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Developing Theoretical Framework for Evaluation of Engineering Education in Sub-Saharan African Countries

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ABSTRACT

The rising challenges of engineering education facing Sub-Saharan African (SSA) countries are considered to be one of the main factors that have been crippling the development of the region, which is desperately needed to elevate its economy. This paper established the need for constructing a new theoretical framework for the purpose of evaluation of engineering education programs within the context of SSA countries. Therefore, combining both PST and constructivism theory, along with How People Learn (HPL) framework, Outcome-based Education (OBE) model, and Constructive Alignment (CA) model, an integrated theoretical framework capable of evaluating the situation of the SSA engineering education programs and identifying the appropriate conditions required for transformation of these programs has been developed.

Keywords:
Sub-Saharan Africa; engineering education; theoretical framework; poststructuralism; constructivism

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1. Introduction

Many researchers stated that theoretical frameworks are very important for the quality of the qualitative research [1-5]; and even Grant and Osanloo [5] called it the "Blueprint" of a research. Therefore, qualitative researchers should frame their research by selecting appropriate theoretical frameworks, and pinpoint how a framework could be aligned and interconnected to the research concepts, namely: the problem statement, objective and the significance of the research, and the research questions. In addition, the theoretical framework reveals the researcher's epistemological and methodological stance [5].

This paper intends to construct a framework for evaluation of engineering education programs within Sub-Saharan African (SSA) countries. According to Vinz [6], there are three steps to develop a theoretical framework: 1) identify key concepts such as problem statement, objective of the research, and research questions. 2) Literature review of existing theoretical frameworks, including their pros and cons, and their limitation for the research purposes. 3) Combine various theories, from

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different fields, into a unique theoretical perspective suitable for the specificity of a certain research topic.

According to the African Union classification, there are 48 out of 55 countries belong to the Sub-Saharan African (SSA) region, which separated from the North Africa by the Sahara Desert, and the region is divided into four distinct subregions: Central Africa, East Africa, West Africa, and Southern Africa, Figure 1- a&b [7-8].

SSA countries are diverse culturally, socially, and economically. However, except few of them such as South Africa, Botswana, Mauritius, Namibia, most of SSA countries are low-economy countries, also known as developing countries, which is evident by gross national income (GNI) per capita. In 2022 the GNI, for all SSA countries, was estimated to be $1,638. Another economic indicator that characterizes most of these countries is the high poverty headcount ratio (at $2.15 per day), which made about 34.9% of the total population, in 2019 [20].

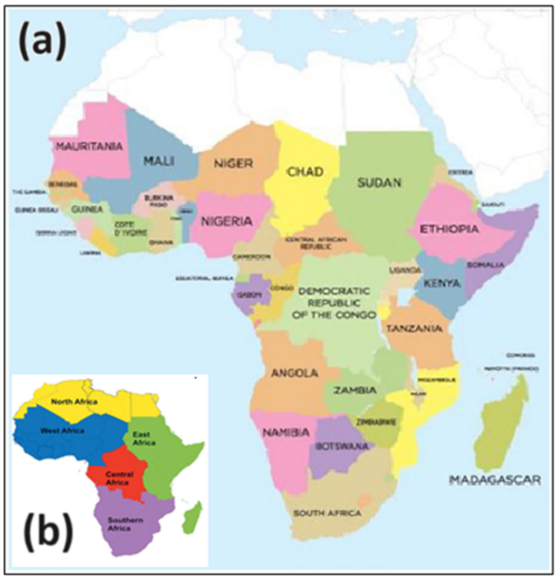

Fig. 1. (a) SSA countries and (b) Regions [7-8]

Improving the situation of engineering education and engineering profession is one of the key factors to transform the region economically. The direct relationship between a country's economic development and its engineering capacity, which includes enough well-trained engineers, is well known and documented [9-14]. For instance, UNESCO [11] stated, 'The engineering profession plays a major role not only in the growth and development of a country's economy but also in improving the quality of life for its citizens. The engineering profession is also playing an ever-increasing role in enabling a country to participate in the global economy and in the protection of the environment'.

2. Methodology

2.1 Research Purpose

Applying the systematic review method, the purpose of this paper is to construct a theoretical framework, by integrating a number of existing theoretical perspectives, in order to better understand the situation of engineering education within the SSA region.

2.2 Scope

The scope of this paper is limited to provide researchers with a unique theoretical framework for evaluation of SSA engineering education systems; however, further research should involve testing this framework within the context of SSA countries.

2.3 Method

Systematic literature review has been used widely, by many researchers in many fields, for instance: Social science [15], medical research [16], engineering education [17], international development [18], just to name a few fields. It considered by many as reliable, comprehensive, rigor methods. However, others have concerns if it is conducted in a rigid and non-reflexive manner. Systematic review has three core principles: Rigor, transparency, and replicability. Applying them sensitively, systematic reviews have an obvious advantage over the traditional reviews: the quality of reviews is improved through greater transparency; a wider range of studies are identified and screened; implicit researcher bias is theoretically reduced; and reviewers are encouraged to engage more critically with the quality of the evidence [18].

Systematic reviews are difficult to apply in practice due to many practical and methodological challenges and concerns. One of them is, 'Systematic reviews require access to a wide range of databases and peer-reviewed journals, which can be problematic and very expensive for non-academic researchers and those based in Southern research organisations' [18]. Therefore, they described a less rigid and more reflexive form of evidence-focused literature review, and they state, 'In order to overcome some of these practical challenges and methodological concerns, we propose an alternative approach to carrying out a systematic review, one that adheres to the core principles of 'full' systematic reviews but allows for greater flexibility and reflexivity in the process' [18].

As shown in Figure 2, their proposed process consists of 8 stages, where stage 5 includes 3 tracks.

For this paper, the following process were followed, and special attention were focus on:

i. Setting the research question (Stage 1): This paper aims to answer the question of, "How to combine appropriate theoretical perspectives into a unique one capable of evaluating and transforming SSA engineering programs".

ii. Writing the protocol, inclusion/exclusion criteria, and search strings (stage 2, 3, and 4, respectively): To expand the knowledge of theoretical perspectives and their suitability to the field of engineering education, the searching covered the following databases: Web of Science, Scopus, Google Scholar, and IEEE Xplore; used the following phrases: Engineering education, engineering education research, learning theories, theoretical perspectives, etc.; and without specific date range, considered many types of documents such as: Journal papers, books, book chapters, reports, etc.

iii. Retrieval (stage 5), which consists of three tracks:

• Track I- search for academic literature: First, the researcher should identify academic databases, a list of journals, any specific websites, and the number of studies to be reviewed [18]. Then, to obtain relevant materials, Track I should follow search strings, identified in stage 4, into academic databases [18-19].

• Track II- snowballing: For snowballing track, Hagen-Zanker and Mallett [18] state, "This process involves actively seeking advice on relevant publications in a particular field or on a particular topic from key experts—which will then be reviewed—and subsequently looking at the reference lists of those publications". Therefore, the paper started with documents produced by experts in the field of engineering education, such as: How People Learn (HPLI and HPLII), Cambridge Handbook, UNESCO [11], RAE [9], etc.

- Track III- grey literature capture: Grey literature may include any high-quality reports, which are not obtained through the standard databases and search engines (e.g. materials from Google Scholar).

Applying the systematic review method, the purpose of this paper is to construct a theoretical framework, by integrating a number of existing theoretical perspectives, in order to better understand the situation of engineering education within the SSA region.

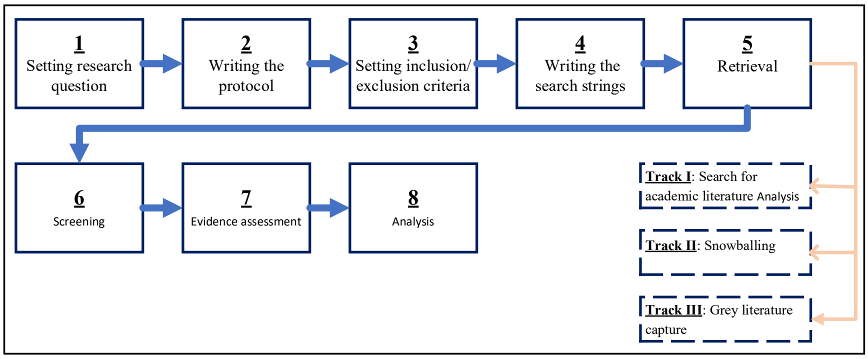

Fig. 2. Stages in a rigorous, evidence focused literature review [18]

3. Literature Review

A systematic literature review was conducted, which revealed that research in the area of engineering education has been increasingly adopting theoretical frameworks. However, a theoretical framework capable of providing the foundation to transform the holistic engineering education field, in SSA countries were constructed, rather than just describing it. This literature review was organized in subsections to discuss: The engineering education, both globally and within SSA; the importance of the theoretical framework; and components of the proposed theoretical framework.

3.1 The Situation of Engineering Education in SSA Countries

It is believed that there is a big shortage of engineering education research, within the context of most of SSA region, and most of related information comes from reports that have been prepared, for diverse intents, by international organization such as World Bank, UNESCO, RAE, etc. [20].

For many decades, persistent issues of engineering education in SSA countries have been the focus of many researchers. For instance, in 1993, the World Bank described the state of engineering education in Sub-Saharan African (SSA) countries as, ‘a sorry state.’ To put this in perspective the report states, ‘… developed countries graduate 166 times more engineers per capita than do the countries of SSA, and the quality of training, already low, is deteriorating as a result of budget constraints’ [21]. On top of that, many research papers proved the situation is worsening rather than getting any better, within the region [11,22-25]. Many researchers have been investigating challenges facing engineering education in Africa, such as: insufficient funding, outdated curricula, ineffective teaching and learning (T&L) methods, inadequate facilities, students under preparedness for college, lack of adequate human capacity, brain drain due to unattractive working environment in SSA, and missing of quality control and accreditation measures. These challenges led to inability of the SSA engineering education programs to graduate enough qualified engineers with the appropriate set of knowledge and skills required by the local and global job market [9, 11, 14, 23, 26-28].

Moreover, the Royal Academy of Engineering (RAE), London, UK has developed a single Engineering Index (EI), which consists of eight different engineering related indicators: 1) Employment in engineering-related industries, 2) human capital investment in engineering, 3) number of engineering businesses, 4) the quality of infrastructure, 5) the gender balance of engineers, 6) the quality of digital infrastructure, 7) wages and salaries of engineers, and 8) exports of engineering-related goods [29]. They stated that, in 2016, about 99 countries were ranked based on the EI; none of SSA countries was included in this ranking either due to data availability or weak indicators' values [29].

3.2. Global Engineering Education Research

The engineering education research (EER) is a relatively new field that started at the beginning of the current century [30], although it began to surface in the United States in the mid-1980s, Jamieson et al. 2009, cited in [30]. Since its inception, EER has been essential for improving the overall education of science, technology, engineering, and mathematics, worldwide. Beddoes [30] linked the emergence of the EER field to rigor and methodology discourses, rather than descriptive engineering education publications.

As well, many researchers have developed frameworks and models in the course of investigating and resolving certain fragmented topics/issues, within the EER field, such as: Curricular design, educators' readiness to support engineering students, innovative T&L methods, 21st century engineering attributes, technological progress, underrepresentation issue, sustainability, etc. Some examples are: Framework for Assessing Teaching Effectiveness (FATE), [31]; Engineering Ecosystem Conceptual Framework for Research and Training in SSA Countries [32]; The Project-Based Learning (PjBL) in Developing non-Technical Skills [33]; Lean Engineering Education Framework [34]; Process Model of 'Problem-Based and Project-Based Learning' in Engineering Education [35]; Cooperative Problem-based Learning (CPBL) [36]; Framework for Disassemble, Assemble, and Analyze (DAA) Activities in Engineering Education [37].

Above-mentioned examples reveal vast and diversified scholars' efforts in discursive field of engineering education; yet many others have noticed that the research community has given a little attention to these topics in connection to the broader engineering education field [30, 38-41].

3.3. The Importance for Theoretical Perspectives

As noted by many scholars [1-4], among others, explicit philosophical and theoretical frameworks are key for achieving good qualitative research. Patton [42] stated, in addition to rigours data gathering and data analysis methods, the importance of a theoretical perspective to ensure the quality and credibility of qualitative research. He wrote, '…enhancing the quality and credibility of qualitative analysis by dealing with three distinctive but related inquiry concerns: rigours techniques and methods for gathering and analysing qualitative data; the credibility, competence, and perceived trustworthiness of the qualitative researcher; and philosophical beliefs or paradigm-based preferences such as objectivity versus subjectivity and generalization versus extrapolations' [42]. Also, Creswell [3] stated that rigorous research needs a sound theoretical framework to guide and shape the research. Therefore, framing any study would force the researcher to analyze the data, interpret and generalize the results according to the proposed theoretical perspective; at the same time, a reader would be informed of the assumptions and approach of the study while, objectively, evaluating the progress and findings of the study.

Engineering education research belongs to the ‘research in social world’; it requires qualitative models to understand and describe it in a comprehensive manner. Furthermore, Flick [43] reports the following features of the qualitative research, ‘The correct choice of appropriate methods and theories; the recognition and analysis of different perspectives; the researchers' reflections on their research as part of the process of knowledge production; and the variety of approaches and methods’.

3.4. Components of Integrated Framework

This paper proposes an integrated framework (IFW) based on the need for a comprehensive evaluation of engineering education field, within the context of SSA countries. The IFW combines the following five theoretical components: 1) Foucault’s Post-structuralism theory (PST), 2) Constructivism theory (CT), 3) Outcome Based Education (OBE), 4) Constructive Alignment (CA), and 5) How People Learn (HPL). The following sub-sections explain each component that contributes to the IFW, including strengths, weaknesses, and limitation of each of them.

3.4.1. Foucault’s Post-structuralism Theory

PST started in France during the late 1960s as a movement against structuralism [44-48]. There are many branches of poststructuralism, and it is hard to defined it; nevertheless, Crick [48] defined PST as, 'Post-structuralism represents a set of attitudes and a style of critique that developed in critical response to the growth and identification of the logic of structural relations that underlie social institutions—whether they exist in terms of politics, economics, education, medicine, literature, or the sciences.'

Rather than a philosophy, Crick [48] considers PST as a methodology to investigate, understand, interpret, and change any established system. He wrote, 'Post-structuralism should therefore not be thought of as a distinct philosophy that exists separately as its own “structure”—a proposition that would undermine its most fundamental attitudes. Rather, post-structuralism should be thought of as developing or arising only in response to pre-existing structures and, as a set of attitudes, helping us better understand, interpret, and alter our social environment by calling established meanings into question, revealing the points of ambiguity and indeterminacy inherent in any system, rejecting the rationalistic piety that all systems are internally coherent and circle around an unchanging center, showing how discourses are carriers of power capable of turning us into subjects, and placing upon us the burden of ethical responsibility that accompanies the acceptance of freedom.' [48].

Crick [48] highlighted thoughts of three poststructuralists as follows: (i) Derrida’s PST thought is a critical deconstruction of any discourse that presents itself as completely coherent, centered, and rational; (ii) Barthes’s PST refuses to locate any single point of origin of any text that can ground its meaning; and (iii) Foucault’s PST invites an inquiry into how discourses, texts, and acts of communication are always implicated in relations of power that act upon possible actions.

May [49] classified PST into two types: The first type concerns with anti-representationalism, which emphasizes the diverse and the practices of ones' experience (Michel Foucault, Gilles Deleuze and Jean-François Lyotard). The second type is the deconstruction, which emphasizes an otherness and exclusion in the language (Jacques Derrida and Emmanuel Levinas).

Williams [47] critically discussed PST through selected works of five poststructuralists: Derrida, Deleuze, Lyotard, Foucault, and Kristeva. He considers them as the most important figures in the area of PST; in addition, each of them took stands on key injustices and conflicts; he stated, 'Derrida has written powerfully against apartheid. Lyotard militated for the Algerian struggles for independence and revolution, as well as the May 1968 student uprisings in his own university. Foucault and Deleuze campaigned for better conditions in prisons. Kristeva is an important figure in contemporary feminism.' [47].

The integrated framework considers Foucault's PST as one of its elements; Michel Foucault was a French philosopher (1926-1984), who considered by many, as one of the prominent post-structuralist. His works have covered various subjects in many areas, such as philosophy, history, science, medicine, and state's apparatus, including correction, justice, administrative, political, and social institutions. Through his earlier work, Foucault employed the concept of Archaeology method for discourse analysis of written and/or spoken texts, without regard of the text's author, to reveal, the at work, relationship between power and knowledge. Archaeology is a form of analysis process that investigate discursive changes over time, without understanding the reasons behind these changes, Foucault 1972, cited in [44] and [50]. Therefore, Foucault shifted his attention to employ genealogy approach, which means exploring how and why things are changing over time, rather than just investigation of the causes of discursive changes, Foucault 1972, cited in [44], [50], and Foucault 1983 cited in [44]. Thereafter, Foucault introduced and developed the concept of biopower, which is a power with a positive effect over people's lives. Regarding power, he wrote, 'it exerts a positive influence on life, that endeavors to administer, optimize, and multiply it, subjecting it to precise controls and comprehensive regulations' [51]; or biopower, coupled with governmentality, controls individuals' life, at different levels, by experts in charge of various institutions like, hospitals, workplaces, prisons, and educational institutions [44, 51-52].

Below, the paper highlights, very briefly, Foucault's PST views on certain concepts such as: Discourse, Discourse Analysis, Truth, and Power. Foucault has promoted and developed both 'Discourse' and 'Discourse Analysis' terms, respectively.

Discourse: Drew [53] defined Discourse as a way of perceiving, framing, and viewing the world; while Georgaca and Avdi [54] wrote, 'In a broad sense, discourses are defined as systems of meaning that are related to the interactional and wider socio-cultural context and operate regardless of the speakers' intentions.' According to Gaventa [46], Discourse can be a site of both power and resistance, with scope to 'evade, subvert or contest strategies of power'; while Foucault [51] sees discourse as a range of discursive elements in various strategies.

Foucault has explored the discourse change over time, which is known as 'discursive change'. One of his anti-dominant discourse examples is the denial of the fact that 'The Sun is the center of the Solar System', which was against the Christianity during the medieval time; back then Christianity used to construct the dominant course, due to Christianity's power over others [55].

Discourse Analysis (DA): DA, as emerged from social theory, has many meanings and interpretation. Nevertheless, DA investigates the operation of power in the construction of meaning, at all levels of society [56]. Georgaca and Avdi [54] wrote, 'Discourse analysis is a social constructionist approach. For social constructionism, reality and identity are systematically constructed and maintained through systems of meaning and through social practices.' DA, which has been used in many research areas, allows researchers to show how people's perceptions are shaped and changed, over time, through the power of text and language [55].

Georgaca and Avdi [54] quoted, 'Discourse analysis is a broad and diverse field, including a variety of approaches to the study of language, which derive from different scientific disciplines and utilize various analytical practices [54, 57].

Truth: Unlike structuralism, PST sees that universal truth does not exist, and the truth at any point in time is dictated by the dominant discourse during that moment [58]. As well, Foucault's views of the Truth, unlike essentialism, is the construction of discourse, which is under constant change, over time [44]. In other words, Truth takes the form of scientific discourse, and the system that produces and sustains the Truth.

Foucault states, 'Truth is a thing of this world: it is produced only by virtue of multiple forms of constraint. And it induces regular effects of power. Each society has its regime of truth, its "general politics" of truth: that is, the types of discourse which it accepts and makes function as true; the mechanisms and instances which enable one to distinguish true and false statements, the means by which each is sanctioned; the techniques and procedures accorded value in the acquisition of truth; the status of those who are charged with saying what counts as true', Foucault cited in [44].

Power: Gaventa [46] considers Foucault is the most influential theorist of power of the 20th century. Rather than just negative and repressive, Foucault stated that power could be positive, as well: 'We must cease once and for all to describe the effects of power in negative terms: it 'excludes', it 'represses', it 'censors', it 'abstracts', it 'masks', it 'conceals'. In fact, power produces; it produces reality; it produces domains of objects and rituals of truth. The individual and the knowledge that may be gained of him belong to this production.' (Discipline and Punish p. 194, cited in Gaventa 2003)

Moreover, power and knowledge are linked together [59], and even knowledge is power, as stated by Foucault. His theories dealt with the competing relationship power and knowledge. As quoted by Rabinow [44], 'Power is also a major source of social discipline and conformity problems that arose was that of the political status of science and the ideological functions it could serve. It wasn't exactly the Lysenko business that dominated everything, but I believe that around that sordid affair- which had long remained buried and carefully hidden- a whole number of interesting questions were provoked. These can all be summed up in two words: power and knowledge.'

3.4.2. Constructivism Theory

Constructivism is a widespread theory, which deals with human constructing their knowledge through experience and learning through active process [60]. With the learner in control, he/she creates and stores mental models [61-64]. These learned models (constructions) vary among learners based on their prior experiences and interpretations of at hand situation [65]. As shown by Figure 3, there are three types of constructivism: cognitive constructivism, which based on Piaget theory of 1953; social constructivism, based on Vygotsky's social learning theory of 1962; and radical constructivism, developed by Glasersfeld [66], based on his interpretation of Piaget's individual constructivism [67-68].

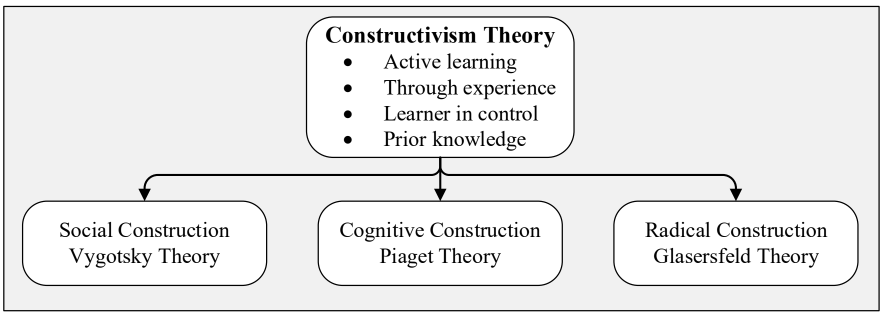

Fig. 3. Types of Constructivism Theory

Constructivism proponents give the following remarks about the ontology, epistemology, and methodology questions:

Ontology Question: Guba and Lincoln [1] state, ‘Ontology: Relativist. Realities are apprehendable in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature (although elements are often shared among many individuals and even across cultures), and dependent for their form and content on the individual persons or groups holding the constructions.’

Epistemology Question: According to Guba and Lincoln [1], as far as constructivism paradigm concern, there is no solid distinction between ontology and epistemology. They added that the epistemology assumes strong link between the investigator and the participants. They state, ‘Epistemology: Transactional and subjectivist. The investigator and the object of investigation are assumed to be interactively linked so that the "findings" are literally created as the investigation proceeds.’

Methodology Question: Guba and Lincoln [1] believe that constructions are obtained, polished, and reconstructed through dialectical exchange among investigator and the object of investigation. They state, ‘Methodology: Hermeneutical and dialectical. The variable and personal (intramental) nature of social constructions suggests that individual constructions can be elicited and refined only through interaction between and among investigator and respondents. These varying constructions are interpreted using conventional hermeneutical techniques, and are compared and contrasted through a dialectical interchange. The final aim is to distil a consensus construction that is more informed and sophisticated than any of the predecessor constructions (including, of course, the etic construction of the investigator)’.

3.4.3. Outcome Based Education (OBE)

OBE has been adopted by many countries, worldwide, to resolve the mismatch between the quality of tertiary education and the required skills and knowledge by the job market. In other words, academic institutions have been using OBE to improve the quality of their graduates in terms of knowledge-based competences and necessary soft skills.

OBE is considered as student-centered learning philosophy measured by ‘outcomes’ [69]. However, other scholars claim that OBE could utilize various didactic methods such as PBL and lecture-centered [70]. Although OBE has drawn many critics, and there have been cases of failure, while implementing OBE, still there are a lot of engineering educators and researchers embracing OBE. Engineering programs have been utilizing OBE framework either to improve learning [71] or to meet accreditation requirements [69].

Many researchers consider William Spady is the father of the OBE. He defined it as, ‘clearly focusing and organizing everything in the education system around what is essential for all students to be able to do successfully at the end of their learning experiences. This means starting with a clear picture of what is important for students to be able to do, then organizing the curriculum, instruction, and assessment to make sure that learning ultimately happens’[72]. He added the OBE system needs, ‘1) Developing a clear set of learning outcomes around which all of the system's components can he focused. 2) Establishing the conditions and opportunities within the system that enable and encourage all students to achieve those essential outcomes’ [72].

Spady [72] believed that the purpose of school is to prepare learners for their role in life after school years. This purpose is well serviced following what is known as transformational OBE rather than traditional OBE. He states, ‘While more traditional forms of genuine OBE clearly showed merit by increasing the numbers of students who were learning more than ever before in higher-challenge programs, what they were learning was mainly preparing them for yet more education rather than preparing them for the complex life roles they ultimately would occupy as young adults' [73].

Engineering educators and researchers are advocating OBE since it allows engineering students to graduate with necessary skills and knowledge for the job markets. However, Morcke, Dornan, and Eika [74] identified two gaps in OBE: OBE limitation due to its root in behaviorism and the missing link between learning outcomes and teaching/learning activities.

3.4.4. Constructive Alignment (CA)

To overcome these two limitations, researchers may use Biggs' CA framework, which align both learning activities and assessment processes with predefined learning outcomes [75]. CA was first introduced by Tyler in 1949 [76-77]. Tyler [78] wrote his book, 'Basic Principles of Curriculum and Instruction' in which he included his fundamental four questions: i. What educational purposes should the school seek to attain? ii. What educational experiences can be provided that are likely to attain these purposes? iii. How can these educational experiences be effectively organized? iv. How can we determine whether these purposes are being attained? In addition, he represented procedures on how to answer these questions, known as Tyler's Curriculum Model [78].

Biggs [71] stated that Constructive Alignment (CA) has two elements: First, 'Constructive' element, which refers to students 'construct meaning' by using relevant learning activities, while teachers act as learning facilitators. The other element is 'Alignment', which refers to the teacher's roles of designing learning environments suitable for achieving intended learning outcomes. Furthermore, Biggs specified the following orders of setting up an aligned system: i. Defining the desired learning outcomes (DLOs). ii. Choosing teaching/learning activities likely to lead to the DLOs. iii. Assessing student' actual learning outcomes to see how well they match what was intended. iv. Arriving at the final grade.

3.4.5. How People Learn (HPL) framework

How People Learn (HPL) is a report, which was published in April 1999. The report was a product of 2-year research on the 'Science of Learning'. Two committees carried out the research: The Commission on Behavioral and Social Sciences and Education of the National Research Council [79].

Although the new science of learning appreciates knowing facts, however it emphasizes learning with understanding. This requires a curricular that encourage students' deep understanding and not only memory of disconnected facts. Deep understanding helps students to become knowledgeable in their domain and capable of transferring to new contexts.

Learning with understanding leads to the second characteristics of the new science of learning, which emphasizes the process of knowing. While pursuing formal education, learners are equipped with pre-existing knowledge, which has great effect on achieving their learning outcomes. This point of view is in line with others' views of learning that people build new knowledge and/or understanding on their current knowledge and beliefs [810-82].

In addition, learning with understanding drives the third characteristics of the new science of learning, which stresses the importance of active learning. In active learning, people take control of their learning process, from recognition of their pre-existing knowledge, to setting the level of new understanding, and assessing their understanding. Active learning activities are considered as part of metacognition. According to Brown [83] and Flavell [84], metacognition means people's abilities to predict and monitor their progress on various tasks. HPL reports, 'Overall, the new science of learning is beginning to provide knowledge to improve significantly people's abilities to become active learners who seek to understand complex subject matter and are better prepared to transfer what they have learned to new problems and settings.' HPL added, 'The emerging science of learning underscores the importance of rethinking what is taught, how it is taught, and how learning is assessed. These ideas are developed throughout this volume.'

HPL framework highlighted the following three core learning principles: i) Students come to the classroom with preconceptions about how the world works. ii) To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. iii) A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. According to HPL, these learning principles have a significant effect on teaching and teacher preparation [79]. Bransford [85] states, 'Evidence from research indicates that when these three principles are incorporated into teaching, student achievement improves'. Moreover: HPL states: 'i) Teachers must draw out and work with the preexisting understandings that their students bring with them. ii) Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge. iii) The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas' [79].

Following the discussion of the core learning principles in light of educational goals for the 21st century, HPL discussed four perspectives on the design of learning environments, namely: Learner-centered, knowledge-centered, assessment-centered, and community-centered environments. As depicted by Figure 4, these perspectives are interrelated; Bransford and Stein stated that the above-mentioned characteristics of learning environments need to be conceptualized as a system of interconnected four components [86].

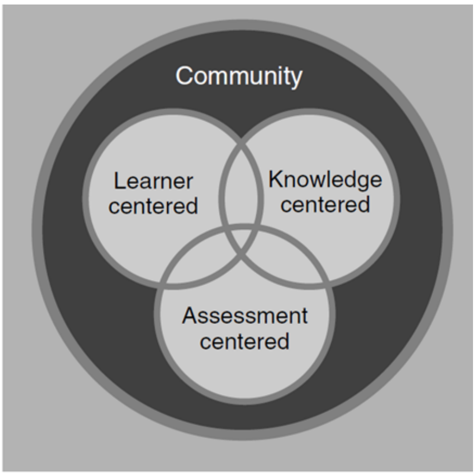

Fig. 4. Perspectives on Learning Environments [86]

4. Construction of Theoretical Framework

The integrated framework (IFW) is developed based on the need for a proper framework for comprehensive evaluation of SSA engineering education field. The following two subsections discuss the development of the IFW (section 4.1) and its potential contribution toward engineering education research within the context of SSA countries (section 4.2). But first, the discussion covers: the contribution of both Constructivism and PST, as standalone theories, in the engineering education research; and the rationale behind them become the main members of the IFW.

4.1. Integrated Theoretical Framework

The framework is mainly comprised from the integration of two theories, namely: Constructivism theory and PST. The former theory serves as a philosophical worldview, known as epistemology and ontology [87]; while PST is utilized as a methodology rather than a philosophy, as suggested by Crick [48]. Both of these theories complement each other. Nevertheless, both see that universal truth does not exist, but it is a construction of discourse, which is under constant change [48]. As well, both suggest strong link between the investigator and the participants to construct knowledge. Moreover, PST should question the pre-existing structures, as a set of attitudes, helping investigators to better understand, interpret, and alter any social environment [48]; while constructivism theory deals with construction of new knowledge, based on existing experience and interpretation of a given situation; subsequently, constructed knowledge is refined through a dialectical interchange between and among the investigator and the participants [1]. In short, the IFW is comprised of two sites, with dual functions: Constructivism and PST sites.

4.1.1. Constructivism site

The function of the constructivism site is to ensure validity and reliability of-, and to provide epistemological consistency to- the qualitative research. Constructivism is linked with qualitative research since its views of concepts of validity and reliability are completely different from positivists' views, due to their opposing epistemology. Positivists use these concepts in quantitative social science, while constructivism epistemology is based on their assumption regarding the reality, which has been discussed by many constructivists. Among them are Stake and Merriam: the former [88] states, 'In our search for both accuracy and alternative explanations, we need discipline, we need protocols which do not depend on mere intuition and good intention to 'get it right.'; and the latter [89] wrote, 'One of the assumptions underlying qualitative research is that reality is holistic, multidimensional, and ever changing; it is not a single, fixed, objective phenomenon waiting to be discovered, observed, and measured as in quantitative research.' [90].

As far as engineering education research is concerned, constructivism theory has been utilized globally for studying, for instance: Curriculum development of Nursing and medical field [77, 91]; single courses in the area of engineering education [92-93]; adult teaching and teacher preparation [94]; online teaching [95]; math and science for elementary and secondary education [96-98, just to name a few.

In addition, the integrated framework incorporates three constructive models: outcome-based education (OBE), constructive alignment (CA), and how people learn (HPL). Their role is to specifically tie the IFW to the engineering education as a social practice. Literature reveals enormous studies based on either OBE or HPL. For instance, [99-101], among many other researchers, have conducted studies on the influence of HPL learning principles in pedagogy and teaching for adaptive expertise. In addition, many studies on engineering education, in African context, have been guided by OBE as a constructive framework [102-104].

Figure 5 shows the relationship between the constructivism theory from one side and the HPL, OBE, and CA from the other side. Solid blue line arrows represent a strong connection between constructivism and the HPL/CA, while the broken blue line arrow shows a weak relationship between constructivism and the OBE. As well, the same figure shows the commonalities among constructivism, HPL, OBE, and CA, which they are: Active learning- learner in control (metacognitive skills) and educator act as a facilitator; learner constructs and stores models (cognitive) based on learner's prior knowledge; in depth knowledge (deep understanding); and student-centered learning philosophy. Moreover, CA framework aligns learning activities and assessment to achieve learning outcomes, in the following order: first, determine the desired learning outcomes (DLOs); then design assessment instruments to ensure achieving DLOs; and finally, establish the T&L activities likely to meet the assessment criteria and lead to the DLOs [71].

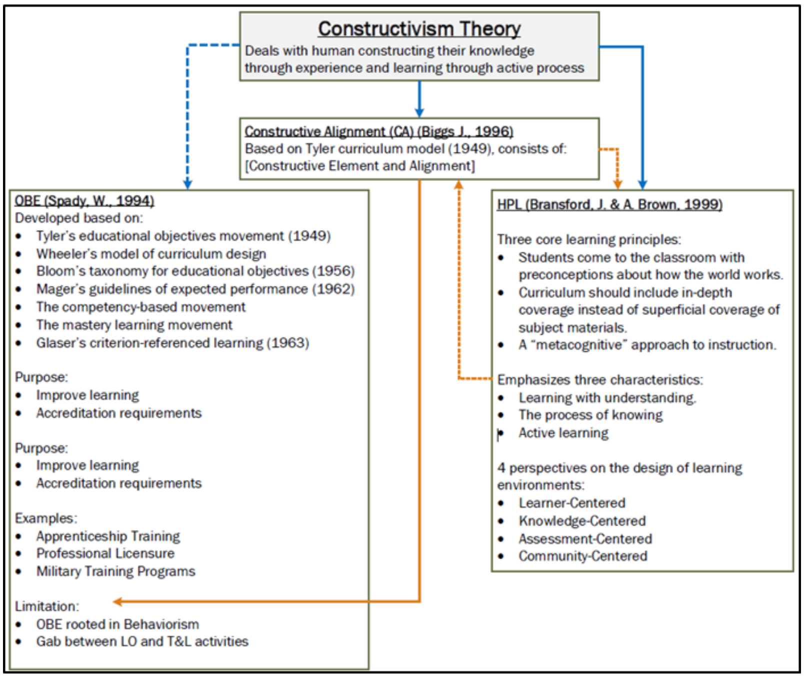

Fig. 5. Relationships among Constructivism, OBE, CA, and HPL

4.1.2. Post-structuralism site

PST is a theory of language, discourses, and knowledge, and it is concerned with people's perspectives, values, beliefs, assumptions, and experiences are socially constructed [105]. It can allow researchers to investigate element of engineering education (e.g. curriculum and pedagogical practices) within the social, political, cultural, and historical contexts. Niesche [106] wrote, 'Poststructuralism has been extensively explored across philosophy, cultural studies, politics, and numerous other fields. It has also received significant attention in education, particularly in relation to education policy…' Moreover, PST allows, among other things, an investigation into relations between the individual and the social in specific sites, and it realizes the complexity of the academic institution with a set of social practices [107].

In addition to providing epistemological consistency and epistemological diversity to the qualitative research, the PST is incorporated into the IFW because of its ability to analyze engineering education field, as social practices, which is influenced by many other social, economic, and political factors. This is confirmed by Brennan (2010), who wrote, 'Starting from a similar proposition to that adopted by Burton Clark [108], that is higher education should be examined within a wider context of social science research, …' (Brennan 2010, 234). According to Clark's model, the broader T&L environment is part of an academic system, which consists of three levels: i) Discipline-centered, such as engineering program; ii) the enterprise, academic institution; and iii) the organization and interinstitutional links [108]. Therefore, introducing PST into the IFW enables it to investigate the power structures within the broader engineering education field, which includes engineering education stakeholders, academic institutions, educational policies, and operational activities.

‘Stakeholder Power Analysis’, which is about the power, its origin, and who has it. According to 'Power to influence policies or institutions stems from the control of decisions with positive or negative effects. Stakeholder power can be understood as the extent to which stakeholders are able to persuade or coerce others into making decisions and following certain courses of action. Power may derive from the nature of a stakeholder's organisation, or their position in relation to other stakeholders (for example, line ministries which control budgets and other departments). Other forms of power may be more informal (for example, personal connections to ruling politicians).'

Discourse analysis of engineering stakeholders highlighted how power operates and represents the interconnection operation of a complex network of power. This network of power, among all stakeholders (Governmental Agencies, Academic Institutions, Engineering Educators, Engineering Students, T&L Environment, National Agencies, and International Agencies) has its impact on each one of them, individually and collectively. In other words, each stakeholders manifest and exercise power (rights and privilege) over the rest of the stakeholders within the discursive engineering education field; while the same stakeholder bear certain responsibilities and accountabilities, since it is subject to the others’ power.

4.1.3. The developed IFW

As depicted by Figure 6, the IFM mainly represents integration of two theories PST and Constructivism; the two solid dark blue arrows represent their share into the IFW. However, there is a strong relationship between them that is shown using a solid black arrow. Both of them ensure epistemological consistency and epistemological diversity across various aspects of qualitative research design [109,110].

Yet, Constructivism’s role comes into play, as the basis to design and/or evaluate the T&L environment, through three individual constructivism models, HPL, OBE, and CA; as shown in Figure 6, each model’s share into the IFW is represented by a light blue arrow. These 3 models are based on the constructivist approach; still each one has its own role. For instance: Principles of OBE/CA can be used to evaluate elements of T&L environment. Spady’s OBE, outcome-based education, and Biggs’ CA, Constructive alignment, require the outcomes of a course (CLO) to be aligned with assessment tasks (AT) and teaching and learning activities (TLA).

While, the HPL model could be utilized to evaluate T&L environment through its four overlapping lenses (Figure 4): Knowledge centered (how the knowledge is actually being used), learner centered (how knowledge is produced based on the students’ background and prior knowledge), assessment centered (including summative and formative assessment), and community centered (encouraging and guiding students to learn in a team) [54].

At the same time, PST comes into the new framework, as a methodology, to enable researchers to investigate, understand, interpret, and change the engineering education discursive field. In addition, Foucault’s PST, including his concepts of truth, power, discourse, and discourse analysis, allows the researcher to: Highlight the pre-existing power relationship among stakeholders, within the engineering education field; realize stakeholders’ rights and responsibilities; and align the academic system with objectives as stated by the relevant governmental agencies.

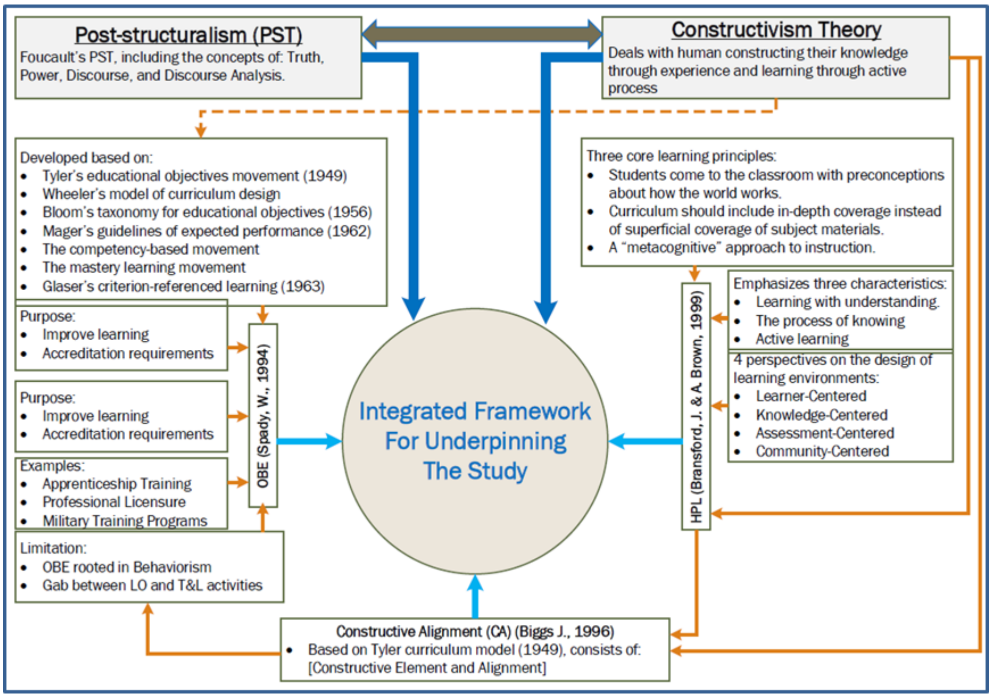

Fig. 6. Theoretical perspectives framework

4.2. *IFW Contribution toward EER within SSA Countries*

According to many, of them are [111-114], engineering education has been experiencing a paradigm shift due to globalization, the 4th Industrial Revolution (4IR), and advancement in engineering education research. For instance, Kumar, Ochieng, and Onyango [26] wrote, 'The practice of engineering is no longer restricted to a particular country, region, or continent. It is becoming increasingly international and, to some extent, multicultural.' Moreover, the world is living the 4IR which is characterized by what is known as Cyber-Physical Systems (CPS); 4IR has become possible due to Internet of Things (IoT), Internet of Services (IoS), and emergent technologies such as nanotechnology, biotechnology, quantum computing, artificial intelligent, etc. The term itself was coined, in 2015, by Schwab [115], who is the founder and executive chairman of the World Economic Forum (WEF). The disruptive nature of the 4IR has not only influence, but also revolutionized all aspects of people's life around the globe. Yet, the technological innovation and the disruption of the 4IR has presented a wide range of opportunities in every walk of life, including education sector [112-113, 115-116]. Accordingly, transformation of engineering education, as part of education sector, is a must for all nations to equip their population with required skills for the 4IR. Uleanya [111] wrote, 'The role of education to ensure that countries and their citizens are well-prepared for the Fourth Industrial Revolution (4IR) can never be overemphasized. This is evident in the works and submissions of the OECD Education and Skills Today (2019) and World Economic Forum (WEF) (2016a), among others.'

Within developed countries, where the 4IR has been occurring, components of 4IR, such as CPS, IoT and IoS, have enabled transformation of engineering education in those countries. However, developing countries, including most of SSA countries, have lagged behind as far as engineering education research is concerned. Uleanya and Yu [117] state, 'Nonetheless, preparation for the 4IR still remains a challenge in the African continent. However, some of them, for example: South Africa [111,118,119] and Botswana [111], have already started preparing for the 4IR by utilizing its technologies to enhance the higher education systems, including engineering education. This is because South Africa and Botswana (among others such as Mauritius, Namibia, Cape Verde, Kenya, and Seychelles) are considered relatively developed with respect to the other SSA countries. Moreover, in the 2019 report of the WEF, these seven countries were considered among the 'Top 10 African Countries with the best Education Systems'.

The dilemma of the rest of SSA countries, on one hand they have to start preparing for the 4IR, and on the other hand their engineering education programs have been plagued with many issues. as above-discussed in section 3.1, many researchers have been investigating challenges facing engineering education in Africa, such as: insufficient funding, outdated curricula, inappropriate facilities, lack of adequate human capacity, brain drain due to absence of academic freedom, as well as unattractive working environment in SSA, and missing of quality control and accreditation measures. These issues have been the main cause for inability of SSA engineering programs to prepare for the 4IR.

However, the paper identified the research gap in the area of engineering education and calls for additional research efforts utilizing proper framework. Yet, the starting point should be comprehensive evaluation of the holistic engineering education programs within these countries. Furthermore, the paper has suggested the new IFW, which has been tested and it is before the researchers who are concerned with the SSA engineering education research.

The suitability and applicability of the IFW were tested while conducting a case study, titled 'Evaluation of Engineering Education in Sudan'. The study has offered a comprehensive understanding of the overall engineering education programs in Sudan and proposed a path to transform these programs; however, findings of the study are beyond the scope of this paper. It is believed that the IFW is ready to be use in similar studies.

5. Discussion

In response to the vast engineering education challenges facing SSA countries, interested researchers should utilize a suitable theoretical perspective to better understand the overall engineering education situation, identify areas for improvement, and propose new strategies for revamping the situation of the engineering education and engineering profession, which are key for the region development at both economic and social levels. Therefore, a decision to construct a theoretical framework, capable of investigating and transforming the SSA engineering education programs, was proposed.

To develop the proposed theoretical framework, this study considered the systematic review method, which is beneficial in the field of engineering education, and it can lead to synthesize prior work, better inform practice, and identify new directions for research.

The IFW combines PST, which includes Foucault's concepts of discourse, discourse analysis, truth, and power; and constructivism theory, along with HPL, OBE, and CA models. Coupling PST and constructivism theory allows investigators to understand and transform social environment [48]. The role of PST is to evaluate and transform the engineering education field, in SSA countries, rather than just describing it, by questioning the pre-existing structures of this discursive field. While the constructivism role is to evaluate the T&L environment and identify the gap between engineering education practices and the elements of the T&L environment, namely curriculum, educators, and T&L methods. Moreover, well-design qualitative research requires epistemological consistency [110] and epistemological diversity [109]. Both of constructivism and PST ensure epistemological consistency and epistemological diversity across various aspects of qualitative research design.

As complex as it looks, the IFW is very simple and flexible framework. Basically, it consists of two parts with dual functions, the constructivism part and PST part. Both parts could be utilized, in tandem, for the purpose of a holistic evaluation of any SSA engineering education system, which operates in unique and complex social, economic, and political conditions. The role of the constructivism part is to investigate and understand the T&L environment, while the PST part is concern with deconstruction of the pre-existing structure of the broader engineering education field, which includes engineering education stakeholders, academic institutions, educational policies, and operational activities. Nevertheless, these two parts could be utilized separately, in parallel or sequentially, for achieving similar research objectives.

6. Conclusion

The literature (section 3.2) shows that many researchers have studied elements of engineering education in SSA countries utilizing diverse generic frameworks. Others proposed specific frameworks to help guide specific studies in the area of engineering education research. However, none has provided a comprehensive evaluation and understanding of the situation of engineering programs within the SSA context due to the lack of a proper theoretical frameworks that consider the pre-existing structure of the social practices, including the SSA politics, economic, education, etc.

Throughout this article, it has been demonstrated that constructivism and PST are aligned on many ontological and epistemological fronts. Together represents a simple and innovative IFW for the study of engineering education system. Constructivism tie to the social practices paired with PST adherence against the structural relations that underlie social institutions (within politics, economics, education, etc.) and power relationships, among them, to extend the possibility toward transforming SSA engineering education systems.

In conclusion the paper developed the IFW, which is capable of providing the foundation to transform the holistic engineering education field, in SSA countries, into programs that are more focused on knowledge, technologies, and competence to meet the challenges of the 21st century.

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