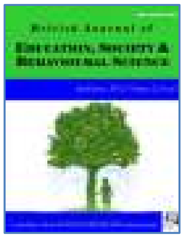

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Greening the Chemistry Curriculum: Catching Them Young

K. O. Oloruntegbe[1*] and J. O. Agbayewa[1]

[1]*Science and Technical Education, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author KOO designed the study, wrote the protocol and the first draft of the manuscript while author JOA managed the literature searches. Both authors read and approved the final manuscript.

Case Study

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ABSTRACT

This paper aims at advocating the integration of green chemistry principles for sustainability into the existing senior secondary or high school chemistry curriculum. Researches and training in this all important area had been targeted towards university level education and research and industry with little or no effort at inculcating the principles of green chemistry in the youngsters. Using the Nigerian Senior Secondary Curriculum as a case study for the proposed integration, it was observed that several of the contents could be made to incorporate the principles of green chemistry without much overburdening. It is the opinion of the authors that catching them young this way will yield a long term benefit of producing chemists and industrialists who would enforce greener policies and work for safer environment. This would in turn help to achieve sustainable environment devoid of prevalent environmental problems occasioned by incessant climate change and other greenhouse effects.

Keywords: Green chemistry; senior secondary chemistry curriculum; catching them young.

**Corresponding author: Email: ko_oloruntegbe@yahoo.com, kooloruntegbe@gmail.com;*

1. INTRODUCTION

Green chemistry is a concept that addresses the need for chemical reactions and products to be environmentally friendly. For over two centuries, chemical science has been practiced on a large scale, enabling the production of a wide variety of goods that are valued by humans, pharmaceuticals that improve health and extend life; fertilizers for increased food production; semiconductors have made possible computers and other electronic devices. The benefits are too numerous to mention. But there can be no denying the fact that in years past, and even at present, chemistry has been misused in many respects, such as the release of pollutants and toxic substances and the production of nonbiodegradable materials, resulting in harm to the environment and living things, including humans. It is like a case of gains in chemical science being cancelled by the loss due to the abuse of it. Green chemistry, however, came as an answer to curb these abuses by encouraging chemical industries to make their reactions and products environmentally benign.

Much research had been and is still being carried out generally on how to promote green chemistry and protect the environment [1,2,3] Many grants had been awarded - Green Chemistry STAR Grants [4], many workshops have been held with green catalysis and reagents, biocatalysis, selective activation, alternative solvents, renewable sources of chemicals and research policy as the central themes of discussions. Many chemical industries have been sensitized on the need to prevent waste, design safer chemical processes, use renewable feedstocks, use safer solvents and reaction conditions, analyze in real time to prevent pollution, and minimize the potential for accidents. (See appendix for the full list of twelve principles of green chemistry). Many of these industries are now practicing green chemical principles to the extent that only graduates that are versed and able to foster such are attractive to the industries. There have been global and regional efforts also aimed at popularizing the subject with substantial dividends. However, much of the training and researches in this area are targeted towards industry managers and university scholars and students particularly postgraduates with little or no effort at the secondary and high school level. There is therefore the need to catch them young by greening the chemistry curriculum at this level. This paper aims at advocating the integration of principles of green chemistry into the existing senior secondary or high school chemistry curriculum globally and particularly in the developing nations where there have been serious environmental problems with little or no attempt at inculcating green chemistry principles at any level of the nations' educational system. The Nigerian senior secondary school chemistry curriculum is taken as a case study for this advocacy.

2. THE CURRENT NIGERIAN SS CHEMISTRY CURRICULUM

The Nigerian Senior Secondary (SS) Chemistry Curriculum covers three classes, Senior Secondary classes 1 – 3 and was developed around four themes (which are: Chemistry and Industry, the Chemical World, Chemistry and Environment and the Chemistry of Life [5], (Table 1). In selecting the contents, three major issues shaping the development of nations worldwide and influencing the world of knowledge today were identified [5]. These are globalization, information/communication technology and entrepreneurship. The desire that Nigeria be identified with contemporary development worldwide has called for the organization of the contents of the curriculum around the four themes. Thus, the curriculum is packaged with content that leads to self-actualization by students. In addition, the curriculum content focuses on practical activity with emphasis on locally available materials. This is to imbue the learners with the spirit of inquiry. The curriculum, if effectively implemented, will enable the learner achieve his/her maximum potential in the subject of chemistry and its various applications. The major topics covered in four themes in the three classes are summarized in the table below.

Table 1. Summary of Nigerian SS1-3 chemistry syllabus

Theme/ class	SS1	SS2	SS3
Chemistry and industry	Chemistry and industries	Periodic table, chemical reactions, Mass volume relationship	Quantitative and qualitative analysis
The chemical world	Introduction to chemistry, Particulate nature of matter, Symbols, formulae and equations, Chemical combination, Gas laws	Acid-base reactions, Water Air , Hydrogen, Oxygen , Halogens, Nitrogen , Sulphur	Petroleum Mental and their compound iron Ethical, legal and social issue
Chemistry and environment	Standard separation techniques for mixtures Acid bases and salt Water	Oxidation-reduction(redox) reaction Ionic theory Electrolysis	*Topics asterisked below are to be treated here to enable students prepare and write their examinations towards the end of the term. Actually the term was left open and free.
The chemistry of life	Carbon and its compounds	Hydrocarbons Alkanols	*Fats and oil Soap and detergent Giants molecules

3. JUSTIFICATION FOR THE INTEGRATION

With the enormous damage to the environment due to activities of chemical industries, It is now obvious that chemical science must be turned away from emphasis upon the exploitation of limited resources and the production of increasing amounts of products that ultimately end up as waste. Much emphasis should be toward the application of chemistry in ways that provide for human needs without damaging the Earth support system upon which all living things depend. Chemical science and industry have to move steadily in the direction of environmental friendliness and resource sustainability. The practice of chemistry in a manner that maximizes its benefits while eliminating or at least greatly reducing its adverse impacts is good justification for green chemistry.

In addition to this, there are other justifications for the integration of green chemistry into the nations' education system generally and secondary education in particular. Four fundamental reasons were advanced in "*Science and Engineering Indicators*" [6] *which* are necessity, responsibility, interest, and efficiency.

Green chemistry is necessary chemistry. As things currently stand, human consumption is not a sustainable process. This problem will be exacerbated as developing countries industrialize and our fossil fuel resources become depleted. Furthermore, recent discoveries about eco-toxic effects such as endocrine disruption have made it clear that synthetic chemicals released into the environments are disrupting world ecosystems in new and disturbing ways. An approach including the green chemistry principles of sustainability and the synthesis and use of benign substances whenever possible will help mitigate the effects of man-made interference in the natural environment.

Green chemistry is responsible chemistry. Many workers in the chemical field, in either academic or industrial settings, have had accidents with the potential to cause long-term damage to their health and wellbeing. As chemical workers, however, we have knowingly chosen to accept the risks of working in a chemical laboratory and typically have the opportunity to protect ourselves by gathering as much information about the potential risks as possible. The general public, however, has not chosen to accept the same risks, hence the need to help young ones to be well informed.

Green chemistry is interesting chemistry. Few substitutes to traditional chemical practices exist using green alternatives, and the development of these substitutes will provide new research areas for young chemists and chemical engineers. Furthermore, green chemistry requires a large amount of cross-disciplinary interaction, which will lead to new developments as researchers in differing disciplines interact with one another.

Green chemistry is efficient chemistry. The development of benign, non-wasteful alternatives to traditional chemistry has the potential to save industrial and academic interests large amounts of money due to decreased regulation compliance costs and disposal costs. Furthermore, the basic decrease in process hazards drastically increases both worker and consumer safety. Green chemistry is necessary, responsible, interesting, efficient, and above all, good chemistry.

And in Nigeria, a number of prevalent practices inimical to human health and sustainability necessitate green chemistry abound. Incessant bush burning; felling of trees for firewood; killing of animals for food; dumping of refuse around living environment; using toxic chemicals to kill fish for food; and poor sewage disposal are a few of these practices. Introducing the youngsters to green chemistry will go a long way to make them and the entire populace to imbibe environmental consciousness and accounting.

4. THE PROPOSED INTEGRATION

The SS chemistry syllabus was further broken down to performance objectives, contents, teachers and learners activities, materials and evaluation. In this paper only a few sample of the integration made in the performance objectives area are shown with my addition or the proposed addition in italics.

4.1 SS1 Theme 1 Chemistry and Industry, Topic 1 Chemistry and Industries

Performance objectives- By the end of the lesson students should be able to:

1. State the different standard methods of separating mixtures and their individual applications.
2. Manipulate different apparatus for separation techniques.
3. Draw separation techniques apparatus.
4. State the criteria for purity.

5. Distinguish between pure and impure substances.
6. *Explain the need for pure air and water as life support.*
7. *Explain the need to avoid contaminating air and water.*

4.2 SS2 Theme 3 the Chemical World, Topic 1 Acids, Bases and Salts

Performance objectives- Students should be able to:

1. Define acids, bases, and salts.
2. Identify acids and bases.
3. Describe the nature of proton in an aqueous solution.
4. Explain neutralization reactions.
5. Explain how an acid-base indicator works.
6. Use pH as a scale and discuss the importance of the pH value.
7. Identify and prepare salts (normal, acidic and basic).
8. State properties of salts.
9. State the rules of solubility of salts in water.
10. *Identify green alternatives to strong acids.*
11. *Relate the production of ethanoic acid through a green process using biological reactions acting upon renewable biomass raw materials.*
12. *Explain the reclamation and recycling of acids particularly spent and hazardous ones.*

4.3 SS3 Theme 1 the Chemical World, Topic 1 Petroleum

Performance objectives - Students should be able to:

1. Explain the origin and state the composition of crude oil (petroleum).
2. Discuss the exploration of and drilling for crude oil in Nigeria.
3. Explain the fractional distillation of petroleum and list the major fractions (products).
4. List the location of Nigerian refineries.
5. Explain the terms cracking and reforming.
6. Discuss the use of petrochemicals as starting materials of organic synthesis leading to organic products like plastics, synthetic rubber, drugs, insecticides, detergents, fibres, etc.
7. Explain the use of octane numbers in determining the quality of petrol.
8. Explain the occurrence, packaging and uses of natural gases.
9. State the economic importance of petroleum.
10. *Explain the negative aspect of petroleum refining like oil spill, seismic activities, soil degradation, water pollution and their effects on floral and fauna.*
11. *Explain the pollution effect of gas flaring in Nigeria.*
12. *Discuss how to achieve and sustain lasting relationship between the multinational oil companies and the host communities.*

Under metals and the compounds the following objectives are added. Students should be able to:

1. Explain that some metal ions in water form humic substances that are useful like Fe^{++} and other that are carcinogens (cancer-causing agents);

2. Explain that metal ores are finite in nature and that there is the need to recycle used ones. This kind of addition representing the integration spans the entire contents of the curriculum.

5. STUDENTS' AND TEACHERS' ACTIVITIES IN THE PROPOSED INTEGRATION

The Senior Secondary chemistry curriculum and syllabus have in-built table detailing the performance objectives, the content, students' and teachers' activities, evaluation and reference materials. A specimen of the table is reproduced below. For example, there are nine performance objectives originally on the topic, petroleum. There are three more on the proposed integration on the topic, (Table 2). These are that students should be able to:

1. Explain the origin and state the composition of crude oil (petroleum).
2. Discuss the exploration of and drilling for crude oil in Nigeria.
3. Explain the fractional distillation of petroleum and list the major fractions (products).
4. List the location of Nigerian refineries.
5. Explain the terms cracking and reforming.
6. Discuss the use of petrochemicals as starting materials of organic synthesis leading to organic compounds like plastics, synthetic rubber, drugs, insecticides, detergents, fibers.
7. Explain the use of octane numbers in determining the quality of petrol.
8. Explain the occurrence, packaging and uses of natural gases.
9. State the economic importance of petroleum. Added to these are.
10. Explain the negative aspect of petroleum refining like oil spill, seismic activities, soil degradation, water pollution and their effects on floral and fauna.
11. Explain the pollution effect of gas flaring in Nigeria; and. Discuss how to achieve and sustain lasting relationship between the multinational oil companies and the host communities. The other requirements, content, students' and teachers' activities, evaluation and resource materials follow the same example with more emphasis here on the proposed integration and in italics.

Table 2. Scheme of work detailing students' and teachers' activities

Topic	Performance objectives	Content	Activities		Teaching and learning materials	Evaluation guide
			Teacher	Students		
PETROLEUM OR CRUDE OIL	Students should be able to: Explain the origin and state the composition of crude oil Discuss the exploration of and drilling for crude oil in Nigeria *Explain the negative aspect of petroleum refining like oil spill, seismic activities, soil degradation, water pollution and their effects on floral and fauna;* *Explain the pollution effect of gas flaring in Nigeria;* *Discuss how to achieve and sustain lasting relationship between the multinational oil companies and the host communities*	Origin and composition of petroleum (crude oil) Nigerian and world crude oil reserves Exploration and drilling of crude oil *Negative aspect of petroleum refining like oil spill, seismic activities, soil degradation, water pollution and their effects on floral and fauna;* *Pollution effect of gas flaring in Nigeria;* *Achieving and sustaining lasting relationship between the multinational oil companies and the host communities*	Guides the students in the discussion of origin and composition of crude oil. *Discuss the negative effect of oil exploration on the environment;* *Discuss ways of achieving and sustaining lasting relationship between the multinational oil companies and the host communities*	Participate in class discussion *Discuss the negative aspects of oil exploration;* *Visit the communities where oil exploration is taking place.*	Pictures: - on exploration of oil - of any refinery in Nigeria Samples of plastics, synthetic rubber, insecticides, detergents, fibres (nylon, Dacron, etc) Cylinder of natural gas; *Newspaper cuttings, pictures e*	List the composition of crude oil. *Explain the negative aspect of petroleum refining like oil spill, seismic activities, soil degradation, water pollution and their effects on floral and fauna;* *Explain the pollution effect of gas flaring in Nigeria;* *Discuss how to achieve and sustain lasting relationship between the multinational oil companies and the host communities*

6. BENEFITS

As noted by Braun et al. [7] and Oloruntegbe [8] “Green Chemistry is not intended to be a solo discipline, but rather a means for conducting science in a responsible manner”. The objective is not meant to replace existing class materials or be taught as a separate section altogether. Instead, existing materials should be taught in a new way to incorporate key concepts into the curriculum to make chemistry inherently green. We should also bear in mind that the present curriculum material is already overburdened, crying for trimming down. The major benefit of catching them young is to make the youngsters imbibe environmental consciousness and accounting early in life. These youngsters could grow to become chemists who will make sure the 12 principles of green chemistry are adopted in the industries they find themselves working. In addition to this, the African chemists would be able to uphold the 13 principles of Greener Africa. (See appendix for 13 principles of Greener Africa).

7. CONCLUSION AND RECOMMENDATIONS

From the ongoing discussion it can be seen that green chemistry could be integrated into the SS chemistry curriculum. The existing curriculum could be reviewed to accommodate this. More refinement can be done at that point. It is therefore recommended that stakeholders in education, industries and environmental protection agency take a look at this proposal for implementation. There is a long term benefit of achieving sustainable environment devoid of prevalent environmental problems occasioned by incessant climate change and other greenhouse effects.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

12 Principles of green chemistry [10] and [11].	Thirteen principles for a greener Africa (Pan African Chemistry Network, 2011)
1. Prevent waste	G – Generate Wealth not Waste
2. Achieve atom economy: maximize incorporation	R – Regard for All Life & Human Health
	E – Energy from the Sun
3. Use less hazardous synthesis steps	E – Ensure degradability & No Hazards
4. Design safer chemicals	N – New Ideas & Different Thinking
5. Use safer solvents and auxiliaries	E – Engineer for Simplicity & Practicality
6. Design for energy efficiency	R – Recycle Whenever Possible
7. Use renewable feedstocks	A- Appropriate Materials for Function
8. Reduce derivatives (make what you want!)	F- Fewer Auxiliary Substances & Solvents
	R- Reactions Using Catalysts
9. Catalytic reagents are superior to stoichiometric	I - Indigenous Renewable Feedstocks
	C- Cleaner Air & Water
10. Design for degradation	A- Avoid the Mistakes of Others
11. Real-time analysis for pollution prevention	
12. Inherently safer chemistry prevents accidents	

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