function defined above is continuous in the probabilities and, if all the probabilities are equal, it is a monotonically increasing function of n. If a choice can be broken down into successive sub-choices, then **I** should be a weighted sum of the entropies of the sub-choices. **I** provides a measure of the amount of information that is gained by a measurement of **v.** If a measurement has a probability of either one or zero then **I** equals zero, and the entropy is maximized by the greatest uncertainty (P = ½). The entropy can be naturally defined for continuous quantities:

$$\mathbf{I} = - \int P(s) \log_2 P(s) ds.$$

Our goal is to be able to predict information or knowledge about the next measurement in the next time delay or interval, for the purposes of disseminating knowledge to the learner. Multisource information theory deals with information transmission in a network. Such a network includes information sources (one or many), the destinations (one or many) where information should be delivered, and channels that are used for transmission; some (or all) channels may have limited capacity (Shen A., 2006).

A manifold is a generalised notion of a surface that allows it to be described without reference to an external co-ordinate system. A simple two-dimensional manifold can be obviously embedded into a two dimensional real space. A hydrodynamic system has infinitely many degrees of freedom, yet just beyond the onset of convection it can act as a very low dimensional system. The Center Manifold theorem guarantees that the linearization of a dynamical system accurately reflects the full non-linear dynamics. In the local linearization there will be stable, unstable, and neutrally stable degrees of freedom. Ultimately, the unstable degrees of freedom will diverge until they reach a bound, the table degrees will exponentially vanish, and so the dynamics will collapse down onto the neutral degrees of freedom ("center manifold"). The center manifold, if it exists, will frequently have fewer dimensions than the full system, and so the system will behave as if it had only this reduced number of degrees of freedom. A more complicated possibility is for the stable and unstable manifolds to cross; a situation related which is related to chaos.

The Lorenz attractor comes from a three-dimensional system, yet its correlation dimension of 2.05 is distinctly less than three. This difference suggests that a full three-dimensional plot of the evolution of the Lorenz system, contains redundant information about the flow. The Poincare section is a standard technique, generally applied to near-periodic systems, that is used to dissect the flow and produce a more lucid representation. This section is formed by taking a surface transverse to the flow, and then plotting the intersections of the flow with the surface. The Poincare section replaces the continuous time dynamical system with a map. This map may have a much simpler structure than was obvious from the original system, and serve as a useful step and guide for further analysis.

Lyapunov Exponents

The divergence of nearby trajectories underlies the sensitive dependence on initial conditions in a strange attractor. Whereas fractals quantify the geometry of strange attractors, Lyapunov exponents quantify the sensitivity to initial conditions. The Lyapunov exponents quantify the relationship between nearby trajectories, and provide another indicator of the presence of chaos. The *Lyapunov exponent* or *Lyapunov characteristic exponent* of a dynamical system is a quantity that characterizes the rate of separation of infinitesimally close trajectories (http://en.wikipedia.org/ wiki/Lyapunov_exponent). Quantitatively, two trajectories in phase space with initial separation $\delta\mathbf{Z}_0$ diverge

$$|\delta\mathbf{Z}(t)| \approx e^{\lambda t}|\delta\mathbf{Z}_0|$$, where λ is the Lyapunov exponent.

Lyapunov exponents measure the rate of divergence of trajectories on an attractor or nearby trajectories in a dynamical system. The rate of separation can be different for different orientations of initial separation vector. They characterize the dynamical system as a whole and do not depend on any specific orbit. Lyapunov exponents also reveal how infinitesimal perturbations will behave over long time periods rather than short ones. Generally, Lyapunov exponents measure how random a system is or its stochasticity. A positive value for the Lyapunov exponent usually indicates that nearby trajectories will diverge and that the flow is chaotic (Anderson R.L., Lo M.W and Born G.H., 2003). An analysis of the Lyapunov exponents will allow us to determine whether two nearby orbits will converge toward each other or diverge from each other. This will lead us to a way of quantifying the sensitive dependence on initial conditions which we observed numerically in the Lorenz equations. Similar to the design of digital learning environments being pursued on the ZOU Online platform, the local Lyapunov exponents can be used to indicate where it would be most important to reduce the magnitude of navigation uncertainties (Anderson R.L., Lo M.W and Born G.H., 2003). However, there are several technical difficulties associated with the predictive power of the Lyapunov exponents, as was shown on the study on epilepsy, which include the difficulty in computing the Lyapunov exponents from time series, complexity of the dynamical systems concerned and the fundamental relationship between fractal dimension and Lyapunov spectrum (Lai *et al*, 2001).

Consider the growth of an arbitrary perturbation dx about a point x. The growth rate of this perturbation will be exponential, with the rates locally given by the eigenvalues of the Jacobian matrix:

$$dx/dt = f(x)$$
$$d(x + \delta x)/dt = f(x + \delta x)$$
$$df/dt + (d/dt)\,\delta x \approx f(x) + (D_x f)\,\delta x$$

Each of the eigenvectors of the Jacobian matrix $D_x f$ will locally grow at a rate $e^{\lambda_i t}$, where the λ_i 's are the eigenvalues of the matrix. Taking the flow to be u_t, the growth of dx is given by the Jacobian, T_x^t of the flow:

$$\delta x(t) = T_x^t\,\delta x(0) = (D_x u_t)\,\delta x(0)$$

The Lyapunov exponents are given by the asymptotic growth rate of the eigenvalue of T_x^t:

$$\{\lambda\} = \lim_{t\to\infty} \|T_x^t\|/t$$

This definition is easily extended to discrete time systems, where the flow u_t is replaced by the nth iterate of the map u_n . T_x^n is defined to be the Jacobian of u_n , and the chain rule allows this to be written as the product of the derivatives of the map at the points along the trajectory:

$$T_x^n = D_{x0}u^n$$
$$= D_{x0}(u...u)$$
$$= (D_{xn-1}u)...(D_{x1}u)(D_{x0}u)$$

A dynamical system may have some positive exponents, corresponding to directions associated with chaotic stretching, some negative ones, corresponding to directions of contraction, and some zero ones, corresponding to directions in which trajectories at most converge or diverge at a rate slower than exponential; the distribution of the signs of the exponents is itself a useful description of the nature of the dynamics. The positive exponents are traditionally ordered as $\lambda_1 \geq \lambda_2 \geq \lambda_3$,..., $\geq \lambda_n$.

Lyaponov exponents measure “stretching”, whereas fractal dimensions measure “folding.” Weak turbulence is the deterministic chaos associated with the detection of chaos. The theory given above offers little insight into strong turbulence, which is the disorder of, for example, the fully-developed turbulence of a high Reynold's number fluid flow. The interactions of the eddies and vortices in such flows are certainly governed by deterministic rules. This theoretical framework is applicable to a digital learning environment. In the atmosphere and ocean, a poleward heat flux arises to balance heating at the equator and cooling at the poles and this differential heating generates large overturning cells. However, the atmosphere and ocean are dominated by rotation and stratification, which add important complications to geophysical transport. The meridional temperature gradient and its associated sloping isopycnals give rise to a zonal flow through the thermal wind balance. The zonal flow is unable to relax the meridional gradient, but potential energy stored in the sloping isopycnals is released through baroclinic instability. Baroclinic instability leads to the formation of mesoscale eddies and atmospheric storms (Biello J.A. and Majda A.J., 2004). We can obtain better understanding of the level of complexity when we get deeper and conside both barotropic and baroclinic aspects of the atmospheric fluid flow. A two-mode (barotropic and baroclinic) model was shown by Lee *at al* (2008) to capture three fundamental dynamic processes: 1) a heat-induced baroclinic mode; 2) a barotropic Rossby wave source resulting from conversion of the heat-induced baroclinic mode into barotropic anomalies; and 3) barotropic teleconnections to high latitudes.

METHODOLOGY

The research methodology describes ways of obtaining and analyzing data to reach conclusions, thus building up empirical evidence to back up these conclusions. The methodology used was largely qualitative on technology capacity needs assessment that covered 6 countries (South Africa, Kenya, Tanzania, Botswana, Zambia and Zimbabwe), and also quantitative on GDP and Infodensity covering 18 countries in East and Southern Africa. The 18 countries covered by the qualitative study are South Africa, Angola, Bostwana, Burundi, D.R. Congo, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. The countries covered by this research study are shown on the map for Southern Africa shown in Figure 6.

The quantitative approach involved the use of surveys and conducting interviews on GDP and infodensity. The survey method used is good for comparative analysis, got lots of data in a relatively short space of time and was cost-effective. GDP and infodensity data was collected for 18 African countries to ascertain the link between ICTs diffusion and GDP density per country. Data was collected on *nominal gross domestic product* (GDP) of selected East and Southern African countries, i.e. the market-value of all final goods and services from a nation in a given year. The GDP dollar values presented here were obtained from the IMF (http://www.imf.org/external/pubs/ft/weo/2009/02.weodata/index.aspx) and are calculated at market or government official exchange rates by the International Monetary Fund (IMF) staff. 2009 values and some of 2008 values are estimates. The methodology for collecting data on infodensity is supported by secondary data covering East and Southern African countries. GDP of Africa was 2.5% of the total GDP of the world in 2008, and was estimated to be 2.3% of the world GDP in 2009. In this case, ***GDP Density = GDP per capita * Number of people per square kilometre.***

Data on infodensity was obtained from the International Telecommunications Union (ITU, 2010).

Figure 6: Map of Southern Africa

The *qualitative research* was used to deepen our understanding of the link between diffusion of ICTs and economic growth. It is pleasing to note that the Tripartite Summit signed in October, 2008 provided a political framework for the harmonisation of various policies, initiatives, infrastructure, institutional arrangements and cooperation from the Common Market for East and Southern Africa (COMESA), East African Community (EAC) and the Southern Africa Development Community (SADC) member states.

The technology capacity needs assessment was conducted in institutions and regional bodies in Kenya, Tanzania, South Africa, Botswana, Zambia and Zimbabwe for the period December 2008 to December 2009. Data was collected from government officials, heads of institutions/organizations and experts in various organisations in East and Southern African countries. The capacity needs assessment was conducted in the context of the systems level, the entity level and individual human capital development needs. Capacity needs assessment included both the human capital development and social capital aspects in order to achieve sustainable information and communication technology capacity development. Human capital development is central to capacity needs. A training need exists when there is a gap between what is required of a person to perform their work competently and what they actual know. Interviews were conducted for the organisations and a questionnaire administered in the form of a Capacity Needs Assessment Questionnaire. Secondary data was also compiled and analysed. The following data collection techniques were used in this study:

- Formal meetings and focus group discussions
- Face-to-face oral interviews
- Questionnaires on capacity needs assessment

- Secondary data and records observation

The face-to-face interviews allowed for in-depth knowledge sharing, helped to develop the bigger picture on ICTs for development and was good for networking. Focus group discussions were held with selected regulatory, training and research institutions to pick up grassroots input and in developing ideas, whist sharing latent knowledge spontaneously, on technological capacity needs assessment. Site visits were conducted in selected organizations and institutions. The face-to-face interviews were conducted with heads of institutions and focus group discussions held with approved organisational representatives according to the following distribution by country:

Country	**Number of interviews and focus group discussions held**
Kenya	4
Tanzania	6
South Africa	8
Botswana	3
Zambia	2
Zimbabwe	2

The face-to-face interviews were conducted according to a guideline that assessed the following areas:

1. A situational analysis of the mission, values and vision of each regional or national training institution in order to determine the institution's purpose, its distinctive features, its mission statement, its organizational and management values, its goals, objectives and strategies and their compatibility with the proposed ICTs for development initiatives.

2. An analysis of the macro and micro environment of each regional or national training institution in order to identify phenomena in macro environment (political-administrative, economic, technological, socio-cultural, physical and stakeholders in the micro environment) that would contribute or impede the achievement of the proposed ICTs for development initiatives. The stakeholders analysis would lead to the determination of the number of government officials to be trained in ICT policy and planning and related areas by site. Any additional training gaps of stakeholders and targets groups identified in ICT were also to be highlighted.

3. An analysis of the current internal human (trainers, faculty, support staff, etc) and institutional (governance, management, financial, material (classroom, training equipment, computer laboratory, software, etc) capacity of each regional/training institution to be used for ICTs for development initiatives. This analysis would lead to the identification of capacity gaps in internal human and institutional capacity that will be filled for the regional/national training centre to be used in the region.

4. Recommendations on ways of addressing the institutional and human capacity gaps identified in each regional/national training institution so as it can be used as a pilot site for ICTs for development initiatives.

Focus group discussions were held in the same institutions where interviews were held and the data was sourced largely from the regional bodies, government ministries, national institutions and centres, and industry experts. Annual reports and publications also provided additional data. The major components of the data collected in focused group discussions include the following:

1. Identity of the institution, its vision and values, and strategic direction of the business.
2. The availability and status of the national/corporate ICT policy framework, and progress towards its implementation.
3. Current capacity of the institution with respect to ICTs and the student enrolment levels by various categories.
4. Current and future interventions on human capital development and ICTs capacity.
5. Quality assurance philosophy and framework.
6. Programme development, management and reviews.
7. Materials development challenges and strategies.

A structured questionnaire, the Capacity Needs Assessment Questionnaire, was administered in the same institutions in order to solicit detailed information in support of the interviews and focus group discussions. The capacity needs for the regional and national institutions/organizations assessed during this project are categorised into the components shown on the table below:

Components	**Regional / National Institution**
Policy Formulation and Planning	National Communications Secretariat (Kenya)
	East African Community (Tanzania)
	PALAMA (South Africa)
	Dept. Of Education (South Africa)
	Reserve Bank (South Africa)
	Dept. Of Communications (South Africa)
	National ICT Committees (All Countries)
	Ministry of ICT (Zimbabwe)
Harmonisation of ICT Infrastructure and facilities	East African Community (Tanzania)
	SADC Secretariat (Botswana)
	COMESA (Zambia)
	Dept. Of Communications (South Africa)
	PALAMA (South Africa)
	National ICT Committees (All Countries)
Legislative Framework	East African Community (Tanzania)
	COMESA (Zambia)
	SADC Secretariat (Botswana)
	Dept. Of Communications (South Africa)
	PALAMA (South Africa)
	Govt. Ministries (All Countries)
Establishing Centres of Excellence	Link Centre, Wits University (South Africa)
	ESAMI (Tanzania)
• *Centres of Specialisation*	Microsoft (Kenya and South Africa)
• *Internationalisation*	Meraka Institute (South Africa)
• *Professorial Chairs* • *Adjunct Professors*	Zimbabwe Open University (Zimbabwe)
Human Capital Development and Institutional Capacity	ESAMI (Tanzania)
	BIDPA (Botswana)
• *Staff Development Programmes,*	Dept. Of Education (South Africa)
	Link Centre, Wits University (South Africa)

• *Professional Continuous Development,* • *Workshops* • *Seminars* • *Conferences* • *Digital Libraries.*	University of Botswana (Botswana)
	University of Zambia (Zambia)
	Dept. Of Provincial & Local Govt (South Africa)
	Govt. Ministries (All Countries)
	Zimbabwe Open University (Zimbabwe)
E-Skills Development & ICT Training • Short-term • Long-term • Open and distance learning • Professional Continuous Development	Government Ministries (All Countries)
	Microsoft (Kenya and South Africa)
	ESAMI (Tanzania)
	BIDPA (Botswana)
	Reserve Bank (South Africa)
	National Communications Secretariat (Kenya)
	Dept of Provincial & Local Govt (South Africa)
	Zimbabwe Open University (Zimbabwe)
Collaborative framework & Research Leadership • Collaborative Networks • Research Leadership Training/Mentoring	Meraka Institute (South Africa)
	Link Centre, Wits University (South Africa)
	BIDPA (Botswana)
	ESAMI (Tanzania)
	Reserve Bank (South Africa)
	Zimbabwe Open University (Zimbabwe)

The key components of the collaborative strategy for regional integration assessed are:
- ❖ Infrastructural facilities for connectivity and access,
- ❖ human resource development,
- ❖ a common electronic–business framework
- ❖ information and content sharing platform,
- ❖ a conducive political, legal and technical environment, and
- ❖ ICTs industry and support services.

The data was analysed using various methods. Qualitative data was synthesised to pick out the key findings from the stakeholder analysis. Quantitative data was analysed statistically using existing software packages.
The Zimbabwe Open University (ZOU) is a state university, which was established on 1st March 1999 as an open and distance learning (ODL) university. The ZOU vision is to become a world class open and distance learning university, and the university offers great opportunities to previously marginalized students through its affordable education using distance teaching and open learning modes that reach out to all willing and capable students throughout our ten (10) regional centres in each province countrywide, as shown on the diagram below on Figure 7.

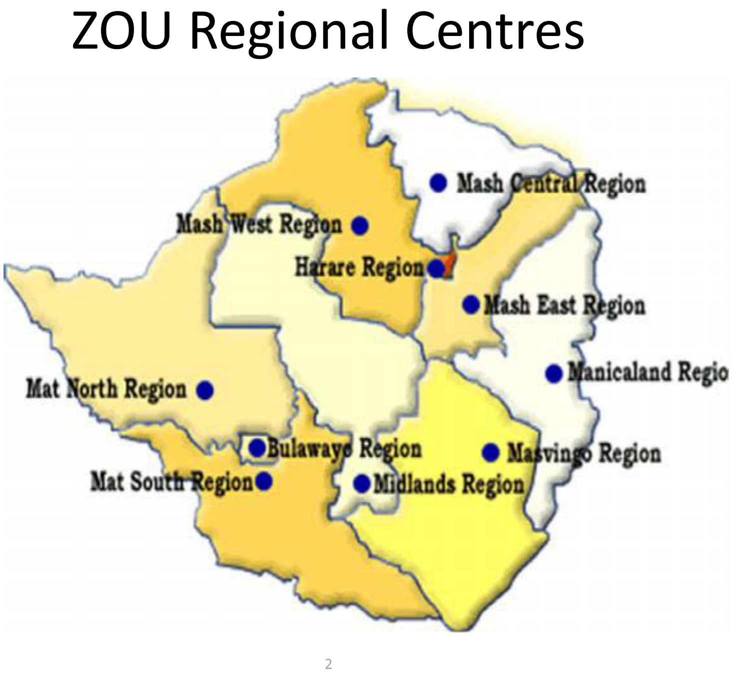


Figure 7: The Regional Centres of Zimbabwe Open University

The full potential of digital learning environments at ZOU was explored with a view to improve on the e-learning platform and associated learner support environment. The web-based learning environment was assessed with respect to motivational, instructional, modelling, feedback, and assessment tools. An exploratory assessment was conducted on the e-learning platform to identify the components and assess the design with respect to the following components and determine how Chaos Theory could improve the design:

- Desktop and laptop computers
- Mobile and wireless tools, including mobile phones and PDAs
- Software, including assistive software
- Interactive whiteboards or mimio boards
- Electronic communication tools, including email, discussion boards, chat facilities, virtual classroom and video conferencing
- Digital cameras and videos
- Virtual Learning Environments (VLEs)
- Managed Learning Environments (MLEs)
- Learning activity management systems

GDP FOR SOUTHERN AND EAST AFRICA COUNTRIES

The world nominal GDP per capita for the year 2008 was 60,917.477 USD and for the 2009 was 57,228.373. However, the total for Africa was only 1,282.373 (2.11%) in 2008 and 1,184.891 (2.07%) in 2009, respectively. The nominal GDP per capita for the 18 African countries in East and Southern Africa are shown below, with Figure 8 showing the top 8 countries only. Notably South Africa leads all the countries by far, followed by Angola and then Kenya. The lower end in this group has Uganda, Botswana and DRC.

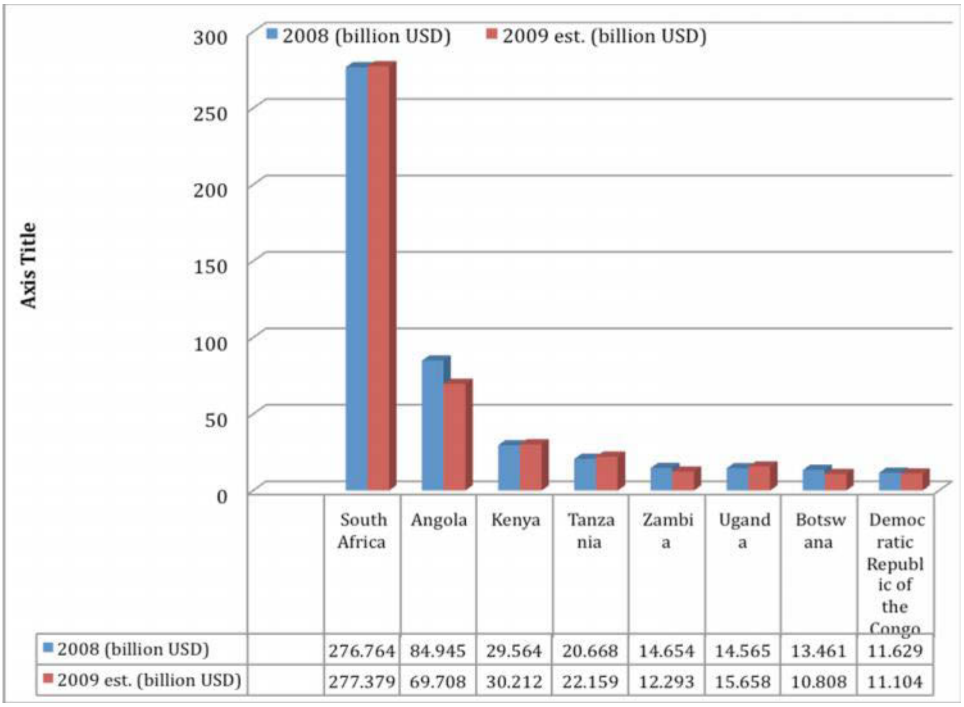


Figure 8: Nominal GDP per capita for period 2008-2009 for top 8 countries

The diagram below on Figure 9 shows Nominal GDP per capita for period 2008-2009 the bottom 10 countries. This league is led by Mozambique, Madagascar and Mauritius in that order. The lowest 3 in this group are Swaziland, Lesotho and Burundi.

Figure 9: Nominal GDP per capita for period 2008-2009 for the least 10 countries

The nominal GDP per capita excluding South Africa is shown in Figure 10 below. Outside South Africa, Angola is a leader followed by Kenya.

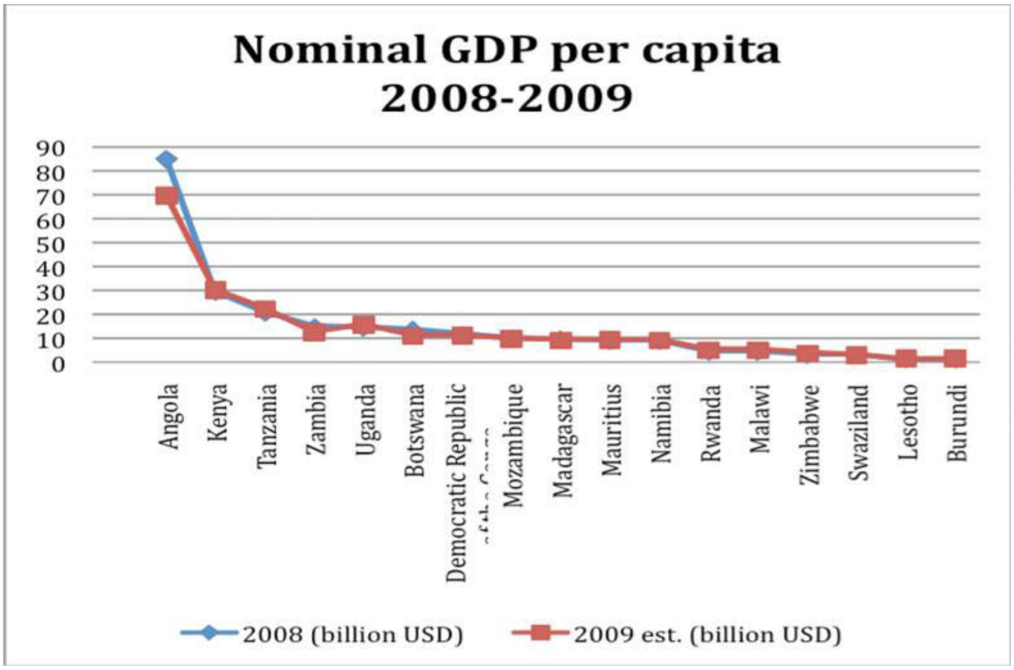


Figure 10: Nominal GDP per capita for 2008-2009 excluding South Africa

The GDP per person of the 18 African countries for the period 2008 to 2009, converted to US dollar through estimated IMF exchange rates, are shown below, with Figure 11 below showing the top 8 countries only. Botswana, Mauritius and South Africa are the top 3 in that order whilst Swaziland, Zambia and Kenya are the last 3 among the top 8 countries with respect to the GDP per person.

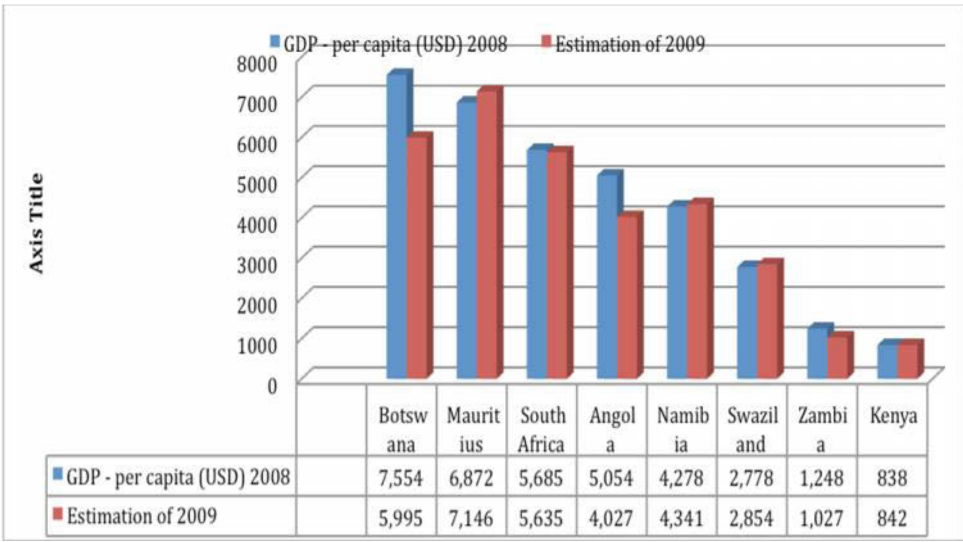


Figure 11: GDP per person for the period 2008-2009 top 8 countries

Similarly, the last 10 countries with respect to GDP values are shown on Figure 12 below. The leading country in this group is Lesotho whilst Burundi is the last one.

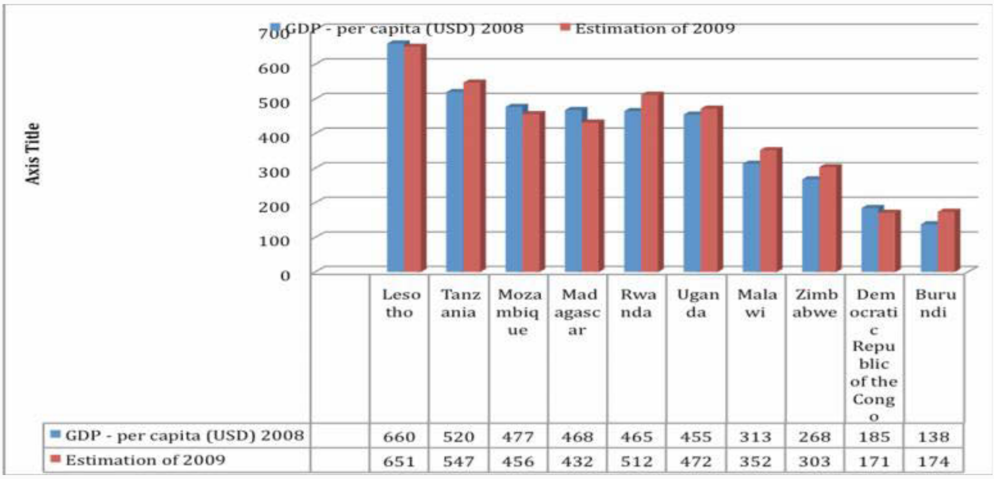


Figure 12: GDP per person for the period 2008-2009 lowest 10 countries

Source: **World Economic Outlook Database for October 2009**

The ratio of GDP per person/nominal GDP per capita was analysed for the 18 African countries for the period 2008-2009 and results are shown on Figure 13 below.

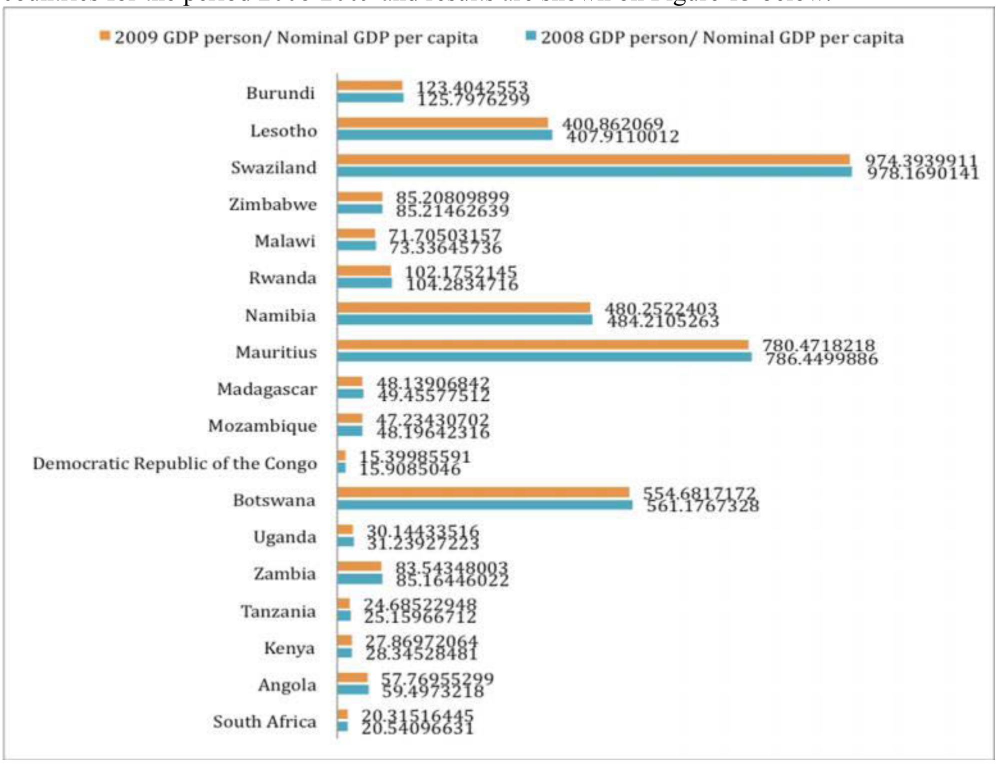


Figure 13: GDP per person/nominal GDP per capita

The strongest economies showing economic growth are South Africa, Angola, Kenya, Tanzania, Zambia, Uganda, Botswana, DRC, Mozambique, Madagascar, Mauritius, Namibia, Rwanda, Malawi, Zimbabwe, Swaziland, Lesotho and Burundi in that order.

INFODENSITY FOR SOUTHERN AND EAST AFRICAN COUNTRIES

There is a close correlation between the country's infostate and GDP per capita. For every point increase in infodensity, GDP per capita increases by an approximate US$150, rendering widespread, affordable access to information services an absolute imperative. The last decade has seen continual growth in infrastructure development and service uptake. Over the last five years, the ITU reports developed and developing countries have increased ICT levels by more than 30%.

However, notwithstanding the rapid expansion, to date access and adoption of Internet services is highly unequal across and within countries. Emerging countries face considerable challenges in broad-basing Internet utilization for their growth and development on account of inadequate fixed-line infrastructure, and lack of supporting infrastructure, including electricity and steep prices of personal computers. An approximate 75% of the world populace, a large segment of which lives in emerging markets, consequentially have limited or no access to the Internet. Data on Infodensity was obtained from the International Telecommunications Union (ITU, 2010) and the analysis is shown below on figures 14-18. The fixed teledensity by continent is shown on Figure 14 whilst the mobile cellular subscriptions (%) is shown on Figure 15. Both charts show that Africa has the lowest penetration ratio for fixed teledensity and mobile cellular subscriptions, respectively.

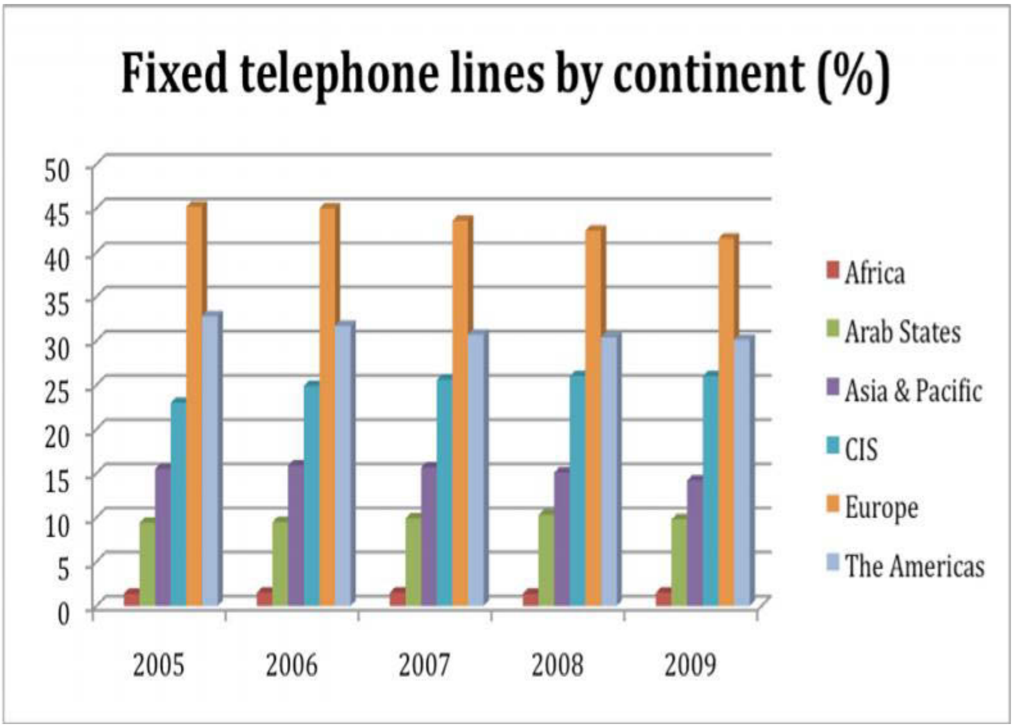


Figure 14: Fixed teledensity by continent (%)

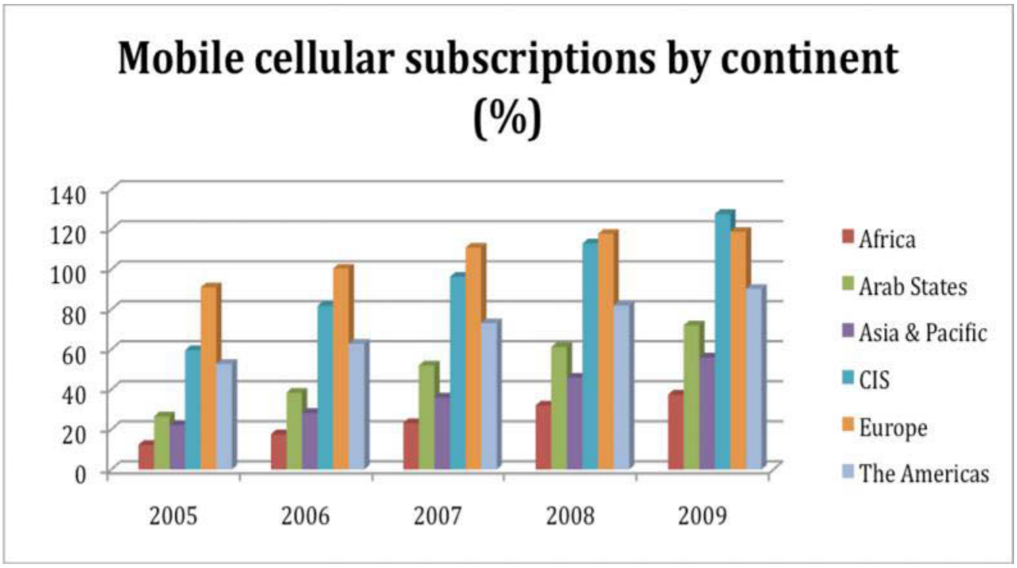


Figure 15: Mobile cellular subscriptions by continent (%)

The mobile broadband subscriptions by continent are shown on Figure 15 below. Europe leads all other continents whilst Africa remains the least, with at most 2%. The same picture is reflected on internet users shown on Figure 16 The fixed broadband subscriptions shown on Figure 13 show even a wider gap between Africa and other continents.

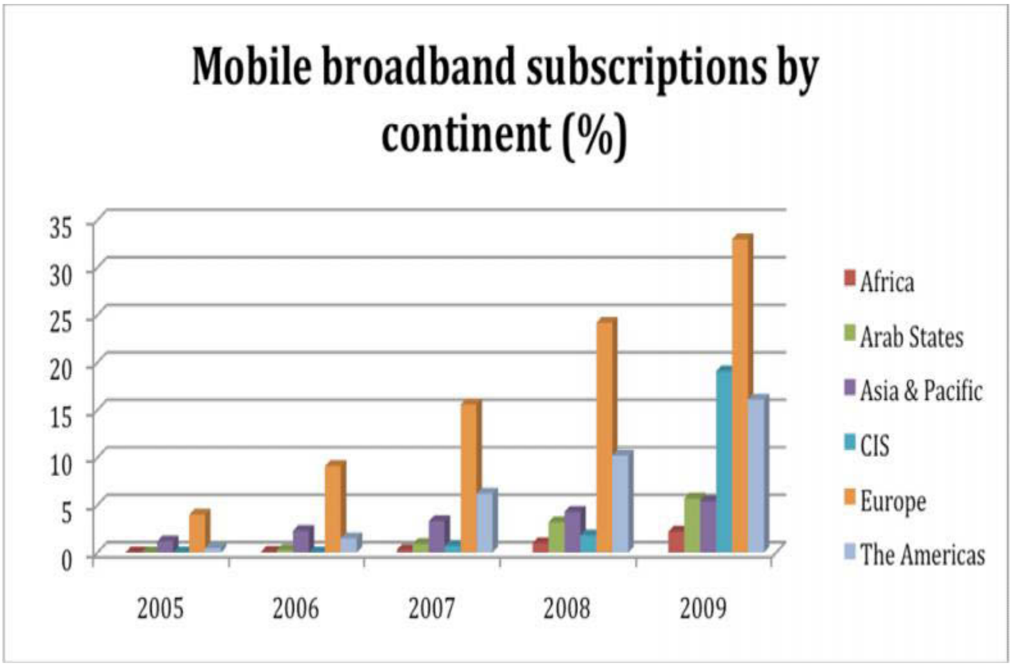


Figure 16: Mobile broadband subscriptions (%)

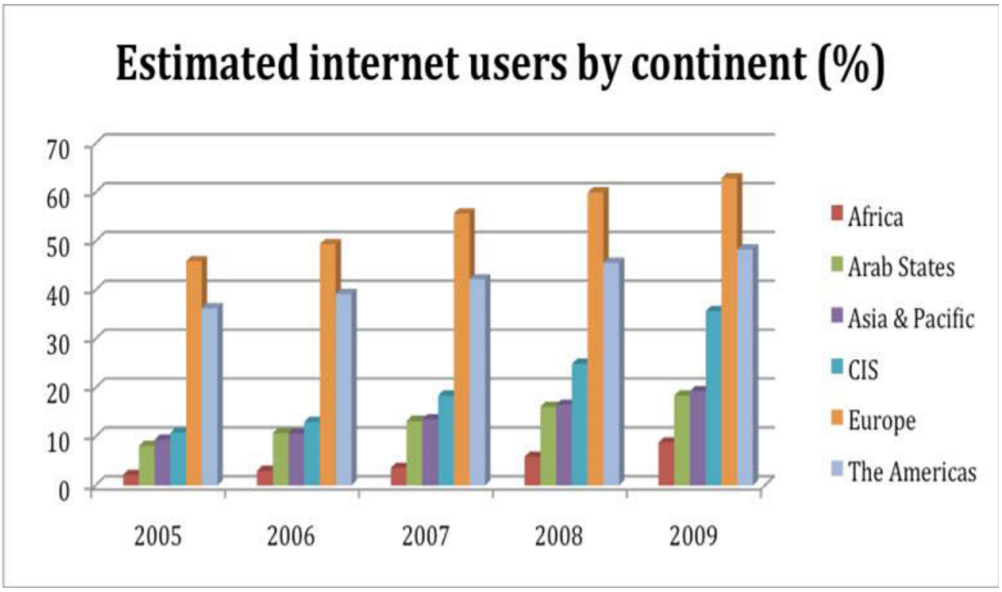


Figure 17: Internet users by continent (%)

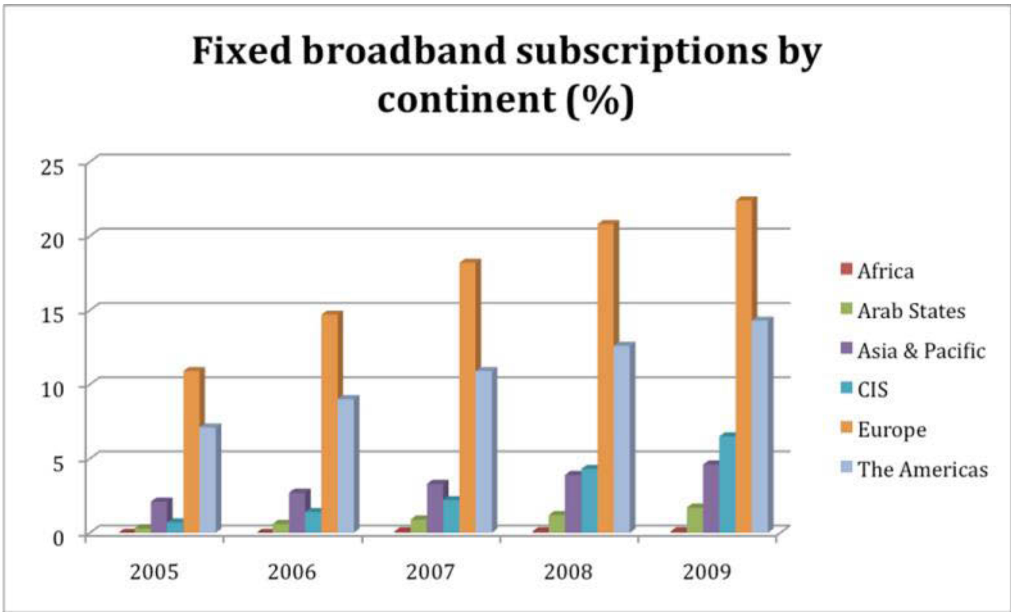


Figure 18: Fixed broadband subscriptions by continent (%)

The ICT indicators by country for the 18 East and Southern African countries are shown on Figure 19. South Africa has the highest number of mobile subscribers followed by Botswana and Mauritius. However, Mauritius has the highest density for main telephone lines and internet users.

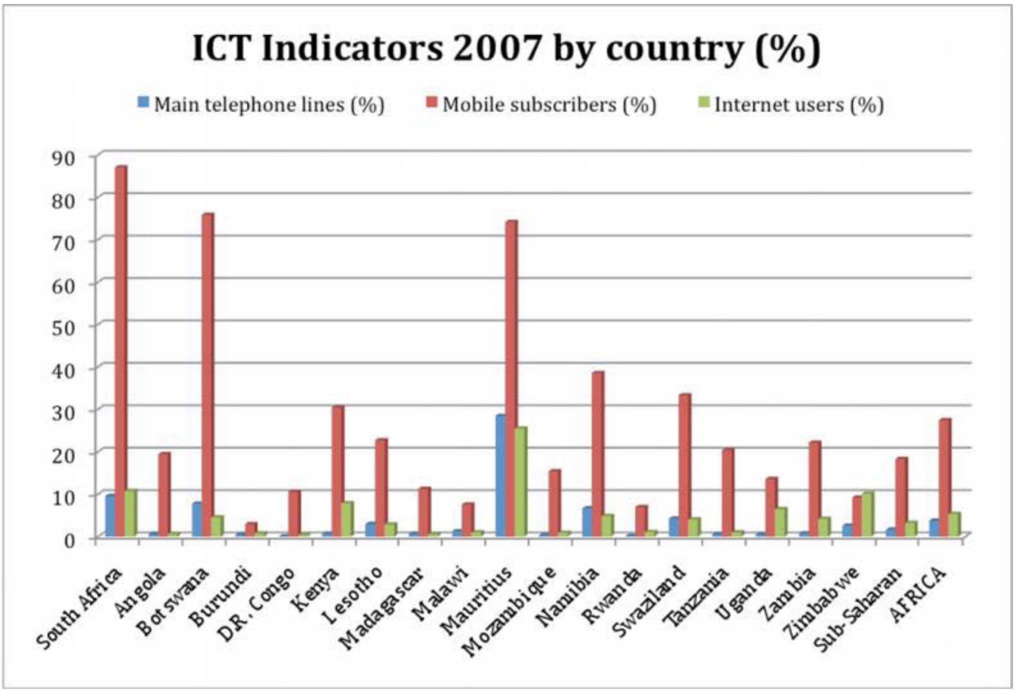


Figure 19: East and Southern Africa ICT Indicators for 2007

A summary of the statistics on infodensity as measured by the ICT indicators and the GDP per capita for the 18 countries in East and Southern Africa is shown on Table 1 below. The mean for the 18 East and Southern African countries with respect to main telephone density is 3.8%, mobile subscribers is 27.87%, and internet use is at 4.87%.

Table 1: Descriptive Statistics for East and Southern Africa

	N	Minimum	Maximum	Mean	Std. Deviation
Main telephone lines (%)	18	0%	28%	3.80%	6.791%
Mobile subscribers (%)	18	3%	87%	27.87%	25.490%
Internet users (%)	18	0%	25%	4.87%	6.124%
GDP per capita 2008 (US$)	18	138	7,554	2,125.33	2,554.349
GDP per capita 2009 (US$)	18	$171	$7,146	$1,996.50	$2,349.695
Valid N (listwise)	18				

A one-sample T-test for the same data for the 18 East and Southern African countries is shown on Table 2 below. The 95% confidence interval for the lower and upper levels are shown on the same Table 2.

Table 2: One-Sample Test for East and Southern Africa

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Main telephone lines (%)	2.374	17	.030	3.800%	.42%	7.18%
Mobile subscribers (%)	4.638	17	.000	27.866%	15.19%	40.54%
Internet users (%)	3.371	17	.004	4.866%	1.82%	7.91%
GDP per capita 2008 (US$)	3.530	17	.003	2,125.333	855.09	3,395.58
GDP per capita 2009 (US$)	3.605	17	.002	$1,996.500	$828.02	$3,164.98

CORRELATION BETWEEN ICT INDICATORS AND GDP PER CAPITA

The correlation coefficients between the ICT indicators and the GDP per capita for both 2008 and 2009 are summarized in the table 3 below. The correlation coefficients between the main telephone lines (%) to the GDP per capita is 0.721 and 0.798 for the years 2008 and 2009, respectively. The mobile subscriber rate (%) is strongly correlated to the GDP per capita, showing values of 0.881 and 0.902 for the years 2008 and 2009, respectively. However, the correlation coefficients between internet use (%) and GDP per capita remains as low as 0.531 and 0.619 for the years 2008 and 2009, respectively.

Table 3: Correlations between ICT Indicators and GDP per capita

		GDP per capita 2008 (US$)	GDP per capita 2009 (US$)
Main telephone lines (%)	Pearson Correlation	.721**	.798**
	Sig. (2-tailed)	.001	.000
	N	18	18
Mobile subscribers (%)	Pearson Correlation	.881**	.902**
	Sig. (2-tailed)	.000	.000
	N	18	18
Internet users (%)	Pearson Correlation	.531*	.619**
	Sig. (2-tailed)	.023	.006
	N	18	18

The correlation cofficients between the ICT indicators and the GDP per capita are shown on Figure 20 below.

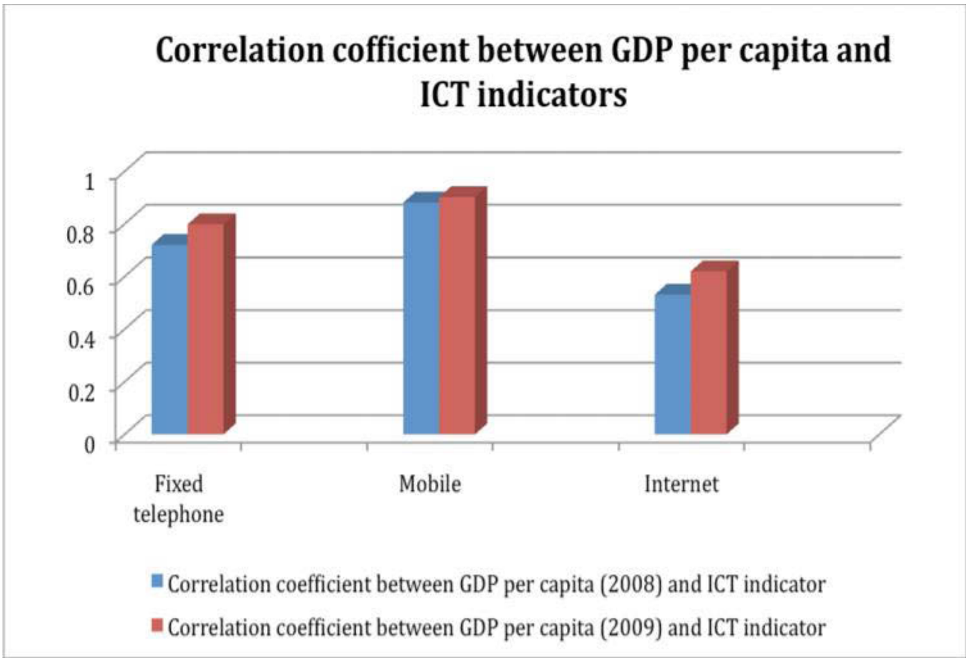


Figure 20: Correlation between ICT indicators and GDP per capita

From the above chart on Figure 20, the correlation coefficient between GDP per capita and ICT indicators is highest with the mobile density (about 90%) and then followed by fixed telephony (about 75%), and lowest with internet penetration ratio (about 57%). Hence the mobile density of a country in East and Southern Africa is a good measure of the relative proportion with the GDP per capita.

SUSTAINABLE TECHNOLOGY CAPACITY IN EAST AND SOUTHERN AFRICA

The ICT policy formulation process went through the due process in all the countries in East and Southern Africa, and its implementation is at various stages from country to country depending the availability of financial resources. Notable achievement have been achieved in ICT Policies, coordination with National ICT Committees, improvement of regional connectivity through coordination ministries, and access to information through the website, portals, SMEs, etc. ICT education and training is required to address the various e-skills opportunities identified in the public sectors. However, social capital/networks have not received much attention with respect to technological development and much work is required to establish basic e-business framework in all countries outside South Africa. Availability of electricity in remote parts of member countries is adversely affecting rapid implementation of the telecommunications infrastructure. The convergence in ICTs is shifting the focus to infrastructure, protocols, applications and services (ERPs), and content as specific areas that need capacity building initiatives.

ICTs affect all the MDGs. There is a strong correlation between ICTs and economic growth. The data collection techniques used in this study include formal meetings, oral interviews, questionnaires and records observation. The major components of the data collected included the identity of the institution; current capacity of the institution; current and future interventions on staff capacity development; the availability and status of the national/corporate ICT policy framework, and progress towards its implementation; quality assurance philosophy and framework; and strategic programme development, management and reviews. The capacity needs of the national and regional institutions/organisations identified by the study were categorised into the following major components, and then detailed by institution and country:

(a) Policy Formulation and Planning
(b) Harmonisation of ICT Infrastructure and facilities
(c) Legislative Framework
(d) Establishing Centres of Excellence
(e) Human Capital Development and Institutional Capacity
(f) E-Skills Development & ICT Training
(g) Collaborative framework & Research Leadership

The research showed evidence of technological capacity with tremendous opportunities that can change the face of East and Southern Africa through identified public institutions in each of the countries covered by the research project. Table 4 below shows the ICT Capacity Needs Components by country, identified by the research:

Table 4: ICT Capacity Needs Components by Country

Capacity Components	**Country Regional / National Institution**
Policy Formulation and Planning	Kenya, South Africa, Tanzania, and Zimbabwe
Harmonisation of ICT Infrastructure and facilities	All countries in East and Southern Africa
Legislative Framework	East African Community , COMESA, and SADC with support from Government Ministries in All Countries concerned.
Establishing Centres of Excellence • *Centres of Specialisation* • *Internationalisation* • *Professorial Chairs* • *Adjunct Professors*	South Africa, Tanzania, and Zimbabwe through the Universities/Colleges
Human Capital Development and Institutional Capacity: • *Staff Development Programmes,* • *Professional Continuous Development,* • *Workshops /Seminars/ Conferences* • *Digital Libraries.*	All Countries in East and Southern Africa through the Universities
E-Skills Development & ICT Training • Short-term • Long-term • Open and distance learning • Professional Continuous Development	Government Ministries and Universities in All Countries in Southern Africa
Collaborative framework & Research Leadership • Collaborative Networks • Research Leadership Training/Mentoring	South Africa, Botswana and Tanzania

All the six (6) African countries covered by the qualitative research have National ICT Policy Frameworks which are in different phases of implementation due to challenges in the availability of financial resources. The common strategic areas of focus for meaningful ICTs development in East and Southern Africa are summarised in Table 5 below and these form a basis for the goals and specific objectives for implementation (Government of Zimbabwe Ministry of ICT Strategic Plan 2010-2014, 2010):

Table 5: Key Areas for ICTs Development

	KEY AREA FOR ICT DEVELOPMENT
1.	**Infrastructure establishment and development**, e.g. connectivity, fibre, VSAT, wireless, wireline, VoIP, etc.
2.	**Human Capital and Social Networks Development** (***Humanware***), e.g. advocacy, skills, e-literacy, sustainable capacity building, languages, curricula, etc.
3.	**Governance,** e.g. policy frameworks, ICT Bill, regulatory framework, corporate governance, etc.
4.	**E-government & e-business** e.g. Govt portal, e-commerce frameworks, e-learning, national payment systems, etc.
5.	**Application development**, e.g. innovation, animation, e-development, etc.
6.	**ICT Industry, Investment, & partnerships**, e.g. PPPs, innovative SMEs, tax incentives, etc.
7.	**Research and development**, e.g. Research, Cross and multidisciplinary collaborative projects, etc.
8.	**Security and quality assurance frameworks**, e.g. interoperability, quality of service, etc.
9.	**Corporate Services**, e.g. internal ministry support requirements, resource mobilisation, etc.

It is envisaged that the above key areas for ICTs development would change the landscape for sustainable ICTs development in East and Southern Africa within a period of about five years, as the government support and commitment is very high in all the six African countries studied. The political will and common singleness of heart throughout the public institutions visited needs to be maintained and developed further with the required resources for ease of implementation. The 6 African countries covered by the study showed commitment and joint initiatives on ICT policy harmonization efforts in order to:

(a) Respond to challenges facing Partner States in the areas of infrastructure, human resources development, ICT sector development, participation in global ICT regimes and addressing the challenges of cyber security;
(b) Align with other regional efforts on the harmonization of trade, tariffs, capital, labour markets, legislative and judicial systems (e.g. high skill human resource development in ICT sector, tariffs, regulations);
(c) Conform with other initiatives in the region (political, economic and infrastructural harmonization's). The ICT policy should tie to electricity/energy policies and projects to expand the power pools to Partner States;
(d) Take both the process and the actual outcomes of harmonization into consideration. The process of harmonization requires ongoing and long lasting interaction between players. Policy harmonization is largely about a process and consensus building between players;
(e) Draw on experiences of other regions and economic grouping in Africa, Asia, Latin America, Europe, the Caribbean and the Pacific.

Human capital development is central to capacity development, as adequate human resources are an essential component of a nation's ability to carry out its mission. In pursuit of the broader objectives of the African Union to accelerate economic integration of the continent, with the aim to achieve economic growth, reduce poverty and attain sustainable economic development, the Tripartite Summit of the Heads of State and Government of the Common Market for East and Southern Africa (COMESA), East African Community (EAC) and the Southern Africa Development Community (SADC) met in Kampala, Uganda on 22nd October, 2008. The East African Community Partner States have various advantages in terms of geographical proximity, common socio-cultural characteristics, and economic complementarities for maximizing the benefits from regional cooperation in the ICT sector. Regional cooperation in ICT does not only facilitate greater access to ICT infrastructure, but is also essential to promote trade, governance and ICT business opportunities within and beyond the region. Regional ICT Special Projects covers COMESA, IGART, etc.

ICTs have tremendous roles in achieving the regional economic integration objectives of SADC, COMESA and EAC (http://www.eac.int/treaty.htm), which include the following:

- Promotion of sustainable growth and equitable development of Partner States including the rational utilization of the region's natural resources and protection of the environment;
- Strengthening and consolidating the long standing political, economic, social, cultural and traditional ties between Partner States and associations between the people of the region in promoting a people-centres mutual development;
- Enhancing and strengthening participation of the private sector and the civil society;
- Mainstreaming gender in all its programmes and enhancement of the role of women in development;
- Promoting good governance including adherence to the principle of democratic rule of law, accountability, transparency, social justices, equal opportunities and gender equality; and
- Promotion of peace and stability within the region, and good neighborliness among partners States.

ANALYSIS OF ZOU ONLINE E-LEARNING PLATFORM

The telecommunications infrastructure in Zimbabwe is very much challenged with very low teledensity and mobile density. The use of wireless technology around each digital access point is the best way forward in establishing a digital learning environment. Chang and Sheu, (2002) designed and used advanced wireless technologies for building an Ad Hoc classroom in order to create a modern and new learning environment, as illustrated on Figure 21 below. The Ad Hoc classroom system and electronic school bag (e-Schoolbag) systems was used on both PC server and mobile devices such as PDA and Notebook.

There is a great need to extend the Web-based learning pedagogy to the level of incorporating the concept of virtual reality. A virtual learning environment can be created in a manner that uses 3D spatial learning, telepresence, immediate visual feedback, and interactivity. Hence, the need for chaos theory in the detailed design of such a digital learning environment at ZOU, in order to establish a 3D learning space witch sufficient playground and capacity for an assortment of intelligent agents. Digital learning objects are the new object-oriented instructional elements in computer technological education (Wiley, 2001). In this case, the instructional elements can be reused in different learning environments, no matter whether it's digital or non-digital

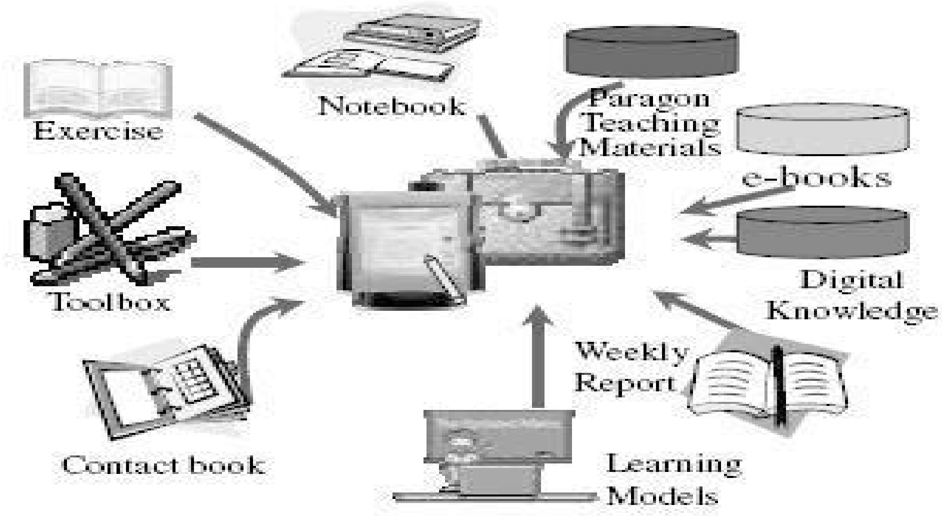


Figure 21: Ad Hoc classroom and E-schoolbag system (Chang and Sheu, 2002)

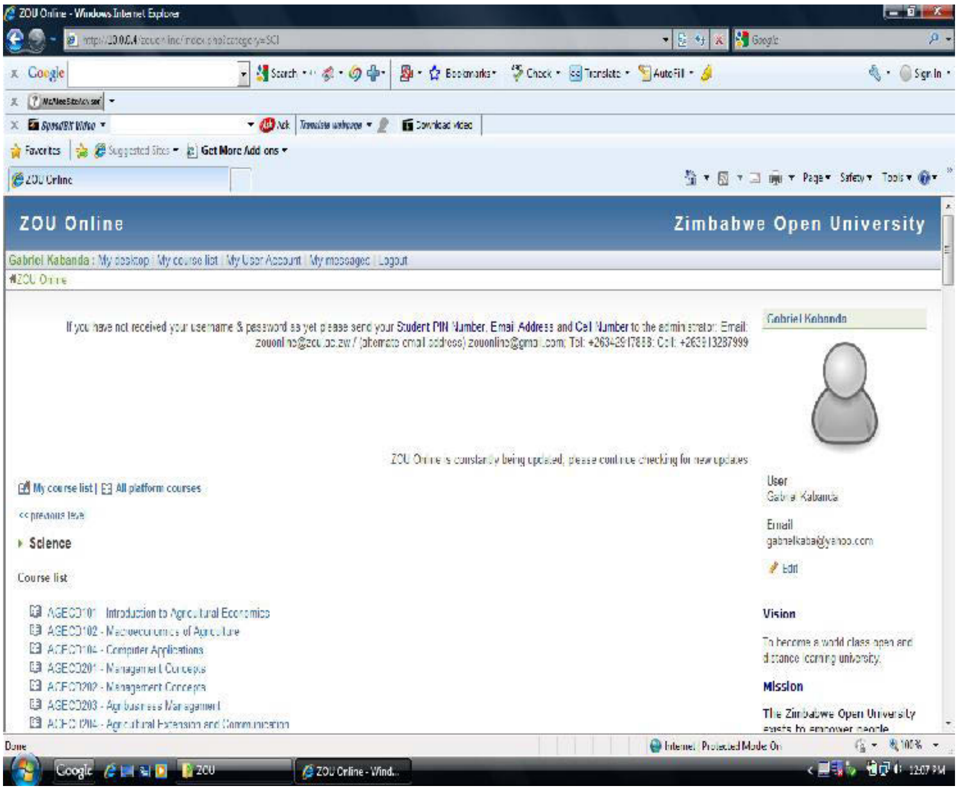


Figure 22: The ZOU Online List of Science and Technology Courses

ZOU Online provides a highly interactive, Internet-based distance education materials to its student population in Zimbabwe and abroad. All programmes are instructor-led. Students interact with their instructors and classmates through e-mail and web-based “threaded” discussions, encouraging interaction and networking among the select group of professionals who attend. For example, the list for the Faculty of Science & Technology with 167 courses available on the platform is shown on Figure 22.

The web-based Learning Content Management System (LCMS) is used as a teaching and learning tool which can be placed either on the Internet or within an organization's intranet. The LCMS is based on programs which the majority of ISPs already support, the program is easy to access and use for most people. The platform provides powerful multimedia content, limited interaction and has different options for assessing and evaluating gathered knowledge (tests, exercises).

Wi-Fi is probably the best-known wireless networking technology being used today. ZOU Online requires localised WiFi access to cover each Regional Centre computer laboratory (indoors and outdoors), LAN and Internet Connectivity. The ZOU online Access Network is shown on Figure 23 below. The network solution is a Mesh type of Network with a WiMax 5.1—6.1GHz backbone connectivity and 2.4Ghz WiFi LAN/HOT SPOT distribution. Scalability is inbuilt into the equipment. Security is provided by MAC level authentication and WEP/WPA2 (128 bit Encryption with up to 3 Keys). The network carries the ZOU online platform and internet connectivity. The choice of a WiFi based network is significantly reduces the cost of Customer Premises Equipment for students.

The ZOU Online Access Network (Figure 24) extensively uses Wi2, which offers the ultimate IP wireless broadband solution for a variety of applications and services – anytime, anywhere, i.e. supports ubiquitous computing. Services delivered with Wi2 range from basic public Internet access to public safety, traffic management, video surveillance, indoor coverage and other advanced voice, video and mobile applications. The advantages of using Wi2 at ZOU include the following:

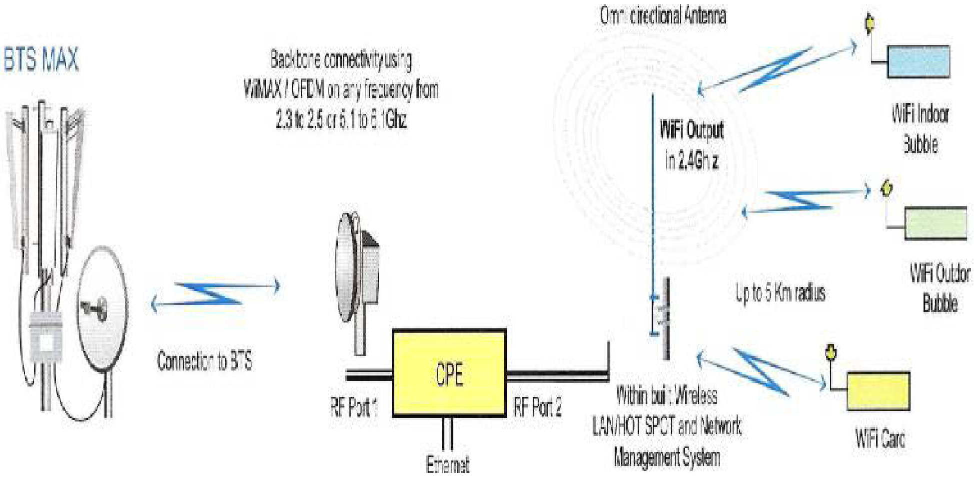
- Easy-to-deploy outdoor Wi-Fi mesh access solution integrated with built-in management and OSS support
- Readiness for immediate connection with the robust QoS capabilities of a BreezeMAX/BreezeACCESS backhauling network providing Personal Broadband services.

Module development is carried out in a cooperative process. Educators and technical people come together to design, author and deploy courses. An open authoring environment based on web authoring tools is created. A workflow engine controls the creation of the modules. The workflow provides a guide to the authoring process, while coordinating the cooperation among authors, thus helping the group to efficiently produce e-learning material. The e-learning environment is divided into four basic elements: a workflow engine that controls the other elements, a web authoring tool, multimedia tools, and a set of functions supporting the cooperative work. However, it is concluded that a true highly interactive e-learning platform is more sophisticated than what is currently available at the ZOU Online platform, and hence the need to use Chaos Theory to handle the complexity of future designs and improvements.

CONCLUSION

ICTs impact all the MDGs, especially in eradicating extreme poverty and hunger. The solution to poverty and hunger is not money but knowledge, hence the thrust on human capital development national programmes with a bias towards sustainable social networks/capital to ensure empowerment of local communities and indigenous people. Revolutionary science and technology innovation drive at the lowest level of education, e.g. pre-school, up to universities and colleges and then across all communities is inevitably very critical in the eradication of extreme poverty and hunger. Curriculum reviews for schools and universities to contextualise the technology diffusion and innovation to an African environment require urgent attention. Furthermore, the harmonisation of the infrastructure and equipment facilities for schools, colleges, and institutions that drive education for sustainable development, is equally important. ICTs are therefore key enablers to the generation and dissemination of knowledge, hence the achievement of the MDGs. In fact, ICTs contribute to economic growth, as evidenced by the strong correlation between the GDP growth and ICT indicators. ICTs increase productivity through:

- Better communication and networking at lower costs



- Digitalisation of production and distribution
- New trade opportunities through e-commerce
- Access to knowledge
- Increased competition

The mean for the 18 East and Southern African countries with respect to main telephone density is 3.8%, mobile subscribers is 27.87%, and internet use is at 4.87%. With the exception of South Africa, all the East and Southern African countries are among the late majority and laggards with respect to diffusion and adoption of ICT innovations, i.e. they are largely late end-consumers of technology that has been tried and tested from developed and some developing countries. The ICT capital comprises network infrastructure and ICT machinery and equipment. ICT and non-ICT factor inputs are combined to produce ICT and non-ICT goods and services, without a one-to-one correspondence. There is a strong correlation between ICT diffusion and high economic growth. The correlation coefficient between GDP per capita and ICT indicators is highest with the mobile density (about 90%) and then followed by fixed telephony (about 75%), and lowest with internet penetration ratio (about 57%). Hence, the mobile density of a country in East and Southern Africa is a good measure of the relative proportion with the GDP per capita.

SUMMARY AND RECOMMENDATIONS

The methodology used was largely qualitative on technology capacity needs assessment that covered 6 countries, and also quantitative on GDP and infodensity covering 18 countries in East and Southern Africa. GDP and infodensity data was collected for 18 African countries to ascertain the link between ICTs diffusion and GDP density per country. Policy-formulation frameworks and sustainable capacity building provide a conducive environment for meaningful development in the SADC countries. Capacity needs assessment included both the human capital development and social capital aspects in order to achieve sustainable information and communication technology capacity development. Human capital development is central to capacity needs. There is a strong correlation between ICT diffusion and high economic growth. The solution to poverty and under-development in African countries is knowledge and economic empowerment. The recommended sustainable technology development with an African model is proposed.

The East and Southern African countries covered by the study showed tremendous development potential, even though they are among the late majority and laggards with respect to technological innovations. The solution to poverty and under-development in African countries is knowledge and economic empowerment. The recommended sustainable technology development using an African model is proposed with the following major components:

1. Human capital development national programmes with a bias towards social networks/capital to ensure empowerment of local communities and indigenous people
2. Curriculum reviews for schools and universities to contextualise the technology diffusion and innovation to an African environment
3. Revolutionary science and technology innovation drive at the lowest level of education, e.g. pre-school, up to universities and colleges and then across all communities.
4. Universitisation of the entire education system where the academic leadership offered by academia and research institutions inculcates and influences the curricular of the entire education system in order to provide a meaningful contribution to knowledge
5. Harmonisation of the infrastructure and equipment facilities for schools, colleges, and institutions that drive education for sustainable development
6. Review of the legal framework and policy formulation mechanism with a view to rapid development initiatives
7. Establishing centres of excellence in specialised fields to provide leadership (academic, research and consultancy) on key developmental issues.

E-learning is learning supported or enhanced through the application of Information and Communications Technology (ICT), and has become an important pillar in open and distance learning. The learning vortices are represented by learning objects created by authors, academics, instructional designers, and other professionals contracted to create learning content. The strategy being implemented by Zimbabwe Open University ZOU Online platform was assessed as a promising digital learning environment. Chaos Theory was proposed as a better design of the digital learning environment in order to make the platform fully functional and highly interactive, especially for a fully online platform. Digital learning objects reflected in the ZOU Online platform increase opportunities for teaching and learning. The ZOU Online platform supports ubiquitous learning and provides intuitive ways for identifying learning collaborators, learning contents and learning services in the right place at the right time.

The Chaos Theory nomenclature equivalent to the ZOU Online platform components is summarized in the table below, shown as Table 6, illustrating the correlation between the two areas:

Table 6: Correlation between Chaos Theory and design model for ZOU Online Platform

Chaos Theory	ZOU Online Platform components
Learning vortices	Sources of knowledge or learning objects created by authors, academics, instructional designers, and others professionals contracted.
Fluid flow	Knowledge accessible by a learner
Chaotic system	Digital learning environment
Quasi-periodicity or two modes of chaotic dynamics	Synchronous and asynchronous mode of learning
The Lorenz System	Assessment and evaluation models for e-learning
Attractor or point of convergence	Achieved learning outcomes through different technologies and appropriate pedagogy
Information entropy	Learning delays and amount of knowledge acquired or disseminated to the learner
The center manifold	Interactive functional e-learning
Lyapunov exponents	Capacity and capability of the learner
Strong Turbulence	Learning difficulties in a virtual digital learning environment with 3D space
Chaotic Dynamics	Access network with learning content management system

From Table 6 above, Chaos Theory offers tremendous opportunities for handling the complexity associated with the design of a fully interactive e-learning environment available online. There are more complex issues centered around both the learning objects and the learner.The digital learning environment provides tremendous benefits to the Zimbabwean learners to have anywhere, any time access to lifelong education. With Chaos Theory, a complete functional online platform can be established. The use of wireless technology around each digital access point is the best way forward in establishing a digital learning environment.

References

Anderson R.L., LO M.W and Bornn G.H. (2003), *Application of Local Lyapunov Exponents to Maneuver Design and Navigation in the Three-Body Problem.* American Astronautical Society Paper No. 03-569: AAS/AIAA Astrodynamics Specialist Conference, August 2003. Copyright by the Jet Propulsion aboratory, California Institute of Technology (USA), 2003.

Baliamoune-Lutz Mina (2003), *An analysis of the determinants and effects of ICT diffusion in developing countries,* Information Technology for Development 10 (2003) 151–169 151, IOS Press.

Chang, C.Y. & Sheu, J.P. (2002). Design and Implementation of Ad Hoc Classroom and eSchoolbag Systems for Ubiquitous Learning. Proceedings of the IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'02). Retrieved from http://ieeexplore.ieee.org/servlet/opac

Gershenfeld Neil, "An Experimentalist's introduction to the observation of dynamical systems", in Directions of Chaos, Hao Bai-lin edition, World Scientific, 1988.

Gershenfeld Neil A. and Weigend Andres S., Time Series Prediction: Forecasting the Future and Understanding the Past: Addison-Wesley: Reading, Massachusetts, 1993.

Government of Zimbabwe (2010), "*The Ministry of Information Communication Technology (MICT) Strategic Plan 2010-2014*", Republic of Zimbabwe Government Printers, February, 2010.

Heeks, R. (1999) 'Information and Communication Technologies, Poverty and Development'. **Development Informatics Working Paper Series**, Paper No. 5, June 1999, IDPM, Manchester. http://www.man.ac.uk/idpm/idpm dp.htm#devinf_wp.

International Telecommunications Union (2010), World Telecommunication/ICT Indicators Database: ITU, June, 2010, http://www.itu.int/ITU-D/ict/ statistics/index.html.

Kabanda, G. (2008), *Collaborative opportunities for ICTs development in a challenged African environment,* International Journal of Technology Management & Innovation, Volume 3, Issue 3 of 2008, pages 91-99, ISSN 0718-2724.

Kabanda Gabriel and Unganai L.S., Methodological Guidelines for crop weather calendars in the SADC region: SACCAR SADC-L&WMRP. Gaborone, Botswana: Printing and Publishing Company of Botswana, June 1994.

Kauffman Stuart A, The origins of order: selg-organization and selection in evolution. New York: Oxford University Press, 1993.

Kekana, N. (2000) Information Communication and Transformation: A South African Perspective. Communication, Vol. 28 No.2, p54-61

Kyem, P.A. and LeMaire, P.K. (2006), "Transforming recent gains in the digital divide into digital opportunities: Africa and the boom in mobile phone subscription", The Electronic Journal on Information Systems in Developing Countries, EJISDC (2006) 28, Volume 5, pages 1-16.

Lai Y.C., Harrison M.A., Frei G. and Osorio I. (2004), *Controlled test for predictive power of Lyapunov exponents: Their inability to predict epileptic seizures*. CHAOS Volume 14 Number 3, September, 2004. Copyright 2004 American Institute of Physics.

Lee S.K., Wang C. and Mapes B.E. (2008). *A Simple Atmospheric Model of the Local and Teleconnection Responses to Tropical Heating Anomalies.* Journal of Climate, Volume 22, July 2008, pages 272 -284. Copyright American Meteorological Society, 2009.

Moradi, M.A. and Kebryaee, M. (2010), "Impact of Information and Communication Technology on Economic Growth in Selected Islamic Countries", http://www.ecomod.org/files/papers/987.p.

Murugesh S. and Lakshmanan *M (2005), Nonlinear dynamics of moving curves and surfaces: applications to physical systems.* International Journal of Bifurcation and Chaos, Vol. 15, No. 1 (2005) 51–63

Quéau P. and J. ROSE (1998): Telematics as a Driving Force for African Development. In: Ras-Work 1998, pp 102-123.

Quéau P. and J. ROSE (1998): Telematics as a Driving Force for African Development. In: Ras-Work 1998, pp 102-123.

Rogers, E.M. (1995). Diffusion of innovations (4th edition). New York: The Free Press.

Rogers, E.M. (2003). Diffusion of Innovations (5th Edition). New York. The Free Press.

Sciadas G. (2003), "Monitoring the Digital Divide and beyond", The Orbicom project publication, in collaboration with the Canadian International Development Agency, the *Info*Dev Programme of the World Bank and UNESCO: Claude-Yves Charron, Canada, 2003 (ISBN 2-922651-03-7), page 10. *http://www.orbicom.uqam.ca.*

Shen A (2006), *Multisource Algorithmic Information Theory.* Dagstuhl Seminar Proceedings 06051 1, Kolmogorov Complexity and Applications: http://drops.dagstuhl.de/opus/volltexte/2006/626.

The Free Dictionary (2008). Ubiquitous. Retrieved March 7th, 2008 from http://www.thefreedictionary.com/ubiquitous.

UNCTAD (2006), The United Nations Conference on Trade and Development "The least developed countries report for 2006: developing productive capacities", Paper number UNCTAD/LDC/2006, United Nations New York and Geneva, 2006 (http://www.unctad.org/en/docs/ldc2006_en.pdf).

UNESCO (2010), "Universities and the Millennium Development Goals Report 2007", Association of Universities and Colleges in Canada, WDI publication, presented at the Association of Commonwealth Universities conference, Cape Town, April 2010.

Wafula-Kwake,A.K. and Ocholla Dennis (2007), "*The feasibility of ICT diffusion amongst African rural women: a case study of South Africa and Kenya*", International Review of Information Ethics Vol.7 (09/2007)

Wiley, D.A. (2001). *Learning Object Design and Sequencing Theory*, June 2001. Retrieved May 18, 2001, from http://wiley.ed.usu.edu/docs/dissertation. pdf

World Development Report (1998/99). The power and reach of Knowledge. [Online]. Retrieved 15 January, 2006 from: http://www.worldbank.org/ wdr/wdr98/ch01.pdf Accessed 15/01/06

World Bank (2003). *Lifelong learning in the global knowledge economy: Challenges for developing countries*. Washington, DC: World Bank.

World Bank (2002). *ICT Sector Strategy Paper*. World Bank. http://info.worldbank.org/ict/ICT_ssp.html

World Development Indicators (2004). "E-Strategies: Monitoring and Evaluation Toolkit", The World Bank INF/GICT Volume 6.1B 3rd January, 2005. http://www.worldbank.org/ict/.

Yang, S. J. H. (2006). Context Aware Ubiquitous Learning Environments for Peer-to-Peer Collaborative Learning. Educational Technology & Society, 9 (1), 188-201.