



Chaos Engineering (Principles of Chaos Engineering) As the Pathway to Excellence and Relevance in Engineering Education in Africa

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Abstract: A study on engineering in sub-Saharan Africa revealed that engineering is pivotal for economic and social development of any country. This is profound as it underscores the potentials embedded in engineering education for excellence and relevance in Africa. This has not been the case in Africa, as the region has not developed evenly with other countries from the Global South. Hence, the impetus for chaos engineering as a panacea to excellence and relevance in engineering education in Africa. Chaos engineering has been defined by various authors and one of the profound definitions is that chaos engineering is the discipline of experimenting on a distributed system with the intent to build confidence in the system's capability to withstand turbulent conditions during production. This study therefore looked at chaos engineering, its history and applicability and conceptualize it as a pathway for excellence and relevance in engineering education in Africa. Findings from the that engineering is pivotal for economic and social development of any country but it has not resulted to such in Africa which necessitates chaos principles. It was found out that experimentation is a basic principle of chaos engineering while the advanced principles are hypothesizing about steady state, vary real-world events, run experiments in production, automate experiments to run continuously, minimize blast radius. These all were conceptualized as the pathway to excellence and relevance in engineering education in Africa. The study recommended that there is a need to intensify effort on researching more into chaos engineering in Africa.

Keywords: engineering, engineering education, principle, chaos principle, excellence, relevance, chaos engineering.

I. INTRODUCTION

Engineering has been defined by various authors in time past and one of the most profound definition was given by UNESCO in 2010. Engineering was defined as the field, discipline, practice or profession that has evolved with development, acquisition and application of technical, scientific and mathematical knowledge which is crucial in understanding, design, development, invention, innovation of materials, machines, structures systems, processes for different purposes. This definition typifies the dynamics and multi-versatility of engineering as a discipline. While engineering education is the pathway by which knowledge and principles related to engineering discipline is been taught. Basically, engineering education is the process by which engineers are trained. A study conducted by the Royal Academy of Engineering (RAE) on engineering in sub-Saharan Africa (Matthews *et al.*, 2012)

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revealed that engineering is pivotal for economic and social development of any country. This is profound as it underscores the potentials embedded in engineering education for excellence and relevance in Africa. This has not been the case in Africa, as the region has not developed evenly with other countries from the Global South. Hence, the impetus for chaos engineering as a panacea to excellence and relevance in engineering education in Africa. Chaos engineering has been defined by various authors and one of the profound definitions is that chaos engineering is the discipline of experimenting on a distributed system with the intent to build confidence in the system's capability to withstand turbulent conditions during production. It is important to bear in mind that in a system, there are various elements embedded in it with differing abilities and capabilities. With engineering being a discipline that involves production, there is the possibility of unpredictable events occurring which might not have been envisaged before. With many actors also involved, there is interaction among various elements along engineering education line which must be factored in for optimal performance. Excellence and relevance are not mere buzzwords in engineering education, they are milestones that must be realized to make the discipline significant in Africa. This study therefore, will take a look at chaos engineering, its history and applicability and conceptualize it as a pathway for excellence and relevance in engineering education in Africa.

II. METHODOLOGY

This study seeks to understand Chaos engineering (principles of chaos engineering) as the pathway to excellence and relevance in engineering education in Africa. The study was qualitative as evidences from established literature was used to add credence to the crux of this study. Elements from the general principle of chaos were also conceptualized as the pathway to excellence and relevance in engineering education in Africa.

Deconstructing Chaos and chaos engineering as a concept

Chaos literally has to do with a state of disorderliness. Chaos is characterized by randomness and disorder. In scientific parlance, it's a series of complicated and noise related phenomena which stemmed from nonlinearity in deterministic dynamic systems (R. L. Devaney 1989, J. M. T. Thompson and H. B. Stewart 1986).



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The possibility of changes occurring in systems coupled with it occurring in nonsequential patterns.

There has been growing interest to understand this fuzzy phenomenon called chaos and attempts at this are becoming widespread. Chaos is a vital research field in sciences and it has wide application across other disciplines which include information processing (H. Nozawa 1992: C. Moore 1991.), plant control (K. Aihara and R. Tokunaga, ed. 1993), analysis and estimation of biological phenomena (I. Tsuda, T. Tahara and H. Iwanaga 1992: K. Aihara, T. Takabe and M. Toyoda 1990: I. Tsuda, T. Tahara and H. Iwanaga 1992), analysis and prediction of the economy and market (K. Aihara and R. Tokunaga, ed. 1993: K. Aihara, ed. 1992). These all attest to the many potentialities of chaos as seen in the various disciplines. It also has great application in the medical field where chaos theory has been used in creating medical instrument capable of identifying mental and physical condition by observing pulse within the human capillary vessels (I. Tsuda, T. Tahara and H. Iwanaga 1992). Chaos engineering was defined as the generic study associated with theoretical and technological foundations applicable for deterministic chaos, fractals, and complex systems which originated from Japan (Special issue on engineering chaos, 1990: K. Aihara and R. Katayama,, 1995: H. Kanz and T. Schreiber, 1997:). Chaos engineering has been found helpful across various engineering fields such as nonlinear time-series analysis (T. S. Parker and L. O. Chua, 1989:H. Kanz and T. Schreiber,1997.), time series data from real world phenomena. Some of the data in which chaos engineering is applicable for analysis include time series data of temperature in blast furnace (T. Miyano, S. Kimoto, H. Shibuta, K. Nakashima, Y. Ikenaga, and K. Aihara,, 2000), daily peak loads in utility power systems (Y. Mizukami, T. Nishimori, J. Okamoto, and K. Aihara, 1995), irregular and complex roll motion of a flooded ship (S. Murashige and K. Aihara,, 1998). It is important to note that data is a major component of engineering and it is on the basis of such quantifiable parameters that decisions are taken and made to create, build and design solutions to systems, processes or structures. Engineering education is not left out as a discipline where data is important for decision making. Chaos theory is also referred to as the dynamical systems theory. It is the study of unstable irregular behaviour in deterministic dynamic systems which is predicated on initial conditions (Vaidyanathan, 2013). Chaos and non-linear components have been known to scientists and engineers since and it is seen in feedback processes (Gaponov-Grekhov and Rabinovich, 2011) and in systems interacting with the environment. In engineering education, there are a whole mix of elements involved in it, from the training of the engineers down to the practice of the discipline, there are elements of interaction with the environment which has in it the chaos complex. In engineering, there is chaos characterized by movement which has been derived from some laws such as the Newton's law of motion and the Euler equation. Having a static state might be impossible in the environment as there are a whole lot of forces influencing each other, resulting in chaos. This typifies that there is an element of chaos in all systems. To understand dynamism and movement in systems, algebraic or differential equations are used. In

modern parlance, chaos is likened to a state of motion that occur in a dynamic system which is characterized by complexity and disorderliness. With chaos being a state of frequently recurring aperiodic movement, disorderliness and complexity are manifest. In chaos, there is a deviation from the equilibrium state. chaos also has in it sensitivity to previous states which results in enormous response to the state. For a dynamic state to be tagged chaos, it must meet three criteria which are boundedness, infinite recurrence and sensitive dependence on initial condition (Azar and Vaidyanathan, 2015: Azar and Vaidyanathan, 2014). With vacuity being an elusive state in the natural environment, chaos is unavoidable. The dynamic nature of the environment and human interaction with it seen from the evolutionary history of humans has attested to the growth and spread of engineering across the countries of the world. With this evolution, the world has moved from simple state to a large complex system where various elements interact and influence each other. The interaction of the elements birthed curiosity which led to drive for knowledge about the environment and hence, engineering came to the fore. Chaos engineering as revealed above has many applications and in engineering, it is a tool used to improve the resilience and certitude in large scale distributed systems. It was formerly referred to as resilience testing and it came to limelight with the traction gained by Netflix emerging into a large culture. There is a need to assess processes and have a better grasp of the output. Hence, the need for resilience testing. It assumes the experimental approach to issues. It is a method that seeks to understand the resilience and confidence of a system. In literal terms, people might see chaos as mere disruption made to a system in order to break it. It is more scientific and empirically driven to expose the weaknesses in a system by exposing it to various turbulent conditions. In exposing the system to the various conditions, certain standards are met such as having a controlled environment for the process. It was argued by (A. Medina, 2018) that chaos engineering is a series of coordinated, strategic experiments targeted at revealing the weaknesses in a system. It is important to bear in mind that an absolute state of perfection is impossible. Hence, the need to understand imperfections, weakness and flaws in systems and processes to make them better. The chaos engineering approach is apt to understand the various weaknesses present in a system. There are other systems for assessing weakness in a system but the chaos approach gives meaningful information about the systems resilience and weaknesses present in it which affects the system generally. With various elements present in a system, it presents the opportunity to have what can be termed chaos variables which are factors that can influence the system. The major goal is to explore and identify various weaknesses within a system and proffer solution to them before they affect the system. The chaos approach to issues seeks to ensure that a steady state is established where there is normalcy and the system works as expected. There are various metrics and standards which typifies steady state and this is specific to systems.

The steady state is also not absolute as it is subject to various factors which influences the system. So also, is this applicable to engineering education as a discipline. With the unpredictable nature of events in the environment, it is important to note that anything can happen at any time. Systems may fail, processes might not work and so many other unpredictable events can happen at any time. These all impact on the performance of systems, structures and processes. It is important to bear in mind that engineering education is not also exempt from this occurrence and as a result of varieties of actors, context and events influencing it, the possibility of having weaknesses is rife. The noble thing to do with the knowing that such unwarranted conditions might be unavoidable is to prevent them from happening while also making systems, processes and structures more resilient and building confidence into it. This will ensure that weaknesses are brought to the fore and what makes it more interesting is the fact that it is not premised on unverifiable standards. Deploying the empirical process of verification encourages building resilience and confidence in systems. In sciences, what is mainly done is carrying out experiments in order to understand more the physical and social phenomena. This has had many implications on the human life with the discovery of better approaches to the conduct of events which has in it elements of engineering. Engineering was previously defined as the creative application of scientific and mathematical principles to create, build and make systems, structures and processes better while also providing solutions. Science through empirical exploration studies the physical and social phenomena and has influenced it. Hence, the advances that are seen in science and technology characterized by improvement in each epoch. Notable amongst these are how civilizations has been graduated along industrial revolutions with the knowing that we are not in the fourth industrial revolution. chaos engineering uses experiments to learn about a particular system. There can be no perfect end to knowing about systems as it is been affected by a whole lot of factors which changes as time progresses. Hence, the impetus to understand more about the system, the factors that have influence on it, the actors at play in the system and the series of changes that can be made to it to make it better while minimizing weakness and building confidence in it. Some people have argued that chaos engineering is not different from testing but this is rather untrue. Though there are elements of similarity in both, they are not the same. Though related, chaos engineering is novel and it seeks to reveal new information about systems while fault injection is an attempt to understand the impact of one condition on the system. Take for instance, when you want to understand why an engineering system misbehaves, a fault like varying dimensions of the same input can be introduced into the mix but when we want to holistically understand various events which impacts the system not just one, chaos experiment is apt for this. This approach unravels the series of unpredictable events that might occur in a system which affects it. In testing, there is the probability of a cause and effect and it can be theorized that under this condition, a system will produce this output. It is more of a binary approach to issues while assigning valence to a known property. Testing also has in it elements of apriorist

expectation which might not be new knowledge while chaos engineering generates new knowledge and proffer new solutions that were unexplored before in systems and processes. Chaos experimentation is nit a means of testing known properties; it reveals new information. Engineering education is characterized with complex situations and in it there is a need for proper management of humans and resources. In engineering education, there is a need for a team of skilled, competent and dynamic workforce that are critical to helping achieve the ideals of the discipline whole also maintaining interaction with them and many parts. This comes with lots of challenges as diversity has been introduced into the system. The engineering education discipline is one that thus can be likened to a complex situation which must be managed appropriately. With various characters needed to ensure appropriate delivery, these all affect the architecture of the discipline and future outcomes. Communication is major along these lines and chaos engineering supports high velocity, experimentation and confidence in the actors and systems through building resilience. In engineering education, there is a long list of elements in the value chain and right from the primary stage to the tertiary stage, various actors and complex processes are involved. Let's put this in perspective, those at the extractive stage, those at the manufacturing and the other professional services rendered along the lines of the discipline represents a complex process which involves interaction among various elements. From the environment, interaction is made and communication is initiated amongst actors. Each deploying his unique competence and interest along the lines of duty which might not be congruent with that of the other team members. This presents a complex situation that must be adequately managed hence the impetus for chaos engineering. These and many more interaction are bound to happen which poses weakness in the system. Hence the need to identify these weaknesses and build confidence in the system to ensure that the systems works better and outcomes are shaped. As it was revealed previously, it is wrong to expect a state of perfectness in engineering system and giving the failings of the human architecture, other system which humans interact with are not exempt from these series of unpredictable events. Chaos engineering is a veritable opportunity to overcome these weaknesses and build confidence in a complex distributed system. With confidence built in a system going forward, elements critical to its performance would have been studies while removing weaknesses from the system. This will prove helpful to various disciplines as it has been opined above that chaos engineering has wide application across various disciplines and domains.

Conceptualizing the pathway to excellence and relevance in engineering education in Africa using the principles of chaos

Excellence and relevance are words that has many applications depending on context.

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It has also been defined by various authors and one of the most profound of the definition in engineering is one given by CASEE (1999), which defined excellence on the premise of effectiveness, engagement and efficiency. This implies that to demonstrate excellence in engineering education, there must be effectiveness, engagement and efficiency. In general parlance, effectiveness is the extent to which activities have contributed to the delivery of service while efficiency is the extent to which resources are used to achieve maximum benefits while engagement is an individual's involvement with, satisfaction with, and enthusiasm for the work he or she does. These three are dimensions of excellence. While relevance has in it a predisposition for time implying practical and social pertinence. Excellence is also a distinguishing factor that differentiates from others. In a study by Cristina Pomales-Garcia (2007) on excellence in engineering education: views of undergraduate engineering students, excellence was characterized by participants of the study as accredited, accurate, analytical, precise, informative, important etc. Excellence and relevance are desirable characteristics that must be encouraged and this has vital import on all disciplines. It is therefore imperative to ensure that excellence and relevance is encouraged in engineering education as a discipline. This study seeks to conceptualize the pathway to excellence and relevance in engineering education in Africa using the principles of chaos. The principles of chaos engineering are specified into four which are hypotheses, independent variables, dependent variables, context (William R. Shadish, Thomas D. Cook, Donald T. Campbell, 2001). With the first chaos principle being experimentation, we have the advanced principles. Experimentation is a systematic approach to inquiry and it is very important in pedagogy. So also, is this applicable in engineering education to understand how the discipline works under various conditions. As scientists are always in a bid to use experiment to unravel natural situations, engineering education specialist can also use experiments to reveal system behaviour as a pathway to excellence and relevance. The advanced chaos principles are hypothesizing about steady state, vary real-world events, run experiments in production, automate experiments to run continuously, minimize blast radius. These all will be conceptualized as the pathway to excellence and relevance in engineering education in Africa. Engineering education also has in it various complex systems and there are lots of aggregated complex parts which works together to influence output. An approach to doing this is to ensure that there is data which reveals salient information about engineering education. It is essential to ensure that engineering education thrives well under varying conditions to ensure excellence and relevance. Understanding that engineering education takes place in an environment, has in it various actors, requires context resources which has the impetus to influence it. To ensure excellence and relevance in engineering education using the principles of chaos, it is vital to build hypothesize about steady states. Some of which have been mentioned above. It is also noteworthy to bear in mind that hypotheses are educated guesses about the possibility of some events occurring. Reasonable questions and hypotheses must be raised as regards engineering education in a bid to ensure

excellence and relevance in the discipline. Raising hypotheses around how various factors influences engineering education as a discipline. This will culminate in excellence and relevance in the discipline. As a principle of chaos, if a hypothesis is formulated in engineering education, the hypotheses must be predicated on specific metrics which can be measured. More so, it is important to note that no system exists in a vacuum and every system from simple to complex is influenced by various conditions. Examples in engineering education include machineries, manpower, data, politics, economy, environment and other unforeseen circumstances. With the knowing that events might be unpredictable and various threats occur in system, it is essential to mitigate them by varying-real time event which is the second advanced principle of chaos. To vary real time events mentioned above in engineering education, real life events can be simulated with failings injected into engineering systems to ensure excellence and relevance in engineering education in Africa. With a whole lot of factors influencing engineering systems, there is a need to enumerate all these factors though all cannot be injected to vary real-world events. Some might be so difficult to quantify such as politics and culture. Moreover, engineering and engineering education are production discipline and there is a need to run experiment in production as a principle of chaos to ensure excellence and relevance in engineering education. It is therefore important to run experiment in production environment as possible so as to understand the behaviour of the overall system. From previous discussion, running experiments helps to build confidence in the system of production which engineering education is a part of and also explore the systemic effect. Automation is pivotal as a principle of chaos and it must run continuously. Automating experiments to run continuously in engineering education helps in the analysis of experimental data and results and it has the propensity to drive the automation of new experiments. With the times changing and the realization that we are at the fourth industrial era, it has immense opportunities for engineering education as there are various technologies emerging in it which include automation, critical to running experiments. Lastly, with the knowing that chaos has elements of disturbances in it, it has the potency to culminate in disaster. Some dimensions of engineering education might also be dangerous and chaos experiment will result in a change to the output. As a principle of chaos, engineering educators must minimize blast radius by understanding and mitigating the risks associated with production. Risks should be minimal as a principle of chaos to build confidence in engineering education system without causing harm.

III. FINDINGS AND DISCUSSION

Findings from the study revealed that engineering is pivotal for economic and social development of any country. This is profound as it underscores the potentials embedded in engineering education for excellence and relevance in Africa.

This has not been the case in Africa, as the region has not developed evenly with other countries from the Global North. It is important to understand that Africa has been a hub for charity, poor infrastructure, widespread poverty, poor leadership, dependence on primary production, political instability, insecurity, corruption etc. this shows that engineering has not delivered on its ideals which has in it the remedy for economic and social development in the region. Hence, the impetus for chaos engineering as a panacea to excellence and relevance in engineering education in Africa. It was found out that excellence and relevance are words that has many applications depending on context. It has also been defined by various authors and one of the most profound of the definition in engineering is one given by CASEE (1999), which defined excellence on the premise of effectiveness, engagement and efficiency. It was also found out from this study that chaos on literal terms has to do with a state of disorderliness. Findings revealed that chaos is characterized by randomness and disorder. In more scientific language, chaos is a series of complicated and noise related phenomena which stemmed from nonlinearity in deterministic dynamic systems (R. L. Devaney 1989, J. M. T. Thompson and H. B. Stewart 1986). The possibility of changes occurring in systems coupled with it occurring in nonsequential patterns. It has gained the attraction of people and there has been growing interest to understand this fuzzy phenomenon called chaos and attempts at this are becoming widespread. It was also found out that a static state might be impossible to achieve as there is a lot of interaction between various factors in the environment. This is also applicable to engineering education, as there is chaos characterized by movement which has been derived from some laws such as the Newton's law of motion and the Euler equation. Having a static state might be impossible in the environment as there are a whole lot of forces influencing each other, resulting in chaos. This typifies that there is an element of chaos in all systems. To understand dynamism and movement in systems, algebraic or differential equations are used. In modern parlance, chaos is likened to a state of motion that occur in a dynamic system which is characterized by complexity and disorderliness. It was found out that Experimentation is a systematic approach to inquiry and it is very important in pedagogy. So also, is this applicable in engineering education to understand how the discipline works under various conditions. Also, engineering education is a composite of various complex systems and there are lots aggregated complex parts which works together to influence output. An approach to doing this is to ensure that there is data which reveals salient information about engineering education. It is essential to ensure that engineering education thrives well under varying conditions to ensure excellence and relevance. To ensure excellence and relevance in engineering education using the principles of chaos, it is vital to build hypothesize about steady states. As a principle of chaos, it was stated that there is a need to vary real-world events, run experiments in production, automate experiments to run continuously, minimize blast radius.

IV. CONCLUSION AND RECOMMENDATION

This research has considered chaos engineering (principles of chaos engineering) as the pathway to excellence and relevance in engineering education in Africa. The import of engineering as a tool for economic and social development has been revealed in the study though the discipline has not lived up to the ideal in Africa which necessitates the need for the principles of chaos. With experimentation being a basic principle of chaos engineering and hypothesizing about steady state, vary real-world events, run experiments in production, automate experiments to run continuously, minimize blast radius the advanced principles of chaos. These all were conceptualized as the pathway to excellence and relevance in engineering education in Africa. The study therefore recommended that there is a need to intensify effort on researching more into chaos engineering in Africa.

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