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Design Science Framework for Individual Innovation Self-Learning

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Abstract — **The study reviewed key elements for successful innovation self-learning using widely available mobile phone technologies as an entry point. Identified elements were integrated into design science research framework (DSRF). Every African owns or has access to a mobile phone making it a candidate platform that can be used most people to start learning technology innovation. Mobile phones use a hierarchical abstraction structure that hides complexity at multiple levels to simplify mobile phone use by different types of users. At lowest user level most complexity is hidden making it easy for almost everyone to use. The study postulates that group of university and tertiary institution students and people, who possess basic mobile phone technology understanding as one that can start innovation self-learning with potential to diffuse to masses. TRIZ is a widely used innovation theory consisting of several methods. It originated in science and engineering, and has been moving to other disciplines. TRIZ inventive principles method is used in this study. Some TRIZ principles at most basic level can be understood by everyone. However deep understanding of how technology was invented requires substantial domain knowledge and expertise. For example to understand how Ugali or Fufu the main African staple food was invented, a food science expert would use food science and technology knowledge. To the common person understanding would be basic using minimal knowledge. Incremental innovation self-learning approach was designed that allows learners to discover how technologies were invented using TRIZ inventive principles by adapting DSRF. Mobile phone hardware and operating system is used as a window to start learning innovation that acts as a bridge for learner to latter move to learning and possibly innovating in area of interest.**

Index Terms— **innovation self-learning, knowledge building, innovation ecosystems, mobile phone innovations, TRIZ inventive principles.**

I. Introduction

Africa has recently seen phenomena growth of mobile phones use. Mobile phones are embedded computers, an advanced technology owned by a large proportion of African population. Individuals, firms and countries must innovate or be left behind. Many countries are moving rapidly to benefit from innovation methods like TRIZ, but some developing countries are unaware or hibernating displaying a sign don't do the extraordinary here [1]. Mobile phones excitement, importance, urgency of mastering innovation and resource constraints make them one of few promising options for innovation self-learning in developing countries.

Mobile phones consists hardware and software. Hardware is the equipment. Operating system (OS) software are instructions that manage hardware. Application software is instructions for performing functions of users work. Mobile phone technology has been abstracted to multiple levels of complexity. Transparency mechanism hides some mobile phone aspects to reduce what one needs to know to use a phone. This makes it possible for people with low levels of knowledge to use a mobile phone, nursery school children at basic level and electronic engineers at advanced level. Innovation self-learning can similarly be abstracted at multiple levels of complexity. This study focuses on university, tertiary students and people with basic mobile phones understanding interested in learning fundamentals of innovation at low cost.

Mobile phone hardware and software has undergone minor and major innovations. The first mobile phone was large, heavy, and was fitted in cars boot. Mobility was in small region a single cell. This has improved to current small, light hand held phones that fits in clothes pocket. Mobility has been increased by having sets of cellular hexagon shaped adjacent cells, fitting together like honey comb hexagons.

TRIZ was developed by AltShuller by mining patents and codifying invention knowledge as TRIZ invention principles [2]. Several technological invention theories exist; TRIZ was selected because it's widely applied across technology disciplines such as computing. It has been extended to other disciplines including social sciences, education and business. It's based on reliable body of knowledge and reduces effort and resources required to innovate.

Innovation has been described as breaking rules, unconventional thinking, and thinking outside the box, thinking in other boxes and trying ways that have never been tried. Necessity driven resource constrained innovation starts where one is, with resources one has or that can be easily acquired. The idea is also applied at organization level by startups. Software startups face problems of low budget, time pressure and few resources every day [3]. Learning to invent in resource constrained environments should start by learning how technologies being used were invented, before trying invent new one.

Innovation adds novel features to something [4] but may include removing and modifying something in a novel way, such that thing remains functional. Beginners learning innovation should with start with simple tasks to build capabilities then gradually move to more and more complex tasks. A software pattern used build knowledge and capability by startups is to learn from existing methodologies [3]. It belongs to a class of solutions of learning from what exists before trying to make discoveries. This pattern and others are being applied by Ugandan startups with adaptations [5]. Some startups begin with student owner as only employee, some without any innovation knowledge and some startups succeed. Innovation self-learners are under lower and fewer constraints like time pressure and task complexity than that of startup student owners. Self-learners

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with similar motivation and passion for innovation are therefore likely to be more successful. Startup environment has many similarities with learning in scarcity environments. Everyone has substantial innovation capability and all one needs is to reawaken it [4] from childhood slumber. The first step in creating an innovation culture is unleashing one's creativity [4]. Learning culture requires continuous learning and leveraging of what is learnt in new situations [6]. Cultures are defined by techniques for thinking, learning, working [7]. Innovation techniques aid envisioning and discovering possible future technology innovation pathways. Predicted OSs future is they will use voice and gesture interfaces, be self-healing and accessed through the Internet [8]. Users use voice interfaces to interact with OS by talking rather than typing on keypad. Gesture input is interacting with computer or mobile phone without non-contact commands. Self-healing OSs repair themselves like human wounds. Analyzing patents is another way of discovering trends and trajectories. Innovation networker role scans for trends and connects internal and external stakeholders with complementary objectives to innovate [9] skills also required by Innovation learners.

Individual learning to innovate follows a steep curve in accumulating exploitable knowledge [6]. It's easier and cheaper to navigate the steep curve by starting slowly and learning how what one knows was invented, before moving to what one doesn't know. Not everything about innovation needs to be new, individuals can mine their past experiences for innovative solutions that can be reapplied in new situations.

A low cost way learning innovation is to start by studying how technologies one uses were invented and commercialized with reference to technologies they substituted or complemented. Mobile phones complemented and substituted computers and fixed phones. Other more expensive innovation learning routes are attending short and long courses. Long innovation courses like higher institutions degrees and diplomas are expensive, take long and are only available to a few. Learning through doing and self-study, is cheaper but requires determined and passionate pioneers. There is lack of short courses on innovation and patenting in Africa [10]. This has slightly improved since then but they are still few. Short courses enable learning, sharing experiences and networking of participants. Learning by invention is learning innovation by combing studying and doing [11]. Proposed self-learning is learning by discovery a subset of learning by invention. Innovation self-learner discovers through learning how TRIZ principles were applied to invent. Those who want to be inventors begin learning by discovery then proceed to learning by innovating.

The study aims to create an approach that is scalable to mass innovation. Mass innovation is defined as expanding and diffusing innovation activities to general population by connecting inventors and entrepreneurs with design techniques needed to realize novel design concepts [12]. People are naturally innovative, and local innovation based on available opportunities can transform Africa [13]. Around everyone are innovation opportunities and connecting systematically those learning innovation synergizes their efforts. Connectors, mavens and salesmen increase diffusion of technology innovation in ecosystems and society [14]. Innovation self-learning adoption is accelerated by connectors who are good communicators and know many people, by mavens who connect people with technology and innovation ecosystem information and salesmen who convince people. The connections can be managed and stimulated towards mass innovation. Study adapts design framework orienting it towards mass innovation by basing it on Rogers [15] diffusion theory.

Governments and leaders are asking: how they can teach their children to be creative and innovative [1]. TRIZ is an innovative method that can be taught to children [16]. Tertiary, university students and people with basic technology knowledge can learn and apply elementary TRIZ on their own. TRIZ cannot be learned and mastered without application to practical problems [16]. TRIZ leverages problems and solutions repeating in different sciences, technologies and industries [17]. Learners should begin with commonly used and every day simple technologies, then look for solutions in other domains to adapt for innovation in domain of interest.

An Internet search found many TRIZ publications including several from Africa, but non dealing with TRIZ self-learning. In Africa only Pretoria and Ghezira universities have introduced TRIZ courses, Kenya and other African countries should introduce TRIZ in university curriculum [1]. To become an innovator one should learn several innovation techniques [18]. Widely used innovation methods have two advantages, having large amount of literature and examples applying them to innovation and wide usage that is usually an indicator of usefulness. TRIZ, Kaizen, lateral thinking, Design Thinking and brainstorming are some popular widely used innovation methods.

One criticism of science and technology education is that what is taught in classroom is usually difficult to relate and apply in world outside classroom. Knowledge applicable in real world is likely to be applied more than knowledge that is not. Innovation learning can be enhanced by being applied to everyday problems. Osaka Gakuin university has been using everyday problems to aid students learn and master innovation. An example is tying a knot for thread shorter than needle at ending of sewing [19]. Two innovations were developed by students: making a needle dividable to make it shorter than string and other was making a specialized needle for only tying the knot as shown in figure

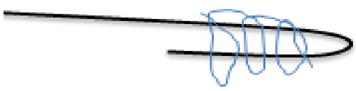

Figure 1: Specialized needle for only making a knot [19].

Technology information systems (TIS) are very useful to technology firms. A TIS with innovation principles used to invent commonly used and technologies is useful for students who desire to learn innovation. Creating such a web TIS database application evolvable at low cost is a first step towards developing a computer aided innovation system. BioTRIZ is a database that aids inventors use biological solutions to invent in other domains [20]. Bioinspired databases are being used to assist innovators and innovation learners. An innovation web database can similarly be useful.

The study objectives were:

1. To demonstrate how TRIZ inventive principles could have been applied in computer and mobile phone innovations.

2. To review literature to find elements required to create an innovation self-learning approach using mobile phones platform as an entry point.
3. To connect innovation self-learners to innovation ecosystems to enhance their learning through interacting with them
4. To adapt design science research framework for a low cost approach that systematically improves innovation self-learning, aids innovation and can be scaled to mass innovation.

II. METHODOLOGY

This study uses Four cycles Design science research framework (DSRF) [21] because of its focus on innovation, connecting innovators to external environment, creating and building knowledge. Impact and change cycle helped align learning with ecosystems. Innovation learning requirements were determined using relevance cycle, framework was adapted during design and build cycle; rigor cycle added and used ideas in knowledge base and informed design cycle.
Literature review was used to determine critical self-learning elements that were assembled with DRSF. DSRF's are used for research, innovation and knowledge creation [22] across several disciplines like education, business, computing and engineering. TRIZ principles are complementary in those disciplines.

III. INNOVATION AND INVENTIVE PRINCIPLES

TRIZ invention principles are innovation best practices, with proven innovation record. They were created by codifying patent invention knowledge.

A. TRIZ Inventive Principles

Innovation principles are basic building blocks of methods and knowledge [23] and accepted rules for reasoning. Inventive principles enable discerning new ideas, exploration of novel spaces using novel search strategies [24]. Altshuller reverse engineered principles used to invent patented science and engineering products. TRIZ invention reasoning rules are applied by inventors during invention. They were adapted to software by an analogical reasoning to make them easier and appropriate to apply to software [25, 26]. A subset of TRIZ inventive principles used in this paper is presented in table 1.

TRIZ principle	Explanation
Merging	Unconventionally combining selected parts to form larger components and systems
Segmenting	Unconventionally dividing something into smaller parts
Universality	Making something perform several functions or be usable in variety of situations in ways it has never done before.
Another dimension	Changing or adding dimensions that makes something function in a novel way
Nested doll	Putting something inside another, nesting can be at multiple levels.
Lemon to Lemonade	Making a harmful event or thing useful in unconventional way.
Using composite material	Innovating by combining multiple materials or approaches, like developing application using multiple programming languages.
Intermediary	Using one thing as medium to enable another to function.
Dynamics	Making something static, movable or making something movable, static.
Preliminary action	Planning for something before it's needed.
Beforehand cushioning	Doing something before its needed, preparing before something comes into action
Partial or excessive action	Using more or less of a thing
Parameter changes	Changing flexibility of something
Local quality	Making something perform in conditions that best suit it

Table 1. TRIZ Inventive principles [25, 26, 27, 28].

A. Application of TRIZ inventive Principles

This section addresses objective one by demonstrating how TRIZ inventive principles could have been applied to create computer and mobile phone innovations. Easy to understand examples are selected as goal is basic innovation self-learning.
The processor does all processing. It has evolved by adding new components, improving existing ones and organizing them differently. The processor executes instructions and commands other phone devices. Mobile phone ARM is a widely used processor, that evolved following this pattern. Innovation of ARM3 introduced Cache memory to ARM2 [29]. Cache is a memory whose price, speed is between CPU registers and random access memory. Phone predicts instructions and data that may be needed next and stores them in cache, for faster access if needed. Fetching instructions before they are needed is application of TRIZ principle of preliminary action by planning for instructions before they are needed. Using a cache which is intermediate between RAM and secondary storage is application of TRIZ intermediary principle. Radio frequency identification (RFID) is being introduced in Mobile phones. RFID consists of a tag and a reader. Tag broadcasts using radio waves and the reader receives. RFID reverses the way radio broadcasting works by making broadcasting station mobile and reader/radio fixed. This is TRIZ principle of turning the other way round. Some RFID readers are movable making both broadcasting station and receiver movable which is TRIZ dynamic principle that makes parts movable relative to one another.
GSM phones smart SIM card contains information about subscribers and service providers. The smart card is an embedded computer, with its own OS, processor and memory. The smart card computer is nested in embed mobile phone computer. This is TRIZ nesting inventive principle of

putting something inside another. The mobile phone changed phone address module from fixed to movable. This is TRIZ principle of dynamics. Some mobile phones have radio, video camera, still Camera and are computers. This is TRIZ universal principle of making a device perform multiple functions. There are two OSs in a mobile phone: for smart card and the phone. This is segment principle of dividing mobile phone functionality and allocating it to smart card or mobile phone hardware and software.

Google developed Android OS by building on a little known OS built by Android Inc. Linus developed Linux OS by using a simpler Minix OS. Building on an existing tried OS reduces risks and increases reliability and stability of OS. Google and Linus using a simpler cheaper OS is TRIZ principle of using cheap copies. Google partnered with Open handset consortium of hardware developers in developing Android OS. This changed companies from potential competitors to allies. This is application of TRIZ principle of turning lemon into Lemonade that transforms threats into opportunities. Google being a major Android developer ensures its applications such as its search engine are well supported. This is TRIZ intermediary principle of Android OS acting as an optimized intermediary for Google applications. OSs when delivered to customers contains errors that cause them sometimes to fail or be hacked. OS developers often release system patches which when installed fix errors some before they cause failure. This TRIZ principle of beforehand cushioning trying to prevent a problem before it arises.

[8] Predicts future operating system will be self-healing and use voice and gesture inputs. This is TRIZ parameter changes principle, making phones more flexible. Linux OS was first used in microcomputers then main frame computers, and now in phones and Supercomputers. This is application of TRIZ universal principle of making OS used in many hardware systems. Portable OS run on different hardware's were created through macro innovation by applying TRIZ nested doll principle [30]. There are other macro innovations with TRIZ principles applied some applicable to OS [30].

Distributed OS components running in wide area networks may be located in different geographical regions. Components are placed where they best serve their purpose. Data and software is sometimes placed nearest the user where it's cheaper and faster to access. This is TRIZ principle of local quality. Distributed OS make components distribution transparent. This reduces what user of needs to know to use it. This is TRIZ principle of color changes that hides complexity of what user must know to use system. At higher level physics in information technology is hidden thus transparent [31] making it possible to use IT technologies with little or no knowledge of physics.

Modularity is dividing a large complex system into small components called modules that are independent of each other but module elements are highly interdependent. Modularity allows interchangeability of components between different systems, failure or modification of a module affects one or a few modules [32]. Modularity is application of TRIZ inventive segment principle [30]. Modules are designed to affect least number of other modules when they fail.

Convergence of mobile phones, personal digital assistants and Internet technologies is paradigm shift that has altered the way we live [33]. This is a trend towards the mobile phone becoming a universal device. This trend is enhanced by increased functionality being added to phones such as RFID, TV, radio, photo and video cameras, GPS tracking and others. TRIZ merging, universal and other principles created this paradigm shift.

Examination of TRIZ principles presented above shows they are common principles also applied in daily life. They are applied in routine and innovation activities. They are innovative when applied to create something novel. Principles application complexity is proportional to innovation problem complexity. For simple everyday problems any one can develop ability to apply a few inventive principles. Some large complex innovation problems require countries to collaborate.

IV. BUILDING KNOWLEDGE, LEARNING STYLE AND MODEL

Innovation is a learning process that can be guided by Kolb learning style and design method [34]. Perception in action consciously destroys conventional views, divergently explores information and activates all senses [35] driven by what works. Innovation self-learning will use Kolb learning style, knowledge building model and design science research method to direct learning. The learning process will be based on seed growth metaphor. The seeding model consists of finding and discovering cycle and inventing and making cycle [7]. Innovation learner starts theorizing with proposal or goal discover TRIZ inventive principles applied as shown in Figure 2. Using knowledge learned to invent and is not part of this study.

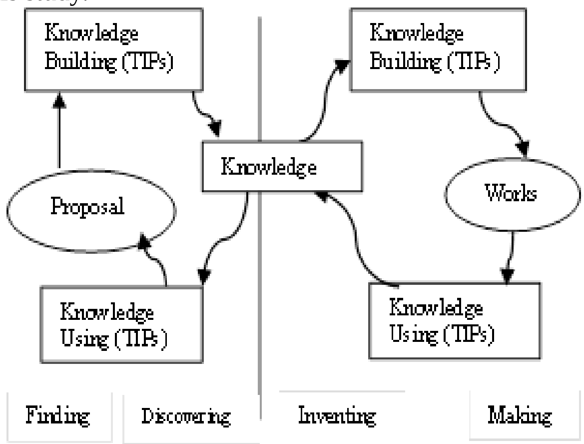

Figure 2. Discovering and inventing cycles adapted from [36].

Concrete experience comes from action. Learner compares innovation and technology it substituted or complemented discovering and experiencing new perspectives. The learner reflects on experiences by analyzing their strengths, weakness, opportunities and threats (SWOT). After Reflection learner decides what to consider and what to ignore. Ideas requiring further development are concretely conceptualized by turning them into concepts, connecting concepts to relevant theories and determining applicable TRIZ inventive principles. Conceptualization created is evaluated for applicability by experimentation and adaptation. Figure 3 presents the learning process.

Seeding, evolution and reseeding model (SERM) [7] is a cyclic model consisting of following steps:

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1. Seeding creates a collection of domain knowledge to be improved over time. Computer and mobile phone domain knowledge and technologies they substituted or complemented, inventive principles and elements of ICT innovation ecosystem for the seed. Seeds are created in increments to enable efficient learning. Learning without putting to practice is not efficient as what is learned is easily forgotten. Practicing improves and creates connections with other knowledge
2. During evolution the seed grows by building the solution. The seed extends by building on insights acquired from interaction with ecosystem components
3. Reseeding reorganizes, generalizes acquired knowledge and creates new seeds. New seeds created are seeded in next increment.

Kolb cycle and SERM model are used discovering and inventing cycles. Learning is an evolutionary process where complex ideas are learned partially in beginning and improved through more learning and practice. Practice makes perfect is half the equation, the other half is more learning. SERM model postulated that systems sustained over long time span must alternate between periods of planned and unplanned activity and periods of restructuring and enhancement [7]. Self-learning will alternate between these periods.

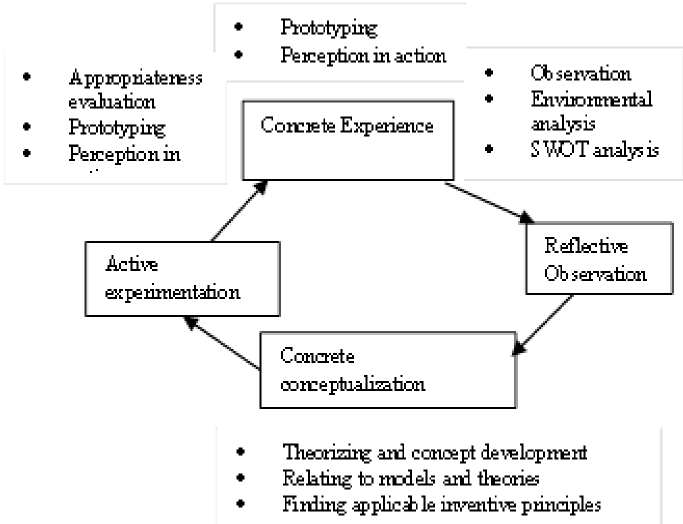

Figure 3. Kolb learning style adapted from [37]

IV. NATIONAL INNOVATION ENVIRONMENT [CONTINUE]

This section addresses third objective of finding a way to connect self-learning and innovation ecosystem, and fourth objective of adapting design framework and completes objective two.

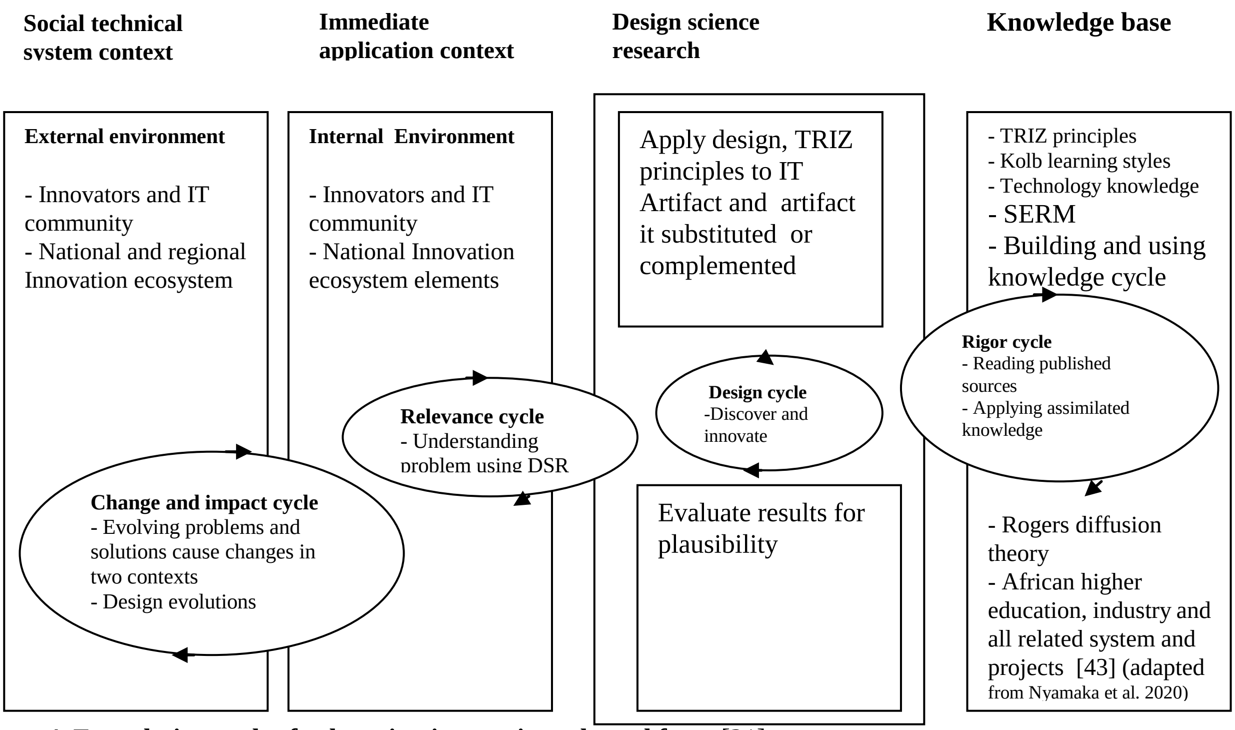

Figure 4. Four design cycles for learning innovation adapted from [21].

Different researchers differ on whether sub Saharan Africa has national innovation systems (NIS) or not. [38] see fragments of NIS, while other like [39] and [40] see nascent/emerging national innovation systems. Embryonic NISs are national learning systems and developing countries are technological learners [41]. Innovation learners are NLS micro agents and successful learning is critical factor in transforming of NLS to NIS.

Two national environment components are innovation strategy and ecosystem. East African ecosystems are fragmented and require further development to create NISs [38]. Innovation is enhanced by making new connections, borrowing insights from other disciplines, networking and having an open mind [4] which requires thriving innovation ecosystems. Ghana and Kenya Tertiary institutions are knowledge based need create linkages to transfer tacit and explicit innovation knowledge [40]. Tertiary institutions self-learners should leverage innovation knowledge in these institutions and act as innovation knowledge transfer agents. Individual innovators are ecosystem micro agents, who aggregate forming groups, firms and communities. Innovation ecosystem boundary objects help incentivize and mediate interaction between innovation learners [42]. A TRIZ principles web database where innovation learners contribute their discoveries is a boundary object. The database is based on blackboard architecture; with intelligent micro agents interacting only through a central data structure. Innovation learners interacting with innovation ecosystems: technological, sociological, institutions and culture components [43] are transformed by ecosystems and in turn transform them. Four cycle design science [21] is a framework for learning mobile phone application innovations that utilizes developing countries innovation ecosystem [43]. TRIZ principle of cheap copies focuses on African local resources [28]. Once innovation learners' gain mastery they can tutor others as way of improving and building their capabilities. This is application of TRIZ strong oxidants principle[28]. Design science African knowledge bases should be populated with knowledge as innovation learning progresses. Adapted innovation learning design framework is shown in figure 4. Design science research frameworks at high level of abstraction can be used by everyone, because they abstract solution development as easy to understand six components and four cycles. Design oriented approaches are being used to increase innovation in technologies and countries [44]. They can contribute to maturing mass innovation. Design of DSRF is based on technology innovation adoption criteria making it easier to adopt [44] at various levels of capabilities and adoption strata.

Designed based research Connects popular understanding of an issue, academic research, civilizational assumptions underpinning an issue, metaphor and proverbial truths that can be used to explore alternative futures by exploring design production and sharing of knowledge [45]. Research and innovation self-learning growth future scenarios can be seeded. Proverbs are innovation design heuristics [23] that can be used to build local design culture.

Individuals should acquire designers' mindset so that they are not passive receivers of knowledge (reading and banking knowledge) but active researchers, constructors and commanders of knowledge [46]. Individual applying SERM model develop a design mindset becoming intelligent consumers and producers of knowledge. SERM designers turn users to designers [46]. Embedding SERM in DSRF will turn innovation learners into designers. If number of novice innovators and innovation self-learners increases to reach critical mass they can trigger mass innovation.

IV. CONCLUSIONS AND RECOMMENDATIONS

TRIZ inventive principles, learning styles, SERM model, discovering and inventing cycle were integrated into design science research framework creating innovation self-learning framework. The framework provides guidance to individuals with some basic technology knowledge to learn innovation as step towards becoming self-made innovators.

If self-learners learn innovation and develop capabilities using widely available mobile phones, they can then proceed to create simple innovations and take advantage local ICT innovation ecosystem to master innovation at low cost. SERM goal of turning users into designers and creators of knowledge is one of adapted design framework drivers. The study contributes to developing foundations for low cost innovation self-learning with potential to evolve to mass innovation.

Future work should concentrate on two tasks: creating an innovation self-learners boundary object web database, where innovation learners contribute discoveries and use discoveries of others. The second task is scaling novice innovation through learning by inventing to mass innovation.

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