Petroleum Technology Development Journal

Process Safety Education Framework: Lessons Learned from Safety and Chemical Engineering Education (SAChE) Faculty Workshops

By

Ebenezer O. Ojo* and Lawrence C. Edomwonyi-Otu**

ABSTRACT

Safety and Chemical Engineering Education (SAChE) program was initiated in 1992 under the auspices of the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) and engineering schools (http://www.sache.org). Historically, significant progress made over the last two decades include newsletter publication, dedicated website hosting different learning materials, faculty workshops and student safety certificate programmes. This paper is aimed at developing an implementable framework for upskilling engineering graduates in process safety using SAChE workshop as a case study. The developed educational safety framework referred to as Cognitive-Experiential (CogEx) is based on combined cognitive and experiential learning pedagogies adapted to process safety education. For an emerging economy, CogEx implies initiating industry-university collaboration with a focus on process safety education. This further extends to different activities such as faculty workshops and training, curriculum development for process safety modules, industry experts' participation in teaching and assessments, and the development of educational materials based on current industry practices. In general, the CogEx framework developed provides a structure for skills transferability and programme implementation outside the USA, where SAChE is domiciled. Learning context such as this becomes necessary for enabling robust safety skills and culture exchange. It also proactively mitigates the shortage in process safety expertise for future expansion of the emerging natural gas industry and the established petroleum industry.

Keywords: SAChE, Cognitive, Experiential, Curriculum, Pedagogies

1. INTRODUCTION

The growth of process industries is often characterised by safety related issues due to accidents associated with hazardous physical and chemical activities. Recently, several industry accidents leading to fatalities have been reviewed and reported[1,2]. In most cases of high fatalities and property destruction, accidents investigation teams are commissioned to determine the root causes and in collaboration with other professional organisations outline possible lessons learnt and mitigation strategies to prevent future occurrences. Recommendations based on the outcomes are forwarded to appropriate government agencies responsible for safety legislations and enforcement.

In many developed countries of the world, there are established organisations whose responsibilities include advising, managing and enforcement of the relevant laws to prevent unsafe practices and operations in the workplace. For instance, in the United Kingdom, the

---

* Biochemical Engineering Department, University College London, UK; WC1H 0AH

** Chemical Engineering Department, University College London, UK. WC1E 7JE

[1] Moura R., Beer M., Lewis P., Lewis J. (2015). Human error analysis: Review of past accidents and implications for improving the robustness of system design, Safety and Reliability: Methodology and Applications. Taylor & Francis Group, London.

[2] Taylor R.H., van Wijk L.G., May J.H.M., Carhart N.J. (2014). A study of the precursors leading to "organisational" accidents in complex industry settings. Process Saf. Environ. Prot. 93, 50–67.

Health and Safety Executive (HSE) oversees workplace ill health and injury prevention (www.hse.gov.uk[3]). All safety related issues in the country are reported to the HSE. Notable is the education and training roles of organisations such as; the Institution of Chemical Engineering (IChemE, www.icheme.org), National Examination Board in Occupational Safety and Health (NEBOSH, www.nebosh.org.uk), and other private industry based safety institutes within the UK.

IChemE presently oversees the safety education across universities in the UK particularly those offering Chemical, and Process Engineering related degrees. The recent acceptance of a multidisciplinary approach embraced by some engineering faculties in the UK hopes to foster process safety education and teaching with a more holistic view of other engineering fields. Within Europe, organisations such as European Agency for Safety and Health at Work (https://osha.europa.eu/en[4]) have been instituted, and similar group exists in other continents and countries such as Asia, Australia and South America. Of particular interest in this paper are Canada and the United States of America (USA). Currently, the Chemical Institute of Canada (CIC) serves as the umbrella organisation for Canadian Society for Chemistry (CSC), Canadian Society for Chemical Engineering (CSChE) and the Canadian Society for Chemical Technology (CSCT). CIC works in close collaboration with the Canadian Engineering Accreditation Board (CEAB) which evaluates undergraduate engineering programs in Canada[5]. It implies that students who go on to become professional engineers (P. Eng) by direct transfer are considered to have achieved the adequate level of process safety knowledge (http://www.engineerscanada.ca[6]).

Process safety education is presently gaining global attention and increasing advocacy for proper inclusions of process safety modules into the curriculum for chemical engineering and other closely related engineering and science courses. On the contrary, most professional safety engineers gained their expertise from further training after university education. Few schools have attempted introducing courses such as Industry Safety and Loss Management, Process Safety Management, and other related titles (http://www.esrmp.ualberta.ca[7]). Under the United States Department of Labor, Occupational Safety and Health Administration, (OSHA), has been instituted to oversee all workplace-related safety issues (https://www.osha.gov/index.html).

Also, Chemical Safety Board (CSB) has been commissioned as an independent federal agency charged with the responsibility of investigating industry chemical accidents (www.csb.gov/about-the-csb[8]). These government instituted bodies are responsible for the enforcement of process safety laws, accident investigations and mitigations. To ensure efficient delivery of their various tasks, professional organisations such as the American Institute of Chemical Engineering (AIChE), American Society of Safety Engineers (ASSE),

[3] www.hse.gov.uk

[4] https://osha.europa.eu/en

[5] Amyotte P.R. (2013). Process Safety Educational Determinants. AIChE J. 32, 126–130.

[6] http://www.engineerscanada.ca

[7] http://www.esrmp.ualberta.ca

[8] www.csb.gov/about-the-csb

American Chemical Society (ACS), and others have provided support in the areas of information dissemination and training[9].

AIChE plays key roles in chemical process safety education amongst several other responsibilities. Within the AIChE, specialised groups such as Center for Chemical Process Safety (CCPS) and Chemical Engineering Education (SAChE) were formed to propagate further and implement the chemical process safety education programmes (**Figure. 1**). This paper focuses on process safety education framework developed based on lessons learnt during the SAChE workshop series with particular attention to the 2103/2014 sessions held in collaboration with Chevron Refinery in Richmond, California. Subsequent sections highlight the history of SAChE workshops and other activities[9,10].

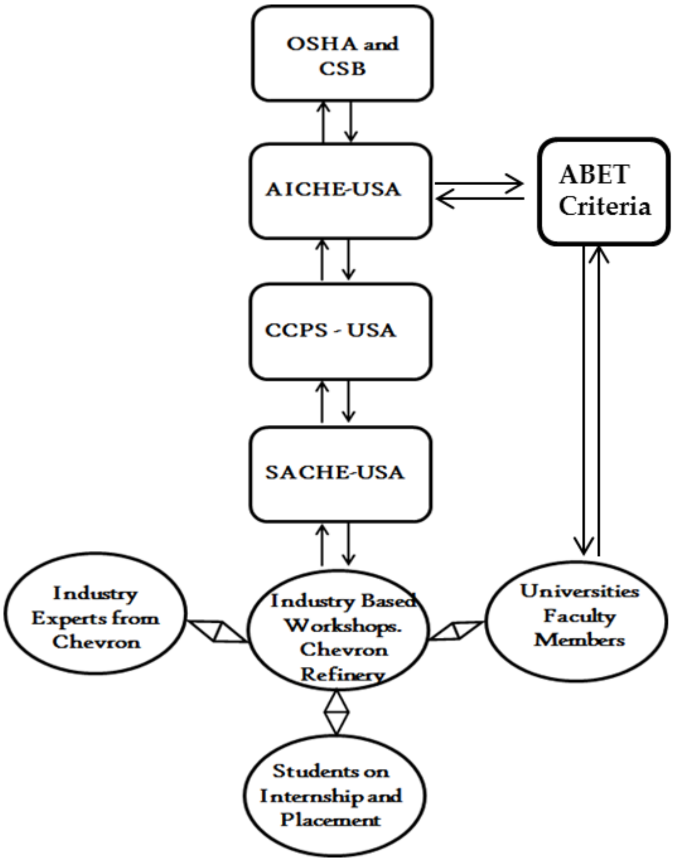

Figure 1: The organogram describes information flows between the different safety advocacy groups and elements of SAChE workshops. Chevron Refinery indicates the host for the last two workshops. Chevron Refinery, Richmond, California, USA.

2. HISTORY OF SACHE FACULTY WORKSHOPS

To ensure well trained chemical engineers with adequate process safety knowledge, the Center for Chemical and Process Safety was formed under the leadership of AIChE in 1992 with a dedicated website (http://www.sache.org). According to the policy document released by a

[9] Spicer T.O., Willey R.J., Crowl D.A., Smades W. (2013). The Safety and Chemical Engineering Education Committee — Broadening the Reach of Chemical Engineering Process Safety Education. Process Saf. Prog. 32, 113–118.

[10] Willey R.J., 1999. SACHE Case Histories and Training Modules. Process Saf. Prog. 18, 195–200.

representation of the Global Process Safety Academia[11], "There is a strong need for research on the pedagogy of process safety and the integration of knowledge for both undergraduate engineering students and workers in the industry. Problem-based learning is important in this regard, and various process safety knowledge tools are available (e.g., CCPS, SAChE and AIChE)". The inclusion of process safety education was recently mandated by ABET for undergraduate instruction and attention in research laboratories[12].

However, with the lack of educational resources in academic materials in process safety, the SAChE Committee was formed to strengthen process safety education further through development and distribution of educational materials to universities. These cover areas such as risk assessment, electrical safety, fires and explosions, and other safety topics. Over the years, its activities have expanded into university – industry partnership and workshop training. According to[9] Spicer et al. (2013), other activities of SAChE include publication of semi-annual newsletters, management of dedicated website and SAChE student safety certificate program currently hosted by AIChE e-learning systems. The faculty workshops are also organised by SAChE in conjunction with supporting industry partners. To date, fifteen faculty workshops have been organised at various industry sites. The updated list of all the workshops is as shown in **Table 1.** The last two workshops were held at the Chevron Refinery, Richmond, California with continued support to host a 2015 edition. **Figure 2** shows 2014 attendees photograph. This paper focuses on the last two workshops held at Chevron Refinery, Richmond, California with lessons applied to develop a process safety education framework based on the proposed CogEx learning model.

3. PROCESS SAFETY EDUCATION (PSE) FRAMEWORK

With increasing efforts for wider acceptance of process safety education inclusion in undergraduate and postgraduate curriculum, the faculty workshop organised by SAChE enables information sharing between academics and industry experts who apply the process safety management principles daily. Participation at the faculty workshop has led to the development of learning pedagogy referred to as combined Cognitive-Experiential learning model (CogEx). CogEx learning model was developed to help define an educational framework for improving chemical process safety teaching at undergraduate and postgraduate degree level. The philosophy of cognitive and experiential learning has been individually reviewed and commented on[13,14]. The implications of cognitive, experiential and CogEx learning for process safety education are subsequently discussed.

Table 1. Updated dates and locations of previous SAChE Faculty Workshops. Data obtained from[9] Spicer et al. (2013). Some companies who have supported are, Dow Foundation, Dow Corning, DuPont, BASF, Rohm and Haas, Union Carbide, Chilworth Technologies, Arkema, US CSB, SAChE, Sunoco, Arkema, CCPS, DOW, BASF, SABIC, DOW CORNING, IoMosaic. Further information is available on *http://sache.org/workshops.asp*.

[11] Mannan M.S., 2011. Process Safety Research Agenda for 21st Century. Mary Kay O'Connor, Center for Process Safety, Texas.

[12] Mannan M.S. and Mary Kay O'Connor (2012). Process Safety Center. Centerline 16, 1–18.

[13] Gavetti G. and Levinthal D. (2000). Looking Forward and Looking Backward: Cognitive and Experiential Search. Adm. Sci. Q. 45, 113–137.

[14] Kolb D.A. (2014). Experiential Learning: Experience as the Source of Learning and Development, 2nd Edition. Pearson Education, Inc., New Jersey.

Date	Location
April 24–26, 1995	BASF, Wyandotte, MI
May 19–21, 1997	BASF, Wyandotte, MI
May 17–20, 1998	The Dow Chemical Company, Texas Operations, Freeport, TX and Anderson, Greenwood and Company
May 16–19, 1999	The Dow Chemical Company, Texas Operations, Freeport, TX and Anderson, Greenwood and Company
September 17–20, 2000	BASF, Wyandotte, MI
April 21–24, 2002	BASF, Wyandotte, MI
September 28 to October 1, 2003	ExxonMobil, Baton Rouge, LA
September 18–21 2005	Rohm & Haas Company, Croydon, PA, & Sunoco Chemicals, Philadelphia, PA
September 14–17, 2008	Rohm & Haas Company, Croydon, PA
August 15–18, 2010	ExxonMobil, Baytown, TX
August 18 – 21, 2013	Chevron Energy Technology Company, Richmond, California
August 17-20, 2014	Chevron Energy Technology Company, Richmond, California
August 9-12, 2015	Chevron Energy Technology Company, Richmond, California

BASF = Badische Anilin- und Soda-Fabrik, MI=Michigan, TX=Texas, LA=Los Angeles, PA=Pennsylvania

Figure. 2: A cross-section of SAChE faculty workshop held at Chevron Refinery, Richmond, California in August 2014. The picture is hosted on SAChE webpage. http://sache.org/workshop/2014Faculty/images/full/DSC_2718.jpg Accessed last on 31-03-2015.

3.1 Cognitive Learning and PSE

Within the cognitive learning domain, information processing in terms of knowledge acquisition, organisation, refining and information build-up forms part of mental functions of the brain. According to[15,16] mental functions were divided into conscious and unconscious

---

[15] Wang Y. and Chiew V. (2010). On the cognitive process of human problem-solving. Cogn. Syst. Res. 11, 81–92.

[16] Thornton M.P. and Mosher G.A. (2014). Quantifying Cognitive Processes in Virtual Learning Simulations, in ASEE North Midwest Section Conference. ASEE, Iowa, pp. 1–6.

processes. These were further sub-divided into six layers of cognitive processes namely; sensation, memory, perception, action, meta-cognitive functions and higher cognitive functions as shown in Figure 3. The conscious, intelligent domain consists of the meta- and higher cognitive processes which expand with information increase based on set goals and motivation. These are further sub-divided into elemental cognitive processes that include attention, memorisation, knowledge representation, abstraction, recognition, synthesis, decision-making, reasoning, quantification, problem-solving and others as shown in Figure. 3[16].

Very often, a process safety engineer will be expected to maintain a real conscious awareness of his immediate environment and processes in operation. This responsibility is coupled with attention to operational details, prompt recognition of differences in set-points and offsets, and the ability to synthesise related information mentally to arrive at timely positive decisions.

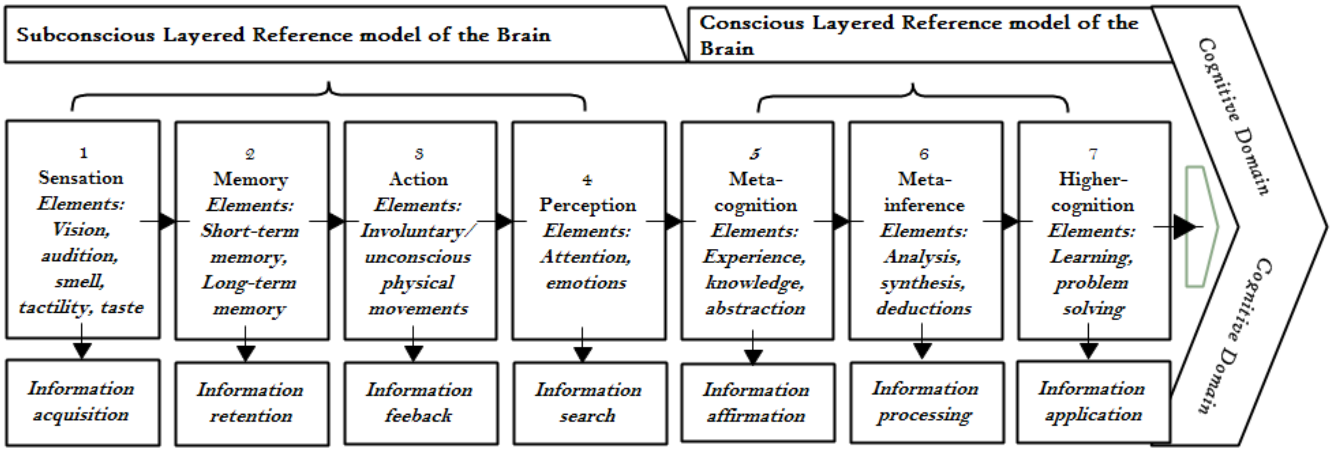

Figure 3: A modified cognitive functions as described in the layered reference model of the brain[15].

For most engineering and science students, especially those studying chemical or process and oil & gas related engineering degree courses, the cognitive ability is better developed and trained during their undergraduate and postgraduate studies. There is a need for a systematic review of the curriculum and incorporation of courses which allow simultaneous acquisition of the basic process safety knowledge in line with basics of process designs and unit operations. Progression to higher levels of studies further exposes the students to several industry case studies that further develop their higher cognitive senses for problem-solving and processing complex information as highlighted in Figure 3. All these do not; however, replace the need for experiential learning. The case studies are expected to provide a theoretical context that the students can visualise and sometimes see in the video or simulated series of the event leading to various accidents from which lessons are drawn.

3.2 Concepts of Experiential Learning and PSE

In recent years, safety lessons learnt from various accidents have subsequently influenced the process safety education. According to[14]**,** 'people do learn from their experiences', and it remains a statement of fact. Experiential learning is defined as a form of learning from life experiences in an environment which bring the learner in direct touch with the realities being studied. Before the experience can be valid for lessons, there must be an inferential learning process. The process voids absolute dependence on emotions by questioning the acceptance of direct experience and allows objective critical reflections[14].

3.2.1 Experiential Learning Philosophies

According to[14], excerpts from few philosophers based on different school of thoughts considered relevant to the process safety education are highlighted below:

> *I take it that the fundamental unit of the newer philosophy is found in the idea that there is an intimate and necessary relation between the process of experience and education*[17].
>
> *Learning is experiential when the learner is directly in touch with the realities being studied. It involves the direct encounter with the phenomenon being studied rather than merely thinking about the encounter or only considering the possibility of doing something with it*[18].
>
> *Experiential learning approach offers the basis for a lifelong learning process based on intellectual traditions of social psychology, philosophy and cognitive psychology. It operates as a framework for identification of critical linkages between education, work and personal development* [14].

On the three traditions of experiential learning,[19] further emphasises on the dialectics of learning from experience and the epistemology, showing the relationship between knowledge and learning[19]. Piaget theories provide guidelines for the application of experiential learning theory and are further explained under the following education based activities. Competence-based education offers the theory of learning most appropriate for the assessment of prior learning and the design of competence-centered curricula. Experiential education focuses on hands-on learning processes such as internships, apprenticeship, experiential exercises, and on-the-job training/learning. Curriculum development emphasises that structure development for any subject can be respectably taught at any level[20].

3.2.2 Vocational Trend

The current shift towards Nigerian graduates seeking vocational training after graduation from higher education is alarming and critical. This trend requires immediate attentions from the Nigerian university governing bodies. Over the years, employers have been forced to seek graduates with Western degrees or foreign certifications due to the unpreparedness of the graduates and the failure of career expectations created by the universities. It shows a clear indication of a misnomer in the linkages between education and work.

3.2.3 Safety Lessons from Experiential School of Thought

Safety lessons are often learned from experience, and the learning outcome can be developed into modules and educational materials that can be assessed and certified for credits in the

[17] Dewey J. (1938). *Education and Experience.* New York: Simon and Schuster.
[18] Keeton M. and Pamela T. eds., (1978). *Learning by Experience—What, Why, How.* San Francisco: Jossey-Bass
[19] Piaget J. (1970b). *The Place of the Sciences of Man in the System of Sciences*. New York: Harper Torchbooks.
[20] Cunningham A.C. (1999). *Commentary*. Eur. J. Mark. 33, 685-697

university. For most engineering and science courses offered by the Nigerian universities and other Western countries, supported programs of experiential learning are on the increase. These include industry placements, student industry work experience scheme (SIWES), internships, field placements, work/study assignments, structured exercises, practical sessions, pilot plants unit operations, co-operative education (co-op), and other experience-based activities. All of these play critical roles in the curricula of undergraduate and professional programs. A non-traditional academic-related organisation such as the Petroleum Technology Development Fund (PTDF) is mandated to develop manpower for the oil and gas industry in Nigeria. Training programmes are designed to supplement the experience-based education which the universities cannot afford to provide. Examples include welders training, process modelling and simulation using computer based software such as Aspen, Hysys, Flarinet and others[21]. Experience-based learning has become widely accepted as an instructional method globally.

3.3 Cognitive-Experiential Learning Space (CogEx) and PSE

Figure 4 shows a combined learning domain called CogEx developed based on the merits of cognitive and experiential learning. However, more attention was given to the meta-cognitive, meta-inference and higher cognitive within the cognitive domain. Meanwhile, the concepts of learning space theory expounded by[22] from the previous work of Lewin's theory of space was embedded into the experiential learning domain. For learning to occur within the experiential learning domain, space is required. Space is said to exist in the experience of the learner and is dependent on both objective (time and environment) and subjective (preference and expectations) factors[22]. For process safety education, this may require a broader overview of the expected learning space. For example, in a refinery operating based on complex and advanced systems, the environment created is such that makes the learning preferences and expectations objective rather than subjective for would-be process safety engineers.

Within the context of time and environment, the cognate abilities have to be well developed particularly for identifying potential hazardous activities and processes and being able to follow logically through mitigation procedures irrespective of the complexities. For process safety education, the learning space is designed to enable knowledge acquisition, synthesis and abilities to make inferences. It forms the objective expectations with a preference for the process being considered and allows the development of deep understanding. Likewise, the environment provides an opportunity for experiential learning which further put to test the cognate knowledge developed over time and also strengthens the psychomotor domain. In essence, for the development of the university curriculum for teaching process safety, the inclusion of the CogEx learning space should be considered.

3.4 Implications of SAChE Workshop for PSE

As previously described in Section 2, the Safety and Chemical Engineering Education Committee organises faculty workshops as one of the principal activities. The workshop provides the learning space for interactions among academics as well as with industry experts: a balanced learning space between practicing engineers with vast experiential knowledge and

[21] www.ptdf.gov.ng

[22] Kolb A.Y. and Kolb D.A. (2009). The Learning Way. Meta-cognitive Aspects of Experiential Learning, in Simulation & Gaming. pp. 297–327.

the faculty members with sound cognitive understanding in the science of process safety. Some of the academics have previously had industry experiences in similar or entirely different environment while others are new to the process safety education.

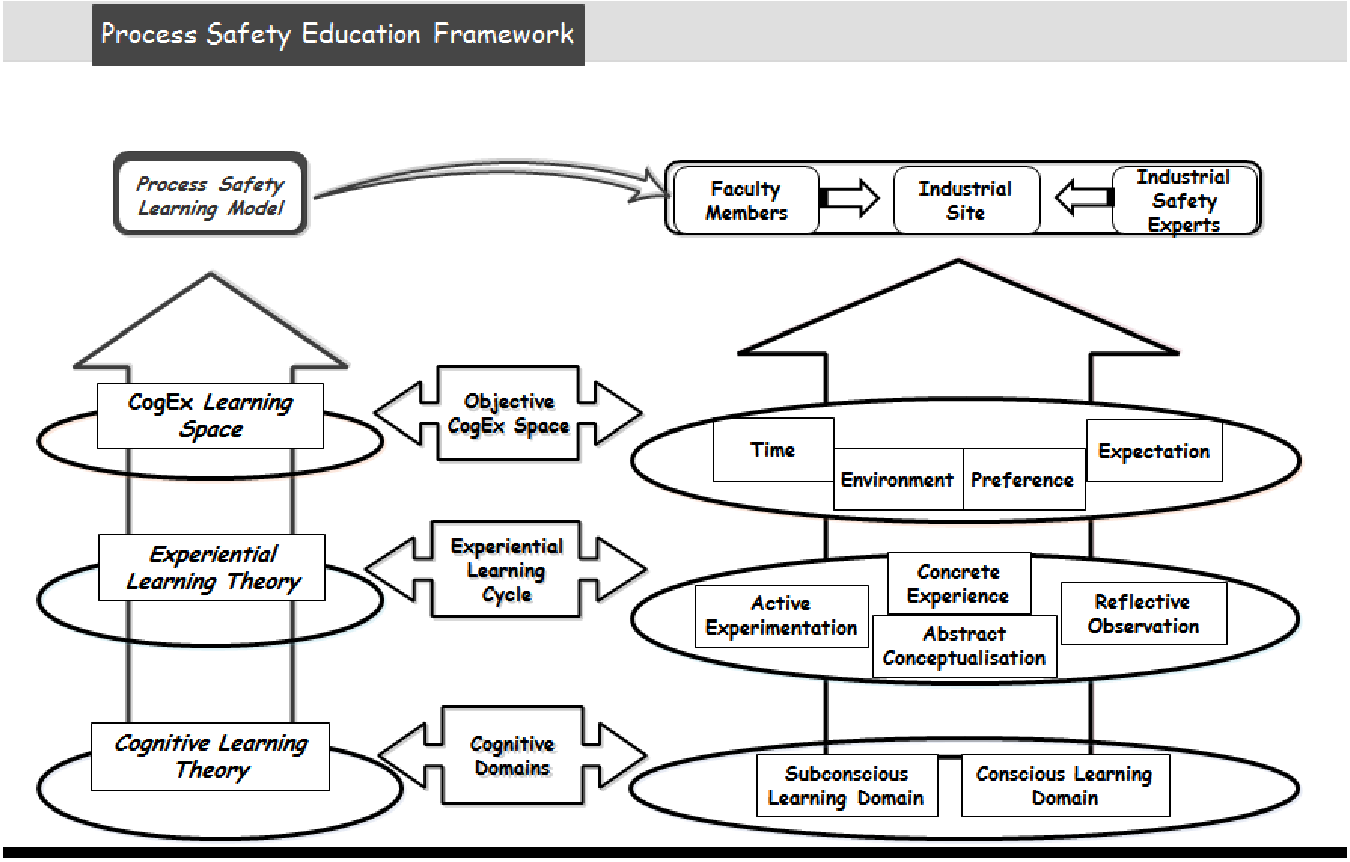

Figure 4: A process safety education framework showing the individual models and CogEx space[9,10,15,16,22,23]

The workshop activities were designed to enable classroom based learning from industry experts on various key process safety topics, facility tour that enhance the cognitive learning by coming in proximity to the refinery processes and learning experientially. The experiences are taken back into the classroom for further discussions on how to incorporate them into curriculum development. Also included in the program are social functions such as dinner where the faculties get to know each other better and also interact with the industry delegates.

Over the years, the SAChE faculty workshops have played vital roles in PSE in the US. Specifically, the last two workshops brought to play a highly structured classroom lectures prepared and delivered by experts from the Chevron Corporation. Some of the areas covered include process safety management and culture, risk management, process safety (PS) in downstream operations, quality by design and design assurances, metallurgy and corrosion, PS in upstream and gas operations, environmental risk management and consequence modelling and process safety management. Opportunities for discussion on curriculum improvement

[23] Kolb A.Y. and Kolb D.A.(2008). Experiential Learning Theory: A Dynamic, Holistic Approach to Management Learning, Education and Development, in Armstrong, S. J. Fukami, C. (Ed.), Handbook of Management Learning, Education and Development. SAGE Publications, London, pp. 1–59.

during the workshop directly allow industry experts input on current industry trends and taught safety activities in the classroom. It further allows talks on industry experts inclusion in classroom teaching based on university-industry partnership. Amongst the faculty members, the workshop provides networking opportunities for thought sharing, exchange of course materials and teaching strategies that could be useful to others as they look forward to improving safety education in their various universities.

In general, a process safety education framework as shown in Figure 5 (as well as Figure 1 and Figure 4) should be adopted. A framework that provides a common platform for industry trainers, university faculty members and students. It provides the opportunities to establish information acquisition and experiential learning scheme, direct external collaborations with industry and students certifications through subject related professional organisations as it is currently done by SAChE. As it were, students' industrial work experience (SIWES) or gap year in the industry should be adequately structured to ensure that students have sufficient process safety exposures during their stay in the industry. Consolidation of their exposures and experiential learning should be well provided for in the curriculum during the final year design project or report writing that substantiate the experiential learning cognitively.

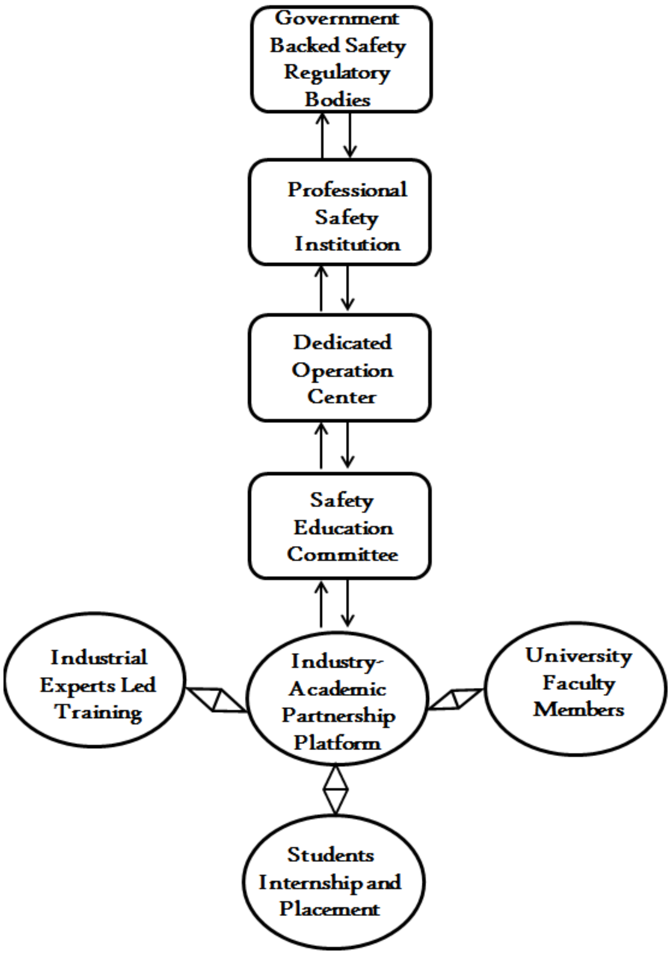

Figure 5: A generic process safety education framework developed from SAChE faculty workshop operational model.

3.5 Process Safety Education Pedagogic Creed and Conclusion

> "…process safety education must be conceived as a continuing reconstruction of experience."
>
> "…process safety education is a continuous lifelong process of developing capacity for experiencing, reflecting, thinking and action."
>
> "…process safety education goal should be one and the same thing across chemical engineering degree programmes globally. Hence the need for internalisation of process safety education curriculum."
>
> "…process safety education evolution in the future should remain inseparable from the academic-industry partnership within the Cognitive-Experiential learning space."

To realise the expected potentials, significant changes in the chemical process safety educational contents, structures and approaches, within the higher education is required. According to[14] there is a need to open up campus facilities and professional expertise linked to a wider range of educational settings, practitioners, field supervisors, and adjunct faculty. The process safety education framework described here provides a platform that enables accessible linkages. They are systematically achieved through relationships with expert groups, industry partnership, affiliations with professional organisations and government parastatals responsible for safety education and at the workplace. The framework for this is supported by flexible collaboration options that fit time to the cognitive requirements and the experiential learning opportunities. Consequently, safety education standards, graduate professionalism are demonstrated by the levels of knowledge and competence gained as students through the university programs.

Acknowledgements:

The authors of this article would like to acknowledge Prof. Ronald J. Willey of Northeastern University, Boston, MA, USA for his permissions on behalf of SAChE to use its online publications and data. We also appreciate Petroleum Technology Development Fund, Nigeria for funding our field trip to SAChE faculty workshop held at Chevron Richmond Refinery, California in 2013/2014.

ABBREVIATIONS

ABET	Accreditation Board for Engineering and Technology Programs (USA)
ACS	American Chemical Society
AIChE	American Institute of Chemical Engineers
ASSE	American Society of Safety Engineers
CCPS	Center for Chemical Process Safety
CEAB	Canadian Engineering Accreditation Board
CIC	Chemical Institute of Canada

CSB	Chemical Safety Board
CSC	Canadian Society for Chemistry
CSChE	Canadian Society for Chemical Engineering
CSCT	Canadian Society for Chemical Technology
HSE	Health and Safety Executive
IChemE	Institute of Chemical Engineers
NEBOSH	National Examination Board in Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PS	Process Safety
PSE	Process Safety Education
PTDF	Petroleum Technology Development Fund
SAChE	Safety and Chemical Engineering Education
SIWES	Student Industry Work Experience Scheme