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Research Article

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Assessing Critical Thinking Outcomes: A Comparative Study of Traditional and Online Teaching Methods in The Classroom

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Abstract: This research aims to examine the influence of traditional and digital teaching methods on the enhancement of critical thinking abilities in students. As educational institutions increasingly embrace digital learning settings, it is imperative to understand how different approaches differ in cultivating analytical and evaluative skills necessary for academic and professional achievement. The research conducts a comparative examination of student outcomes in critical thinking assessments to evaluate the effectiveness of online training, characterised by digital tools and flexible structures, relative to traditional face-to-face teaching in promoting critical thinking. Data were gathered from a heterogeneous sample of students participating in both teaching approaches, emphasising standardised critical thinking evaluations, lecturer comments, and self-reported assessments from students. The results reveal subtle distinctions in critical thinking outcomes between the two strategies, emphasising certain benefits and obstacles linked to each. These findings provide insights for enhancing teaching tactics to effectively develop critical thinking abilities, contributing to continuing debates regarding the effectiveness of online learning in universities.

Results showed that there was a reversal and significant increase in students performances from 2014 when digital learning took effect because of the assessment methods adopted (formative and summative). The percentage Pass of students in ChE 515.1 exceeded that of students in ChE 517.1 in the years 2015, 2016, and 2017 respectively (64.7, 69.2, and 65.15). ChE 517.1 recorded 35.2, 30.7 and 34.8 respectively. It was observed that same set of students taking part in courses at the same level performed poorly in one and excelled in the other due to the course delivery method adopted.

Keywords: Critical Thinking, Teaching methods, Outcomes, Classroom.

1. Introduction

Chemical engineering education in Nigeria started at the University of Ife (now Obafemi Awolowo University), Ile-Ife, where an Applied Chemistry programme was initiated in 1969, was subsequently upgraded to Chemical Technology and eventually Chemical Engineering and graduated the first set of Nigerian-trained Chemical Engineers in 1973. Other premier Universities followed and as at 2022: about 33 Nigerian universities now offer Chemical Engineering degrees. Nigerian Chemical Engineering Departments offer an undergraduate programme leading to the Bachelor of Engineering (B.Eng.) or Bachelor of Technology (B. Tech). Like every other engineering programme, it is a five-year programme for students admitted through JAMB entrance examination and four-year for those admitted through direct entry.

The Bachelor of Engineering (B.Eng.) in Chemical Engineering incorporates a one-year industrial internship for experiential learning. Additionally, some universities provide postgraduate programs (M.Sc., Ph D.) emphasizing research domains such as environmental engineering, process enhancement, and materials.

Chemical Engineering education is aimed at preparing Chemical Engineers for vital sectors such as oil and gas, petrochemicals, manufacturing, and food processing. Chemical Engineering curricula in Nigeria encompass fundamental subjects such as: Fluid Mechanics, Thermodynamics, Chemical Reaction Engineering, Process Design, Heat and Mass Transfer, Unit operations, Separation Processes, Sustainable Energy, Biomedical Engineering, Catalysis, Reaction Engineering, Polymer, Process Systems, Biotechnology, etc.

The curriculum integrates theoretical instruction with practical laboratory experiences and industrial placements. Nigerian institutions adhere to National Universities Commission (NUC) standards, outlining required courses and academic benchmarks for undergraduate Chemical Engineering degrees.

E- Learning Methodologies

E-learning is learning conducted through electronic media, typically on the internet.

E-learning includes a series of methodologies such as Blended learning (B-learning), Ubiquitous learning (U-learning), and Mobile-learning (M-learning).

B-learning combines conventional or traditional learning with online learning, offering the main advantages of both (Cheah et al.,2016). U-learning consist of the use of computers and tools such as video conference or augmented reality applied to any subject in any place and at any time (Cardenas, Robledo and Pena–Ayala, 2018). Lastly, M-learning takes advantage of the possibilities offered by mobile devices which enables students to learn without being in a fixed position. Surprisingly, M-learning has drawn growing attention in recent years as it provides a dynamic learning environment supported by small and easily portable technological devices, including tablets or mobile phones, in most cases with internet access (Crompton et al., 2018; Purwanti et al., 2019).

The number of mobile users worldwide is projected to reach 7.41 billion in 2024 (Statista, 2020), thus, the model Bring Your Own Device (BYOD) consist of the use of students' own devices instead of those provided by schools or faculties (Kariapper, 2019). The main advantage of E-learning which can be combined with other methodologies, is the possibility of involving many students, who have access to the internet, on an electronic device (GSMA, 2020).

On the other hand, M-learning is deemed the most interesting ICT-based method at university level, as most students have personal mobile telephones or tablets (Živkovil, 2016). Thus, the mobile devices are becoming increasingly popular teaching tools in the universities as well as colleges or high schools. E-learning and particularly M-learning can be implemented alongside other andragogical methodologies for teaching and learning of Chemical Engineering students.

Chemical Engineering Curriculum in Nigerian Tertiary Institutions and Need for Curriculum Reforms

An educational reform aimed at integrating E-learning strategy for critical thinking enhancement in Chemical Engineering education in Nigeria is crucial for equipping students for future societal and economic challenges. The emphasis is on enhancing the current teaching methods in Nigerian universities' Chemical Engineering Departments for improved preparedness. This is because, as posited by Emeasoba (2015), Engineering graduates directly impact a nation's economic and technological success, making it Nigeria's sole strong foundation for technological growth.

The Nigeria Universities Commission (NUC) collaborates with the Council for Regulation of Engineering in Nigeria (COREN) to accredit Engineering programmes including Chemical

Engineering. Chemical Engineering departments in Nigeria employs a uniform curriculum. Curriculum reform is imperative due to evolving local and global societal, scientific, and technological landscapes. The traditional curriculum, effective for years, catered to a stable economic context. Reform is essential to equip Chemical Engineers to navigate both conventional and emerging challenges in the field. This reform should encompass subject content, andragogy, assessment, academic environment, and regulations. The core curriculum fosters confidence in Chemical Engineers' ability to synthesise interdisciplinary knowledge for complex problem-solving. It emphasises theoretical instruction, practical exposure, and entrepreneurial skills. The curriculum includes foundational sciences such as Mathematics, Physics, and Chemistry, which are vital for advanced Chemical Engineering studies. Key subjects include Thermodynamics, Kinetics, Transport Phenomena, Separation Processes, Process Design, Chemical Process Systems and Environmental Protection to name a few. The National University Commission and COREN design this Benchmark Minimum Academic Standards, with polytechnics overseen by the National Board for Technical Education (NABTE). Establishing minimum academic standards ensures uniform competency among graduates from different institutions. This standard is crucial for students transitioning from undergraduate to postgraduate programmes across institutions.

The Chemical Engineering curriculum is regularly evaluated to integrate advancements in the field and to enhance the entrepreneurial skills of graduates. The foundational elements of traditional Chemical Engineering must be retained while also incorporating new topics and teaching methods relevant to our context.

Critical thinking is a cognitive process that encompasses the thorough analysis, evaluation and, synthesis of information to enable well-informed decision-making and problem-solving. In essence, it entails evaluating information and making decisions grounded on evidence and logical reasoning.

Critical Thinking in an engineering context is well reported in teaching and learning. However, much of this is framed within theoretical and conceptual frameworks. Practical approaches of how Critical Thinking skills are best promoted in engineering curricula are less common. In general, engineering is about solving problems using scientific and mathematical principles and critical thinking is essential for this process.

In the context of Chemical Engineering, critical thinking entails the capacity to apply acquired knowledge, reason through complex scenarios, and design efficient solutions because the field involves working with complex systems and making decisions that can have a big impact on design of equipment, safety, the environment, and the society at large. The need for critical thinking is implicit in most of the programme outcomes including designing experiments, interpreting data, product design to specifications with realistic constraints, understanding ethical responsibility; and understanding the impact of engineering solutions within a contemporary and societal context, this is key in the field. This exposition delves into the significance of critical thinking in Chemical Engineering education and explores strategies to foster the development of these skills, ultimately resulting in the production of more competent and adaptable professionals. Chemical Engineering graduates must be able to think critically and solve complex problems.

The significance of critical thinking in Chemical Engineering education lies in the fact that Chemical Engineering is a multidisciplinary field that integrates principles of Chemistry, Physics, Mathematics, and Engineering.

Traditionally, students or trainees may receive this practical training through a unidirectional approach that can lack interactive activities through a single material provided in the classroom or laboratory, it is therefore possible that some students might encounter a ‘sink or swim’ situation if they are not able to understand the materials presented during classroom lectures or execute correct procedures during the laboratory sessions with time- intensive training. It is therefore pertinent to develop an approach that will enable the students or trainees to be involved in their own learning. To excel in these roles, graduates must possess more than a mere factual understanding of fundamental concepts; they must possess the ability to engage in critical thinking.

E-learning Implementation and its effect on Chemical Engineering Education in Nigeria

E-learning in Nigeria's Chemical Engineering education is gradually increasing, yet it encounters numerous obstacles. The slow adoption of digital educational tools stems from infrastructural issues, poor internet connectivity, and insufficient technical training for students and educators. Many institutions are ill-equipped to integrate sophisticated E-learning systems into their curricula (Salehin et al., 2024). Notwithstanding these challenges, E-learning offers significant potential to improve critical thinking skills via interactive learning and self-directed study. Nevertheless, its effectiveness varies based on access to E-learning resources. Effectively implemented, it can facilitate deeper engagement with complex chemical processes, critical data analysis, and collaborative work on digital platforms.

Positive Perceptions: Students and faculty alike regard technology as advantageous for fostering interactive and dynamic educational environments, a perception vital for the effective adoption of technology in academic contexts. (Salehin et al., 2024). To fully realise E-learning's advantages, Nigeria's Chemical Engineering programmes require increased investment in ICT infrastructure, enhanced digital literacy, and policies that support E-learning integration into traditional education

(Owolabi and Rafiu, 2010). Without these measures, the opportunity to cultivate critical thinking skills through e-learning may remain unrealised for numerous students.

2. Methodology

Research Design: This research was designed to interpret the data collected by quantitative, numerical expressions, and to build a carefully structured WebApp that will provide a keen understanding of why students must use it to develop and enhance their critical thinking ability.

Data Collection Methods:

Using ChE 515.1 (Process Optimisation), ChE 517.1 (Chemical Engineering Analysis), ChE 211.1 (Introduction to Chemical Engineering), ChE 313.1 (Chemical Engineering Thermodynamics I, and ChE 212.2 (Chemical Engineering Process Analysis) results to redesign a fit for purpose curriculum, we collected results of these courses from the Department of Chemical Engineering, University of Port Harcourt with an approval by the Head of Department. The collected results from the department were for a period of ten years (2006-2017), some of these courses were taught with an online app (a student-centered learning tool - ChE 515.1 and ChE 211.1), while some used the traditional way of teaching (lecturer-centered - ChE 212.1, ChE 313.1 and ChE 517.1). The analysed results from the students centered learning are to be compared with those taught with the traditional method for the same period. The reason for the collection was to get an insight in the method of lecture delivery of these courses, compare the assessment methods used and see if the results meet the expected learning outcomes, and also ensure that insights generated, if positive, will be practiced in other courses which in return will justify the reason for this research.

Table 1: ChE 515.1 (Process Optimisation) Grades for ten (10) years

Student Set	A	B	C	D	E	F	Total
2006	5	14	19	11	38	3	90
2008	11	15	15	11	37	0	89
2009	12	18	31	10	51	9	131
2010	9	13	24	10	24	14	94
2011	4	10	12	4	16	7	53
2013	3	6	4	3	13	2	31
2014	1	3	4	9	18	6	41
2015	10	11	25	5	12	3	66
2016	7	6	23	9	18	0	63
2017	16	18	9	7	7	2	59

Table 2: ChE 517.1 Chemical Engineering Analysis) Grades for ten (10) years

Student Set	A	B	C	D	E	F	Total
2006	27	24	25	18	52	7	153
2008	6	17	39	15	20	5	102
2009	10	28	51	28	25	1	143
2010	3	6	15	9	5	9	47
2011	32	36	29	11	7	0	115
2013	12	17	33	16	45	8	131
2014	9	21	19	10	32	9	100
2015	9	9	7	6	15	1	47
2016	4	8	4	9	7	3	35
2017	7	9	7	4	9	0	36

Table 3: ChE 313.1 (Chemical Engineering Thermodynamic I) Grades for ten (10) years

Student Set	A	B	C	D	E	F	Total
2006	20	38	25	5	4	9	101
2007	3	28	66	29	20	18	164
2008	7	15	33	15	28	15	113
2009	6	17	35	26	28	22	134
2010	18	24	26	12	22	16	118
2011	7	14	30	23	40	13	127

2012	7	10	26	9	48	7	107
2013	8	14	14	5	7	5	53
2014	9	10	14	6	4	5	48
2015	4	10	7	6	12	4	43
2016							0
2017	8	16	14	8	26	4	76

Table 4: ChE 211.1 (Introduction to Chemical Engineering) Grades for ten (10) years

Student Set	A	B	C	D	E	F	Total
2006							0
2007	5	24	48	17	12	7	113
2008	4	20	29	16	16	42	127
2009	4	8	5	15	61	39	132
2010	4	37	46	23	19	21	150
2011	6	24	31	14	24	18	117
2012	7	13	25	7	12	4	68
2013	6	10	12	4	14	4	50
2014	0	13	19	4	4	3	43
2015	4	17	14	4	6	3	48
2016	2	9	24	9	15	7	66
2017	0	12	16	7	33	9	77

Table 5: ChE 212.2 (Chemical Engineering Process Analysis) Grades for ten (10) years

Student Set	A	B	C	D	E	F	Total
2006	1	12	52	27	47	25	164
2007	1	13	44	25	33	16	132
2008	2	9	43	16	42	25	137
2009	0	5	11	24	55	15	110
2010	0	8	27	20	45	39	139
2011	13	18	49	0	25	19	124
2012	1	14	30	11	9	4	69
2013	1	8	17	6	6	8	46
2014	1	6	13	6	18	7	51
2015	2	8	15	7	13	5	50
2016	5	10	26	6	14	5	66
2017	5	11	19	13	18	9	75

To cultivate student's critical thinking skills, educators (eg Noddings, 2015; Tiruneh et al., 2014) recommend using a variety of andragogical approaches such as case studies and higher order questioning. Increasingly, educational technologies are utilized to implement these approaches. Among technological tools, mobile software applications such as learners management system (LMS) emerged, promising increased support for teaching and learning, prompting the educational community to explore affordability, design, and effects of this relatively new innovation (Li et al., 2021; Stevenson et al., 2015). Critical thinking is a much-needed skill especially in this era which is loaded with digital distractions and communication.

3. Results and Discussion

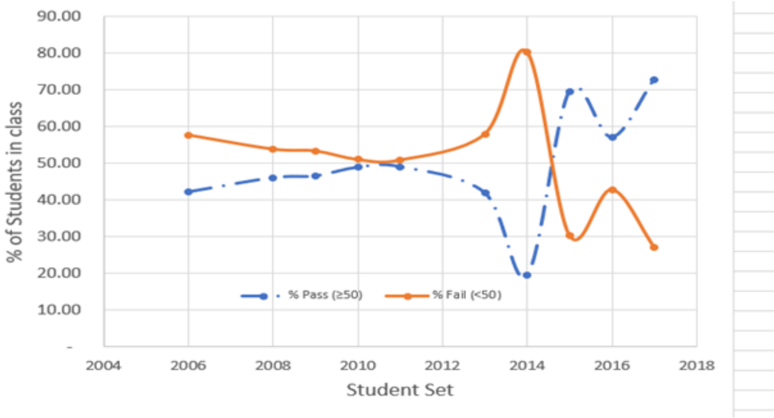

Figure 1: Graph of ChE 515.1 (Process Optimization) for a ten year period

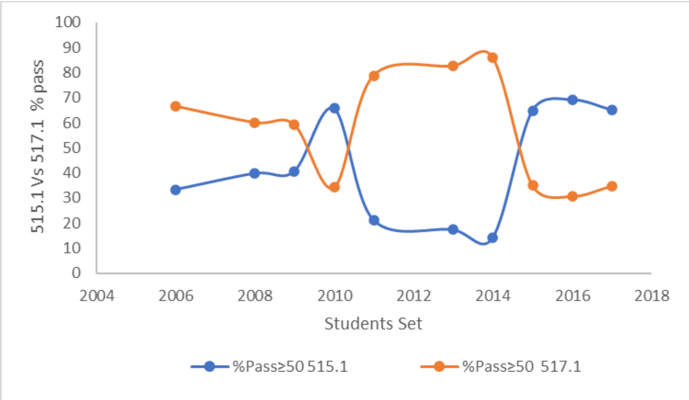

Figure 2: Graph comparing ChE 515.1 (Process Optimization) Vs ChE 517.1 (Chemical Engineering Analysis) pass level for a ten year period.

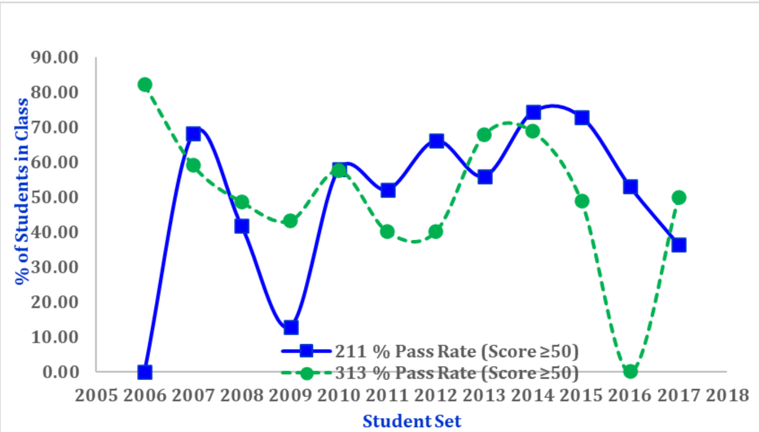

Figure 3: Figure Graph Comparing PASS RATE of ChE 211.1 Vs ChE 313.1 for ten years

From the results, if students centered learning is consistently deployed over a period of time, the result will shift from failure or being an average student in a particular course taken to above average. As shown in Figure 1, in ChE 515.1, the students were taught using Piezza app in year 2, they got used to using online apps, used to collaboration, used to being analytical in discussions, used to modern technology as a means of lecture delivery, the group sharing produced deep thinking when working together to proffer solutions. Alternatively, in ChE 517.1, the lecturer centered was employed in teaching the students. The percentage Pass of students in ChE 515.1 exceeded that of students in ChE 517.1 in the years 2015, 2016, and 2017 respectively (64.7, 69.2, and

65.15). ChE 517.1 recorded 35.2, 30.7 and 34.8 respectively. It was observed that same set of students taking part in courses at the same level performed poorly in one and excelled in the other due to the course delivery method. As at their final year level, the students already mastered the student-centered learning and did better in ChE 515 where it was deployed. The failure rate (less than 50 (<50) of students is a true indication that students centered learning will produce better chemical engineers that will be able to promote the ideologies of the program. This is a clear indication that the students understood what they were taught. Cramming for excellent grades was not the order of the day. They had formative and summative assessment modes. Again, this analysis/ comparison indeed is an indication that outcome-based quality education is achievable if the student-centered andragogy is employed through integration of e-learning strategies.

The overall findings from comparing results obtained from the student-centered learning, and that of the lecturer centered teaching, provide compelling evidence that the profound influence of the level of critical thinking involved in the students centered approach had a positive impact on the outcome of their learning. This shows that there will be a positive outcome in students' performances if the students-centered learning method is sustained through the integration of e-learning andragogy.

4. Conclusion and Recommendation

1) From the viewpoint of educators, future employers, and society in general, **training students to think critically** is among the principal tasks of the educational system.

Critical thinking abilities such as being able to analyse complex issues and situations, generating solutions, making connections and transferring insights into new concepts are key. Developing standards for decision making are necessary to succeed in the chemical engineering industry, business, and the society at large, hence it is very pertinent to integrate critical thinking into chemical engineering education.

2) Lecturers are **to implement both formative and summative assessments** in their method of assessment. Students may not be able to perform creditably when only the summative method of assessment is employed at the end of the semester. So many factors can contribute to the failure of a student if only the summative mode of assessment is employed. Using the e-learning method for formative assessments will enhance critical thinking in students.

3) **Method of lecture delivery and the attitudes and relationship of lecturers with students** also contribute to their level of critical thinking. Lecturers are encouraged to maintain a friendly relationship with students, encourage them and allow them to freely ask questions in class concerning the areas they don't understand, you create a conducive environment for learning by doing so and in turn encourage critical thinking development. Remember, there will be no teacher (educators) if we do not have students.

4) The results of this study suggest that **adequate training and support** is required for instructors to successfully infuse Paul Elders model into course content. Paul and Elders model is not a "quick fix" instructional approach that can be applied to a few course activities or a list of elements, criteria, and attributes to memorise. Instead, it demands a willingness to critically reflect on a course and restore its curricular and andragogic roots by practitioners. Redesigning courses to promote continual thoughtfulness about course content, delivery, and outcome is probably essential for this model to provide the kind of benefits found when the student-centered learning was adopted in this study. This kind of course restructuring requires both in-depth in the model and continued support from government and institutions as instructors are faced with unfamiliar issues along the line of lecture delivery. Training of educators for effective integration of e-learning model to boost critical thinking in course content should be regular. Remember, the land (brain) you water grows greener.

5) **Curriculum Restructuring:** The restructuring of the curriculum is crucial for improving critical thinking in chemical engineering education, this will align educational methods with the requirements of the present-day chemical engineering industry, and cultivate basic skills in students. The use of innovative instructional approaches and self-directed learning in the educational program can greatly enhance students' capacity for critical thinking.

A redesigned curriculum prioritises interactive, learner-centred methods that foster critical thinking and problem-solving abilities, crucial for practical applications in the real world .

Contributions to Knowledge

Implementing the critical thinking technique via e-learning in chemical engineering education greatly improves students' problem-solving skills and equips them to tackle real-world problems. This methodology cultivates independence among students, promotes collaboration, encourages creative thinking, and incorporates practical applications, finally resulting in enhanced academic achievement, student satisfactions, cognitive transformation and professional competence. These are the deficiencies found in the traditional method of teaching. which critical thinking addresses.

The introduction of the e-learning as a means of enhancing critical thinking especially the assignment feature embedded in the Learners Management system (LMS) ensures that our graduates are innovative, creative, smart, skillful and above all problem solvers. Employers are interested in workers who can think and proffer solutions that can lead to maximization of profits. Nigerian chemical engineering departments are all encouraged to switch to the student’s centered approach for better students engagement and excellent output.

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