Editorial Board

Editor-in-Chief  Temechegn Engida  
UNESCO-International Institute for Capacity Building in Africa  
ETHIOPIA

Associate Editors  Ahmed Mustefa  
Department of Chemistry, Addis Ababa University  
ETHIOPIA

Dereje Andargie  
Institute of Education, Debre Birhan University  
ETHIOPIA

Belina Terfasa  
Department of Chemistry, Kotebe College of Teacher Education  
ETHIOPIA

Sileshi Yitbarek  
Department of Chemistry, Kotebe College of Teacher Education  
ETHIOPIA

International Advisory Board

Prof. Peter Mahaffy, King’s University College, CANADA  
Prof. John Bradley, University of the Witwatersrand, SOUTH AFRICA  
Prof. Ameen F.M. Fahmy, Ain Shams University, EGYPT  
Prof. Hassimi Traore, University of Wisconsin – Whitewater, USA  
Prof. Hans-Dieter Barke, University of Muenster, GERMANY

© 2018 Federation of African Societies of Chemistry (FASC)

Enquiries and manuscripts should be addressed to the Editor-in-Chief: email eic@faschem.org, PO Box 2305, Addis Ababa, Ethiopia.
CONTENTS

EDITORIAL
Chemistry for Sustainable Peace Development 1
Temechegn Engida

RESEARCH PAPERS
Proving the paramagnetism of oxygen by molecular modelling 2
Robson Fernandes de Farias

Effects of conceptual change instructional approach on achievement of pre-service chemistry teachers in aliphatic hydrocarbon concepts 7
Woldie Belachew, Hans-Dieter Barke and Sileshi Yitbarek

A toolkit for mastering organic nomenclature in general chemistry 24
Cassandra Orozco, James E. Becvar and Mahesh Narayan

Comparative effect of two problem-solving instructional strategies on students’ achievement in stoichiometry 34
Mandina Shadrec and Ochonogor Chukunoye Enunuwe

Utilization of learning activity package in the classroom: impact on senior secondary school students’ academic achievement in organic chemistry 49
David Agwu Udu and Charles .U. Eze

Re-structuring secondary school chemistry education for sustainable development in Nigerian developing economy 93
Olufummilayo D. Ayodele

Readability of some topics in select current ordinary level chemistry textbook and Nigerian students’ perception about difficulty of the topics 112
Macson Joshua Abiakwo and Godsgrace Chiagaweye Ene

FEATURE ARTICLES AND REVIEWS
Kitchen chemistry: practical chemistry with simple equipment and readily available materials 124
Stephen H. Ashworth

Innovative mnemonics in chemical education: review article 144
Arijit Das

Early chemistry misconceptions: status and implications for science education in Ethiopia 190
Abayneh Lemma Gurmu

GUIDELINES FOR AUTHORS 204
EDITORIAL

CHEMISTRY FOR SUSTAINABLE PEACE DEVELOPMENT

Temechegn Engida
Email: temechegn@gmail.com

According to Rummel [1], peace has always been among humanity's highest values--for some, supreme. Peace is defined as equilibrium within social field. Peace can therefore, be seen as absence of dissension, violent conflict or war. It is the occurrence of harmony which is characterized by lack of violence and other conflict behaviors and includes freedom from fear of violence. Peace is not mere absence of war but includes social balance that ensures the absence of real or imagined causes of conflict from a human grouping. Peace is a perquisite for real development.

Chemistry has been mostly linked to the development of weapons that are anti-peace and anti-humanities. In this regard, RSC [2] states that Chemistry has been central to warfare ever since the first arrow head was forged and never more so following the industrialization of war in the twentieth century with the improvement of explosives and the development of chemical weapons.

UNESCO [3] states that “since wars begin in the minds of men, it is in the minds of men that the defenses of peace must be constructed”. Education in general and science education in particular, thus, have a strong place in realizing this vision. It is therefore vital to look at how Chemistry instills peace in the minds of men and women who study (get acquainted with) Chemistry formally (and informally).

AJCE thus Calls for Papers under the theme of Chemistry and Peace Development. If sufficient manuscripts are submitted until end of October 2018, they will be published as a Special Issue of AJCE in 2018. In the absence of sufficient manuscripts, then the available ones will appear in the January 2019 issue.

REFERENCES
PROVING THE PARAMAGNETISM OF OXYGEN
BY MOLECULAR MODELLING

Robson Fernandes de Farias
Universidade Federal do rio Grande do Norte, Cx. Postal 1664, 59078-970, Natal-RN, Brazil.
Email: robdefarias@yahoo.com.br

ABSTRACT
The present work describes how molecular modelling (semi-empirical and density functional theory-DFT approach) can be used to prove that molecular oxygen is paramagnetic, with two unpaired electrons. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

Since high school, students are familiar with Lewis structures and Valence Bond Theory (VBT). If we simply write the Lewis structure for molecular oxygen (O₂), we conclude that such a molecule has no unpaired electrons and that O₂ is, consequently, a diamagnetic substance (see Figure 1).

![Lewis structure for O₂](image)

*Fig. 1. Lewis structure for O₂*

If we explain the formation of O₂ molecule by using VBT, the same result is obtained: O₂ has no unpaired electrons. Since the electron configuration of O is 1s²2s²2p⁴, the 2p level of each oxygen atom has 2 unpaired electrons. When two oxygen atoms approach each other, the
respective unpaired electrons of each atom, are paired with each other, forming a σ and a π bond, resulting in zero unpaired electrons (Figure 2).

However, it is well known that O₂ is paramagnetic, as some simple demonstrations [1] can easily show.

Molecular Orbital Theory (MOT) (generally introduced only in undergraduate classes) predicts, correctly, that O₂ is a paramagnetic substance, with two unpaired electrons (Figure 3).

![MO Diagram for O₂](image)

*Fig. 3. Molecular Orbital diagram for O₂*

The correct explanation/prediction of O₂ paramagnetism is one of the triumphs of MOT over VBT. Such facts, as well as the MO diagram for O₂ are presented in any college chemistry textbook [2]. But, how can we “prove”, in the classroom, that O₂ has, indeed, two unpaired electrons?
The present work described how molecular modelling can be used to prove that molecular oxygen is paramagnetic, with two unpaired electrons. Such an approach can be a useful tool in the classroom for both general chemistry and inorganic chemistry classes.

METHODOLOGY

Molecular oxygen (O$_2$) was modelled by using Spartan´16 [3], with two possibilities: zero and two unpaired electrons. The calculations were performed by using two approach/levels of theory: Semi-Empirical (PM6) and DFT/M06-2X/6-311-G**.

As is well known from hard and soft acid-base theory, ionization energy, $\text{IE} = E_{\text{homo}}$, that is, the energy of the highest occupied molecular orbital and electron affinity, $\text{EA}= -E_{\text{lumo}}$, that is, the energy of the lowest unoccupied molecular orbital [4]. In fact, according to Koopman´s theorem [5], $\text{IE} \approx E_{\text{homo}}$, and the theorem makes no claim about $E_{\text{lumo}}$ energy. A similar theorem exists in density functional theory (DFT).

Hence, the calculated homo and lumo energies were compared with O$_2$ experimental values for IE and EA [6-8].

RESULTS AND DISCUSSION

The obtained results are summarized in Table 1. As can be verified, only the calculated values for O$_2$ with two unpaired electrons are in good agreement (specially the IE) with the experimental values. In fact, we must pay attention only in the IE values since ($E_{\text{homo}}$) since, in the employed approximations, the lumo energy shows little correlation with the electron affinity [9].
Table 1. Experimental values for $O_2$ IE and EA, and calculated homo and lumo energies.

<table>
<thead>
<tr>
<th>Parameter/Specie</th>
<th>$O_2$ (0 unpaired e$^-$)</th>
<th>$O_2$ (2 unpaired e$^-$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE/eV (exp)$^a$</td>
<td>_</td>
<td>12.1 ± 0.1</td>
</tr>
<tr>
<td>EA/eV (exp)$^b$</td>
<td>_</td>
<td>0.44 ± 0.10</td>
</tr>
<tr>
<td>$E_{\text{homo}}$/eV</td>
<td>8.27$^c$</td>
<td>10.82$^c$</td>
</tr>
<tr>
<td></td>
<td>9.35$^d$</td>
<td>10.93$^d$</td>
</tr>
<tr>
<td>$E_{\text{lumo}}$/eV</td>
<td>1.7$^c$</td>
<td>1.24$^c$</td>
</tr>
<tr>
<td></td>
<td>3.24$^d$</td>
<td>2.99$^d$</td>
</tr>
</tbody>
</table>

$^a$In Ref. 5, there are several reported experimental values for IE, all of them very close to each other. The value employed here is from Ref. 6; $^b$In Ref. 5, there are several reported experimental values for EA, all of them very close to each other. The value employed here is from Ref. 7. $^c$SE(PM6); $^d$DFT/M06-2X/6-311-G**.

Such agreement is a proof that molecular $O_2$ is, indeed, paramagnetic and also a proof that the number of unpaired electrons is two. In fact, $O_2$ with two unpaired electrons (triplet form) is only one of the three forms of oxygen [10], considering the possible distributions of electrons in the MO diagram, and the most stable (less energetic) one. The difference between the calculated $E_{\text{homo}}$ (DFT/M06-2X/6-311-G** approach, for example) = 10.93-9.35 = 1.58 eV = 152.4 kJmol$^{-1}$ is the energetic difference between $^3\Sigma$ and $^1\Sigma$ forms [10].

REFERENCES
EFFECTS OF CONCEPTUAL CHANGE INSTRUCTIONAL APPROACH
ON ACHIEVEMENT OF PRE-SERVICE CHEMISTRY TEACHERS IN
ALIPHATIC HYDROCARBON CONCEPTS

Woldie Belachew*1, Hans-Dieter Barke2 and Sileshi Yitbarek3
1Addis Ababa University, Addis Ababa, Ethiopia, 2University of Muenster, Germany, and
3Kotebe Metropolitan University, Addis Ababa, Ethiopia
*Corresponding author email: woldbe@yahoo.com

ABSTRACT
College students face difficulties in Organic Chemistry because the concepts are generally
abstract, especially functionality chemistry. This study explored college level pre-service
chemistry teachers’ achievement in aliphatic hydrocarbon concepts through conceptual change
instructional approach (CCIA). The participants were 87 pre-service chemistry teachers in
Arbaminch College of Teacher Education, Southern Nations, Nationalities and Peoples Regional
State (SNNPRS), Ethiopia. Two intact classes, taking Introductory Organic Chemistry I, were
randomly assigned as Experimental group and Comparison group. The data collection instrument
was the aliphatic hydrocarbon achievement test (AHAT). A non-equivalent pre-test-posttest
control group design was used to investigate participant’s achievement in aliphatic hydrocarbon
chemistry. Data were collected and analyzed using independent samples t-test and paired samples
t-test. A pre-test established that CCIA group and conventional instructional approach (CIA) group
were similar at the beginning. After interventions, analysis of students’ response indicated that
students in the CCIA group scored significantly higher than those in the CIA group. Based on these
findings and discussions, conclusions were made. [African Journal of Chemical Education—AJCE
8(2), July 2018]
INTRODUCTION

Chemistry is one of the subjects offered in Ethiopian schools starting from grade seven. However, the teacher-centered approach followed by instructors is affecting the learning process in chemistry [1], albeit policy documents and different guidelines prepared in line with the policy maintain on the use of student-centered approach. Instructors attribute students’ problems in relation to chemistry learning generally to poor teaching environment [1][2] like absence of facilities. But when teaching materials are fulfilled, other reasons are given by instructors [3]. Thus, chemistry teachers are expected to make chemistry lessons more relevant, enjoyable, easy and meaningful to their students with concrete understanding ensured. Lee and Byun have described problems related to teaching using a clear explanation [4]. They indicated that bringing successful teaching approaches has been a major challenge for both teachers and researchers. In relation to this challenge it has become apparent that the gap, between what is important from researchers’ viewpoint and what can be set in to actual exercise by teachers, has increased [5].

Learning Chemistry requires a set of skills [6][7]. This makes the subject to be considered as difficult. Its profoundly abstract nature [8][9][10][11] not only causes problems to many students, but also brands it as an unpopular subject. Despite the enthusiasm of chemistry educators, as well as several interventions, chemistry continues to be challenging [12][13]. In particular, Organic chemistry is considered to be a difficult course and is source of major impediments that college students face [14][15]. Researchers [14][15] blame the memorize-oriented approach of teaching used by many course instructors.

Also, research work demystified that student achievement in Organic chemistry is affected by their achievement in General chemistry, their high school performance in chemistry, their test scores, and cognitive variables like spatial ability performance [16][17]. Additionally, chemistry
achievement problems have been attributed to poor teaching methods used by teachers [18][1][19][2] especially in Organic chemistry [20][21]. Strategies like using simulations [22][23] [24][25], peer-lead instructional approach [26], concept mapping [27], concept cartoons [23], Conceptual change texts [28][29][30] and flipped class rooms [31] have showed improvement in understanding and achievement of students in chemistry classes.

For lots of students, Organic chemistry is a course in which they must think critically with understanding rather than memorizing [21]. Understanding basic concepts in Organic chemistry and using this knowledge as a source of prediction are huge challenges for students [20]. Hassana, Hill, and Reida [32] indicated that performance in a first level chemistry course in specific areas of Organic chemistry at college level reflects the grasp of specific underlying ideas gained from school. Organic chemistry text book writers like Bruice [33] have clearly stipulated that meaningful learning occurs when learners grasp contents by a thorough understanding of fundamentals.

STATEMENT OF THE PROBLEM

Teacher Education College students, in the Ethiopian context, take two Organic chemistry courses in which aliphatic hydrocarbon concepts are treated in the Introductory organic chemistry I course. It has been reported that aliphatic hydrocarbon chemistry is among key areas of trouble for students [34] [35]. Investigator’s experience shows that students’ performance in the two Organic chemistry courses is poor. The problem starts with Functionality chemistry which encompasses aliphatic hydrocarbon concepts, also many other concepts are generally abstract to students [20].

There are research works that spotlight on aspects of Conceptual change instructional approach, but there is paucity of studies focusing on the effects of this approach on achievement
in aliphaticity. The ways how using Conceptual change texts affect achievement in aliphatic hydrocarbon chemistry as a whole is uncharted and deserves further exploration. Thus, this study focuses on the effects of Conceptual change instructional approach (using Conceptual change texts) on pre-service chemistry teachers’ achievement in aliphatic hydrocarbon concepts.

Purpose of the Study and Research Questions

The principal purpose of this study is to investigate effects of Conceptual change instructional approach through the use of conceptual change texts (CCTs) on achievement of pre-service teachers’ in aliphatic hydrocarbon concepts.

To achieve the above major purpose of the study the following research questions are given:

1. Is there statistically significant difference between Experimental and Comparison group in reference to Pre-achievement test mean scores?
2. Is there statistically significant difference within Experimental and Comparison group in reference to Pre-and post- achievement test mean scores?
3. Is there statistically significant difference between Experimental and Comparison group in reference to Post-achievement test mean scores when CCIA is used in aliphatic hydrocarbon concepts?

RESEARCH DESIGN

In order to study the effect of Conceptual change instructional approach using Conceptual change text on achievement in aliphatic hydrocarbon concepts the Pretest-Posttest Nonequivalent-Groups quasi-experimental design was used in this study. The quantitative quasi-experimental approach with nonequivalent Control group design with pretest and posttest was selected in this study to use intact classrooms as it is not ethical to conduct a randomized, controlled experiment.
[36][37] in settings like the college environment. The nonequivalent Control group design with pretest and posttest is represented in Table 1.

Two existing student groups were assigned to Experimental and Comparison group, both groups took the pretest. The Experimental group conducted the CCIA treatment while the Comparison group was taught in the traditional way. Both groups administered the posttest.

Table 1: The nonequivalent Control group design (O1=pretest, O2=Posttest, X=treatment)

<table>
<thead>
<tr>
<th>Group</th>
<th>Measurement (Pretest)</th>
<th>Treatment/intervention</th>
<th>Measurement (Posttest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>O₁</td>
<td>X</td>
<td>O₂</td>
</tr>
<tr>
<td>CG</td>
<td>O₁</td>
<td>---</td>
<td>O₂</td>
</tr>
</tbody>
</table>

**Population and Participants**

The research was conducted in Arbaminch College in SNNPRS of Ethiopia, with an enrollment of 3,500 regular Diploma pre-service teachers. The participants in this study were from a convenience sample of 87 pre-service chemistry teachers aged 18 to 24 years (M<sub>age</sub>=20.01, SD=1.28) enrolled in Introductory organic chemistry I.

**Instruments**

The instrument used in this study was Aliphatic hydrocarbon achievement test AHAT (see Appendix-A). The students’ scores on AHAT served as the basis for judging students’ achievement in this study. It was designed to assess pre-service teachers’ achievement in aliphatic hydrocarbon concepts. This test was developed by the researcher based on Bloom, Engelhart, Furst, Hill, and Krathwohl [38] objectives classification in relation to the content under study. The cognitive process dimensions of those taxonomies are: knowledge, comprehension, application and analysis, they were used based on the nature of the content.
The purpose of AHAT was to measure overall achievement and progress of students and covered pretest and posttest in relation to conceptual contents in aliphatic hydrocarbon concepts.

Reliability and Validity of the Instruments

To ensure validity the AHAT was checked by three Senior chemistry lecturers of the college. Also, construct validity was checked by running correlation of pilot data with students’ previous chemistry results [39]. The internal consistency reliability was checked based on appropriate literature [40][41].

Pilot study

The Conceptual change instructional approach using CCTs (see Appendix-B) is an approach that is not familiar to study area and therefore piloting was required. The approach was piloted with 33 students in college context with a lesson plan format designed for the approach. Pilot study was conducted in a different college than the study site. It helped in predicting teacher’s progress from one phase to another phase based on the format. It also helped to see how the CCTs could be used in the classroom setting appropriately.

The participants took part during piloting of AHAT with 20 multiple choice items and four alternatives focusing on factual and procedural knowledge from which respondents were to select responses. Item analysis was carried out for all the items in the AHAT.

First, item difficulty index was computed based on appropriate literature [42] [43] which is the relative frequency of test takers who provided correct answers to an item [44] [45]. Also, the range of discrimination among these respondents was computed using item discrimination analysis [44] [46]. For this purpose, the AHAT is scored, scores were rank ordered: 27% of the highest and 27% lowest scores were selected. This means, respondents were divided into three groups (upper 27%, lower 27% and middle 46%) based on their test results on that item. Then Item discrimination
index was computed by subtracting number of test takers in the lower 27% who pass the test from the number of test takers in the upper 27% who pass that item [47][48], the value was divided to the total number of test takers in the upper group. According to Ebel and Frisbie [48] selecting upper and lower groups for item analysis has an advantage in terms of relevance and convenience. Based on the results of item analysis some items were accepted and some others items were rejected. After piloting, from 20 AHAT only 13 items retained for the main study. The reliability Kuder-Richardson -20 (KR-20) of this tool was found to be 0.70 which is acceptable [40][41].

**Procedures of data collection**

The AHAT should indicate achievement of participants. The Experimental group and Comparison group were given pre-test before the intervention. After the intervention (this took seven weeks), the researcher with the assistance of Organic chemistry instructors administered the post-test in both groups. The administration of this instrument was by creating test or assessment mood among pre-service teachers. The creation of assessment outlook was done in collaboration with Organic chemistry instructors. The next steps were, scoring the responses and generating quantitative data. These steps were completed accordingly.

**Data Analysis**

In this study data were available through AHAT which was normally distributed based on skewness and kurtosis values [49]. For perfectly normally distributed data, skewness and kurtosis value are nearly zero [50][51]. Lack of symmetry (skewness) and pointiness (kurtosis) are two main ways in which a distribution can deviate from normal [50]. However, skewness and kurtosis values in the range between -2 and +2 can be accepted as normal distribution [49][50]. The AHAT data did not deviate from these ranges in this study. After normality check the researcher used
parametric tests (independent t-test, paired samples T-test) to analyze and interpret the collected data on AHAT (pre- and posttest). For this purpose, statistical analysis SPSS 20 version was used.

RESULTS, DISCUSSION AND CONCLUSION

Results

Prior to examining the effect of Conceptual change approach on pre-service chemistry teachers’ achievement in aliphatic hydrocarbon concepts in this study, an attempt was made to ensure equivalence of Experimental Group (EG) and Comparison Group (CG). For this purpose, an independent sample t-test was performed on the AHAT pretest.

Table-2: Independent-samples t-test results for PRE-AHAT with respect to groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>df</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-AHAT</td>
<td>.3</td>
<td>.85</td>
<td>-.398</td>
<td>.691</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td></td>
<td>44</td>
<td>6.39</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td></td>
<td>43</td>
<td>6.53</td>
<td>1.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Independent samples t-test analysis (see Table-2) shows that the differences between the AHAT mean scores of both groups were similar. The maximum possible score of AHAT was 13%. A paired samples t-test was performed to check if there was a change in the mean scores between pre- and posttest results of both groups (see Table-3). Compared to the pretest scores the Experimental group and Comparison and post test scores for achievement test were found to be significant at p=0.001 level. This confirms the evidence to prove change in the mean scores after implementation of CCIA. However, this does not confirm that the CCIA is better than traditional
instruction since the two teaching approaches show significant difference using paired samples t-test. To check if there is a significant difference in scores of achievement independent samples test was employed on post test scores of groups. As the Post-AHAT data were normally distributed, independent samples t-test was used to measure the effect of treatment on participants’ achievement (Post-AHAT) (see Table-4).

**Table-3: Paired T-test results of both groups (M=Mean, SD=Standard Deviation, SEM=Standard Error Mean)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison group</td>
<td>PRE-AHAT - POST-AHAT</td>
<td>-1.23</td>
<td>2.01</td>
<td>-4.02</td>
</tr>
<tr>
<td>Experimental group</td>
<td>PRE-AHAT - POST-AHAT</td>
<td>-2.59</td>
<td>2.38</td>
<td>-7.23</td>
</tr>
</tbody>
</table>

**Table-4: Independent-samples t-test results for Post-AHAT**

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>df</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post-AHAT</td>
<td>.42</td>
<td>.85</td>
<td>2.86</td>
<td>.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td>44</td>
<td>8.98</td>
<td>1.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>43</td>
<td>7.77</td>
<td>1.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Independent samples t-test analysis shows that the differences between the AHAT mean scores of both groups implying that after the intervention the groups were different. Thus, a significant difference for treatment was obtained for Post-AHAT, p<0.01, d=0.61 (manually computed value). This is of medium effect size for Post-AHAT [52]. This result indicated that the
groups differ significantly after intervention in favor of CCIA. In addition, the line graph depicts the difference between groups in terms of Post-AHAT (see Figure-1).

![Figure-1: Line-graph of Post-AHAT scores in comparison to pre-AHAT scores](image)

**DISCUSSION**

In this study, an independent sample t-test was carried out to test differences between the Experimental and Comparison group on pretest mean scores. The groups were not significantly different based on the pre-AHAT mean score: both groups were similar. This means, before treatment the effectiveness of the instructional approaches on pre-service chemistry teachers’ achievement could not be attributed to prior knowledge difference.

In addition, a paired samples t-test was performed to check if there was a change in the mean scores due to the intervention. Compared to the pre-test scores the post-test scores for achievement were found to be significant at \( p = 0.001 \) level-the Experimental group post-test
scores were found to be better. These confirm the existence of evidence to prove change in the mean scores after implementation of CCIA. To check differences by another way the test independent samples t-test was employed. The test results indicated that the Experimental group scores were significantly (at P=0.01) higher than the Comparison group scores. This is due to the use of Conceptual change instructional approach using Conceptual change texts in the Experimental group.

This finding is consistent with the findings in other studies and support the fact that when students are exposed to Conceptual change instructional approach their achievement increases significantly [53][54][55][28][30][56]. For instance, Ozkan and Selcuk [56] found that students in the Conceptual change text group scored significantly higher than those in the traditional instructional group instructing pressure and buoyancy concepts in physics. Also, Sendur and Toprak [30] found that students in the Conceptual change text group scored significantly higher than those in the traditional instructional group teaching alkenes.

CONCLUSION

In a quantitative study, an intervention according to the effectiveness of the use of Conceptual change texts was carried out for seven consecutive weeks. After intervention, analysis of the results revealed that the Experimental group outperformed the Comparison group in a special achievement test. Due to the significant and meaningful results by the Experimental group the superiority of CCIA is confirmed.

In general, through learning by using Conceptual change texts the well-known misconceptions of many students have changed. The knowledge of participants has increasing in
Organic chemistry. By making discussions on those texts during the treatment, students got the advantage to know which answers are scientifically right and which answers with misconceptions.

The results of this study revealed that during preparation for teaching chemistry and Organic chemistry in particular misconceptions well known from literature should be included. Barke, Hazari and Sileshi [59] indicated that students perform better by discussing those wrong answers and with the help of the teacher they grab successfully the scientific mental model.

REFERENCES


**APPENDIXES**

**Appendix-A: Some Items of the Aliphatic Hydrocarbon Achievement Test**

**Directions:** Each of the questions below is followed by four suggested answers. Select the correct one and encircle the letter of your choice.

1. A molecule of a saturated compound is one that
   A. contains only carbon-carbon sigma bonds
   B. contains at least one carbon-carbon pi bond
   C. contains at least one carbon-carbon multiple bond
   D. undergoes addition reaction

2. The molecular structure below is given – what is the IUPAC name?

```
CH3--C=C--CH2--CH2--CH--CH3
   |                       |
   CH3                      Cl
```

   A. 2-chloro-3-ethyl-4-methyl-5-heptyne
   B. 6-Chloro-5-ethyl-4-methyl-2-heptyne
   C. 5-Chloro-6-ethyl-4-methyl-2-heptyne
   D. 6-Chloro-5-ethyl-4-methyl-5-heptyne
3. The removal of water from alcohol leaving an alkene is
   A. Hydration
   B. Dehydration
   C. Hydrogenation
   D. Dehydrogenation

4. If an unsymmetrically substituted alkene molecule reacts with a hydrogen halide molecule,
   A. the H atom adds to the C atom with greatest number of H atoms
   B. the halogen atom adds to the C atom having fewer H atoms
   C. the addition follows Markovnikov’s rule
   D. All of the above

Appendix-B: Alkene Reactions (Markovnikov’s Rule)
What is the name of the compound formed when the following molecules react? Why? Explain.

\[
\text{CH}_3\text{CH} = \text{C} - \text{CH}_3 + \text{HCl} \rightarrow \\
\text{CH}_3 \\
\text{CH}_3 \\
(I) \quad 2\text{-chloro-2-methylbutane} \\
(II) \quad 2\text{-chloro-3-methylbutane}
\]

How do we predict the addition product of multiple bond or double bond containing hydrocarbon molecules?

Some students select option II, because they assume that addition of the HCl molecule takes place at the C atom with the double bond on the side of the longest chain. This is not an idea accepted by scientific community, it is a misconception.
The two C atoms of a double bond can add HCl molecules during addition reactions with reagents such as HCl, HBr, and HOH. For example, two different compounds might possibly be formed by reaction of 1-butene with HCl. In conditions of this sort, the rule that predicts which of the two products is formed is called **Markovnikov's rule**: *In the addition of reagents like HCl to an alkene, H atoms add to the double-bonded C atom that has the greater number of H atoms already bonded to it.* In HCl, HBr and H₂O molecules the H atoms have a partially positive charge because they are bonded to more electronegative atoms. Thus, in the reactions of the type indicated above, the H atom from HCl molecule bonds to the C atom with more H atoms, and the Cl atom bonds to the C atom with less H atoms.

Thus, the name of the compound formed is **2-chloro-2-methylbutane**:

1) \( \text{CH}_3\text{CH}_2\text{CH}==\text{CH}_2 + \text{HCl} \rightarrow \text{CH}_3\text{CH}_2\text{CHCl}-\text{CH}_3 \)

2) 

3) }
A TOOLKIT FOR MASTERING ORGANIC NOMENCLATURE IN
GENERAL CHEMISTRY

Cassandra Orozco¹,², James E. Becvar² and Mahesh Narayan²*
¹Department of Metallurgical, Materials Engineering, University of Texas at El Paso
²Department of Chemistry, University of Texas at El Paso
*Correspondence: Professor Mahesh Narayan, Department of Chemistry, UT El Paso, 500 W.
Univ. Ave., El Paso, TX 79968; Ph: 915-747-6614; Fax: 915-747-5748;
Email: mnarayan@utep.edu

ABSTRACT

In the second semester of general chemistry, students receive an introduction to organic
chemistry. A strong foundation in learning starts with the ability to correctly name organic
compounds. Our proposed strategy involves the identification of the parent chain, the recognition
of resident functional groups, and the ability to discern/indicate the correct isomer if any, etc. We
propose a modular toolbox that facilitates compartmentalization of the nomenclature process of
organic compounds and helps the student adequately identify all structural elements present in an
organic compound. Accurately naming an organic compound is essential to understanding of its
properties; to success in Organic Chemistry 1 and 2; and, for a career as a Chemist in academia,
industry or in government agencies. The advantages of our procedure is discussed using examples
to illustrate the process. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

Organic chemistry is the study of compounds that contain chains of carbons with hydrogens attached or hydrocarbons for short [1]. In the second semester of General Chemistry (Gen Chem II), science majors acquire knowledge of the basic procedures of naming organic structures of the aliphatic group and the aromatic group. Herein, they also learn about functional groups which are atoms that are responsible for influencing the carbon chain’s chemical behavior in reactions [1].

It is common for students not to fully understand the basic naming and reactions or organic compounds. The fundamentals of organic compounds are essential for future chemistry courses. This is a method for guiding peer leaders of the PLTL program in their mission of helping students learn organic chemistry fundamentals. We accomplish this by organizing the naming process into a collection of steps. It helps if students break up a large problem into manageable sub-problems. Learning seems to be achieved when things are broken into steps. Studies have shown that the brain works more efficiently if tasks are done one at a time rather than at the same time [2].

METHODOLOGY

In introductory organic chemistry there are two classes of compounds, the aliphatic and aromatic groups. The rules for their nomenclature are set by the International Union of Pure and Applied Chemistry (IUPAC) [3].

In each group of carbons in a chain (or a ring), there is a name that identifies the chain called parent chain. The parent chain describes what classification the carbon compound is (aliphatic or aromatic) and how long the carbon chain is.
In the first lesson students are taught is that in a chain of carbons, the longest, continuous chain is the parent name. As an example, a chain of five carbons with only single bonds is called pentane, which is an aliphatic member. An image below shows the structure of a pentane:

\[
\begin{align*}
\ce{H & | & \ce{C} & | & \ce{C} & | & \ce{C} & | & \ce{C} & | & \ce{H}} \\
\ce{H} & & \ce{H} & & \ce{H} & & \ce{H} & & \ce{H} & & \ce{H}
\end{align*}
\]

Pentane is a hydrocarbon; i.e., it is composed of carbons bonded to hydrogens. There are various functional groups that are included in the name, and some of these functional groups have priority in being recognized in the parent name and the student can consult with that in their chemistry book. Examples of functional groups are: alkyls, alkenes, cycloalkanes, alkynes, ketones, esters, ethers, aldehydes. The identity of the functional group, depending on its priority, is emphasized in the parent name based upon IUPAC standards [3].

For educational purposes only the alkyls, alkenes, alkynes and alcohols may be used as examples throughout this article. Some functional groups must be specified by name depending on their location in the chain. The key to learning nomenclature is determining the longest chain of carbons. If after extracting the longest chain and there are leftover chains, or substituents attached, those are to be considered in the name as well [1]. The location of those substituents in the chain are identified in the name. If there are several of the same substituent there must be something in the name to signify its quantity.

A method that relates to the steps in identifying the appropriate name of the carbon chain is analogous to having a family that lives in a street and each familiar member that lives in the
street lives in their own house. Their street name will be the longest chain of carbons or the parent name. If there is functional group that has greater priority in the parent name, then it will have significance in the parent name. For example, an alcohol will have an “ol” ending. The street name which is the longest chain of carbons would be the family last name, unless, if there is a functional group of higher priority, the group will hold the last name of the family. Each member that lives in a carbon is their house and their house address can be, for instance, carbon number 2, meaning that family member or substituent or alkyl group is located at carbon 2 in the street of carbons. This method is further explained below:

The following structure shows how the name can be broken into parts in a way that helps the student imagine what this structure looks like, and what it contains:

<table>
<thead>
<tr>
<th># (CARBON #n ASSIGNED)</th>
<th>NUMBER OF THEM SPECIFIED IF THE ALKYL OR SUBSTITUENT OCCURS MORE THAN ONCE USING A PREFIX (e.g. “di” = 2)</th>
<th>FIRST ALKYL OR SUBSTITUENT IDENTIFIED IN THE NAME</th>
<th>… (ANY OTHER ALKYL OR SUBSTITUENTS BETWEEN ALONG WITH THEIR LOCATION AND NUMBER OF THEM IF ANY APPEAR MORE THAN ONCE IN THE CHAIN)</th>
<th>LAST ALKYL OR SUBSTITUENT ATTACHED TO THE PARENT NAME</th>
<th>PARENT NAME OF THE HYDROCARBON CHAIN (LOCATION SPECIFIED IF NECESSARY)</th>
</tr>
</thead>
</table>

When given a structure, and the student needs to identify the correct IUPAC name, the first thing the student should do is to count the longest chain of carbons and the functional group responsible for the carbon group. The student must be able to recognize various functional groups and that specific functional group will give a specific ending. An alkane has an “ane” ending and a ketone has an “one” ending. That parent chain goes in the yellow box above. Then, the green boxes are the smaller chains of carbons or the other substituents attached to the chain and the amount can vary. The last alkyl or substituent will be attached to the parent name. Then, the very
first green box is where the first alkyl or substituent goes. The blue box is reserved in cases where the number of the same kind of substituents or alkyls appear more than once in the chain and those are denoted with Latin prefixes such as di, tri, etc. The pink box is to specify the location of the substituent or alkyl in the carbon chain.

By IUPAC standards there are rules implemented to keep the naming consistent. That is for the green boxes, the order by which the alkyls or substituents appear in the name is alphabetically such as as chloro, flouro, methyl, etc would be listed alphabetically by the first letter of their name. Thus, for assigning the location of these species attached to the chain, by counting along the chain and assigning a carbon number n, the sum of all n(integers) must the least sum possible. This is achieved by counting the chain starting from the direction that produces the lowest possible number for all the substituents. Once the smallest sum is accounted for, then those are the carbon locations or carbon numbers the substituents or alkyl groups are assigned. The carbon numbers are in the pink boxes above. It is also important to note that species in the green boxes are only named alphabetically not the prefixes in the blue boxes. These are the rules obeyed by the IUPAC society; students can learn these rules from their chemistry books [3].

For the parent names that go in the yellow boxes the location of parent function must be specified if it has priority in being mentioned in the last part of the name of the carbon compound. Consider alcohol. Alcohol has authority in the parent name, which gives the molecule an “ol” ending and gets the first call to the lowest carbon assigned to indicate the location of the hydroxyl group. The rest of the substituents and alkyls will be assigned a number according to the lowest integer for the hydroxyl group. For example:
There are two possible answers that a student can come up with - 3,4-dimethylpentan-6-ol and 5,6-dimethylpentan-3-ol. Which name would be the correct name for the structure shown above? Because the hydroxyl functional group has more authority of the name than the alkane functional group, the OH- ion gets the lowest carbon number assigned and the parent name will have an “ol” ending. Thus, the correct name is 5,6-dimethylpentan-3-ol. The remaining substituents or alkyl groups would be assigned carbon numbers according to the hydroxyl group. This method of learning the basic organic nomenclature can be analogous to having a family. A family with all kinds of relatives, personalities and relationships. This concept can help a student relate to learning this nomenclature. Let’s demonstrate to the concept of having a family, see the following name:

3-flouro-2,2-dimethylpentane

The structure of the name is shown:
The longest chain of carbons is the family name, the last name, the last name has authority of the chain. The last name tells you how long the chain is. The last name can tell you, if it is an alkene, alkyne, alcohol, or any other functional group and the location of that functional group.

This structure can be represented as a family of atoms bonded at a specific orientation and to an atom. First, in the name and image the student must identify the longest chain of carbons. The carbons are located at every peak or corner of the chain and end points of the structure. The longest chain is five carbons. Think of the longest chain as a street and each carbon along with the longest chain is a house. The other species attached to the longest chain or remain in the chain are the relatives of the family and live at a specific carbon (at their own house). See the name again:

3-flouro-2,2-dimethylpentane
The last name is also the parent function of the group of atoms. This is highlighted as yellow just like the yellow box above. The last alkyl group or substituent attached to the last name and to the beginning of the name is the first name of the family. The first name of the family tells you all the relatives that live along that street of carbons. The first name is highlighted in green. These species “live” at a specific carbon, so the numbers highlighted in pink are the addresses to the house these species “live” in or the specific carbon they “live” in.

In 3-flouro-2,2-dimethylpentane, there are three relatives that “live” on the street of carbons, a fluorine (Fernando) and two methyls (Marie and Michael). As mentioned before, the three substituents are located at a specific carbon number, Fernando’s address is 3 and Marie and Michael are two cousins that “live” in address 2. The fluorine is located at carbon 3 and the two methyl’s are located at carbon two.

Within the first name, not only does the name tell you what type of substituents or alkyls the molecule possesses but also if there is more than one kind of the same substituent. In the name 3-flouro-2,2-dimethylpentane, the prefix “di” tells that there is 2 methyls at carbon 2, and the location 2 is written twice to indicate that two methyls live at carbon 2. Another example could be 2,3-dinitro-4-nonanol where there are two nitro functional groups located in carbon 2 and 3.

Here are examples this method can be applied (Exploration):

1. 4-methyl-\textit{trans}-2-pentene
2. 3-pentanone
3. 2,3-dinitro-4-nonanol
4. 4-ethyl-2-methyl-hexane

Sometimes the last name of the family can only appear, therefore, only the yellow box would be considered, meaning the family has a street but no relatives live in that street. An example
could be as simple as cycloheptane. The last name tells you that the functional group is a cycloalkane and the most number of carbons is 7. Another example is when a structure can have more than one correct name, but there is one that is most preferred for consistency. An example can be shown:

There are technically two correct names for the structure. One is 5-ethyl-4-methyloctane or 4-ethyl-5-methyloctane. Again, they are both correct, but the most preferred would be the second one because it is more consistent to have the lowest carbon number assigned to the first alkyl or substituent appear first in the alphabet. There are many examples of this, and the student must be able to identify those situations. This tool can be used in the basic learning or organic nomenclature for students taking the second semester of general chemistry.

CONCLUSION

The goal for the Peer Led Team Learning Program in the Chemistry Department at the University of Texas at El Paso strives to implement ways to make learning more effective for students to succeed in their general chemistry courses. One way is, the peer leaders of the PLTL utilizes a workbook to use in workshops to work out problems for students to gain cooperative
skills to work with their peers to learn the material and are encouraged to engage in discussions about the subjects. There is always opportunity to improve on making workshops more effective by coming up with ways students can learn such as memorizing the seven only diatomic molecules that exist at room temperature by the phrase “Have No Fear Of Ice Cold Beer” (PLTL)[4]. Have for hydrogen, no for nitrogen, fear for fluorine, of for oxygen, ice for iodine, cold for chlorine and beer for bromine. Also, the state for ice is solid, so the student can make the connection to iodine being the only diatomic molecule that is solid at room temperature. Same for bromine, beer is a liquid at room temperature so that means the state for bromine is liquid. One of the subjects’ students tend to struggle on is the introduction to organic nomenclature and a method has been invented that can help students make connections to stuff they can relate to.

Overall, organizing the problem into steps from image to name or name to image could be used by the household method. Students can use their chemistry books to determine which functional groups have priority. Then determining the first name means what other species remain on the longest chain identified and their location they are at in the chain. This method could help students mentally proceed through a step process and learn the basic organic nomenclature.

REFERENCES
COMPARATIVE EFFECT OF TWO PROBLEM-SOLVING INSTRUCTIONAL STRATEGIES ON STUDENTS’ ACHIEVEMENT IN STOICHIOMETRY

Mandina Shadrec¹ and Ochonogor Chukunoye Enunuwe²
¹Department of Applied Education, Midlands State University, Zimbabwe
²Cape Peninsula University of Technology, Cape Town, South Africa
Email: smandinas@gmail.com

ABSTRACT

The study aimed to investigate the comparative effects of Selvaratnam-Fraser and Ashmore et al Problem-Solving instructional strategies on Advanced Level students’ achievement in Stoichiometry. The population of the study was drawn from 15 high schools in Gweru urban District of the Midlands province in Zimbabwe. Using convenience sampling techniques 8 high schools with \( n=525 \) Advanced Level Chemistry learners and 8 teachers participated in the study. Four schools formed the experimental group (\( n=250 \)) and the other four schools formed the control group (\( n=275 \)). The study employed a quasi-experimental design with a non-equivalent control group approach consisting of pre-and post-test measures. Intact classes participated in the study as it was not possible to randomly select participants for the study. The principal instruments for data collection were standardized achievement Tests in stoichiometry that were aligned to the Zimbabwe Schools Examinations Council A’ level National syllabus for chemistry. The tests were written by all participants at pre- and post-stages of the experiment. The problem-solving instruction was implemented in four experimental schools by the respective chemistry teachers who had been trained as research assistants in the use of the problem-solving strategies in chemistry teaching. The four control schools were also taught by their teachers using the conventional lecture method. Analysis of Covariance (ANCOVA) was used to analyze data. The results of this study indicated that the participants in experimental schools performed significantly better than participants in control schools on certain aspects of problem-solving performance. The Scheffe’s post-hoc test indicated that students taught using the Ashmore et al problem-solving instructional strategy performed better than those taught with the Selvaratnam-Fraser problem-solving strategy. Chemistry teachers are therefore strongly recommended to use problem-solving instructional strategies in their classes to facilitate students’ problem-solving performance. The study further recommends that pre-service chemistry teachers be properly trained in instruction that promotes problem-solving and how to effectively implement problem-solving instruction. Furthermore, in-service training for practicing chemistry teachers is recommended so that they can embrace the skills of the problem-solving strategies for effective implementation of the strategies in teaching chemistry. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

The critical role that science plays in the technological development of a nation cannot be overemphasized [1]. Recognizing this instrumental role that science plays in improving the socio-economic wellbeing as well as industrialization of nations it becomes important that science educators develop strategies of improving and promoting the teaching and learning of science [2]. Chemistry is one of the science subjects that plays an important role in national development. As noted by [3] the scientific development of any nation hinges upon the quality of chemical education offered in schools. Chemistry as a school subject is relevant to number of manufacturing industries such as pharmaceuticals, food processing, agricultural, clothing and textiles, petrochemical as well as metallurgical industries [1].

However, due to its abstract, complex and conceptually demanding nature, chemistry has been found to be difficult for most secondary school students [4, 5, 6, 7]. According to [8], chemistry students find a number of concepts difficult to learn. Stoichiometry has been identified as one of the topics in chemistry that students find difficult to learn [9, 10]. Research has shown that the poor performance by Zimbabwean students in chemistry is as a result of their poor problem-solving in stoichiometry [11]. The Zimbabwe Schools Examinations Council [12] chemistry examiners report notes the difficulties chemistry students have in performing numerical calculations involving the mole concept as well as writing of balanced equations.

Chemical stoichiometry has been found to be multi-topic, complex and abstract in nature as a result students find it difficult to comprehend [13]. [14] further note that stoichiometry is fundamental to all aspects of chemistry and requires students’ deep problem-solving skills. To be able to solve stoichiometric problems, students should not only possess good mastery of stoichiometry concepts, but also ability to construct and balance reaction equations and using them
in calculation of the quantity of chemical substances [14]. Furthermore, in stoichiometry, students are actively engaged in solving problems that are sophisticated [13]. To be actively engaged in solving sophisticated problems, students need to have knowledge structures that are well organized [15] which in most instances is lacking among high school students consequently they find stoichiometric problem-solving difficult to undertake. This lack of well-organized knowledge structures requires that chemistry educators intervene with different teaching and learning strategies to address students’ problem-solving challenges and improve their capabilities in problem-solving.

Efforts to develop instructional strategies to enhance student’s problem-solving abilities in chemistry have led to the development of many problem-solving models and has seen the establishment of these models in teaching and learning basic science [16, 17]. This has resulted in the enhancement of the academic achievement of students. In the Zimbabwean context, no research has attempted to study how problem-solving instructional strategies can enhance the abilities of chemistry learners in problem-solving. This study, therefore, seeks to investigate how selected problem-solving models [18, 19] can facilitate Zimbabwean Advanced Level chemistry students’ problem-solving skills in stoichiometry.

**STATEMENT OF THE PROBLEM**

Students’ poor problem solving ability, learning difficulties and misconceptions in stoichiometry is an indication of the likelihood of a deficiency in instructional strategies used in the chemistry classroom a conclusion drawn by [1]. Chemistry educators should therefore find strategies of learning difficulties and improve the problem-solving abilities of chemistry students. Currently, the instructional strategies being used in chemistry teaching have not realised
considerable improvements in the quality of students’ achievement in the subject to a considerable extent. As a result, developing better strategies of teaching chemistry has been and is becoming one of the core issues that scholars deal with in chemistry education. The focus on improving learners’ problem-solving skills using problem-solving instructional strategies to foster a deeper and more meaningful understanding of stoichiometry therefore becomes important for chemistry educators.

OBJECTIVES, RESEARCH QUESTIONS AND HYPOTHESES

The study addressed the following objectives:


ii. To determine if gender has an influence on the achievement of students in stoichiometry when exposed to the [18] as well as [19] problem-solving models.

The following Research Questions guided the study:

1. What is the difference in the mean achievement scores of students taught with [18] and [19] problem-solving models and those taught with the conventional method?

2. To what extent would gender influence the mean achievement scores of students taught with [18] and [19] problem-solving models in stoichiometry and ionic equilibria.

The study tested the following research hypotheses:

HO1: There is no significant difference in the performance of students taught using the two problem-solving instructional strategies and those taught using lecture methods.
HO2: There is no significant difference between the performance of female and male students taught stoichiometry using the two problem-solving instructional strategies and those taught using lecture methods.

**RESEARCH METHODOLOGY**

The study employed a quasi-experimental research approach with a non-randomized, non-equivalent pre-test and post-test control group. In this study, intact classes were used instead of randomly composed samples since, school classes exist as intact groups and school authorities would not allow the classes to be taken apart and rearranged for research purposes. The use of intact classes made it possible for the researcher, to administer a treatment or intervention to some of the classes while the other classes act as the control [20]. The views of [21] seem to suggest that random selection is not possible in educational research, while [22] observes that researches involving the effectiveness of teaching strategies to improve student achievement random assignment are rare. Since it was not possible for the researcher to conduct a true experiment, non-equivalent control group design was used in the study [23].

The sample comprised of 525 Advanced Level chemistry learners. The participants were drawn from eight high schools in the district. Two hundred and seventy-five (275) of these participant learners (from four schools) formed the control group, while the other 250 learners from four of the remaining schools constituted the experimental group. The learners in the control group (schools) were taught by their teachers using the conventional lecture method. The learners in the experimental group (schools) were also taught by their teachers who served as research assistants after having been trained on the use of problem-solving instructional strategies. These research assistants implemented problem-solving instruction in their classes.
Data for this study were collected using problem-solving achievement tests in stoichiometry. The test comprised of multiple choice and open ended items. The test was validated by experts in chemistry education before its use in the pilot as well as in the actual study. The internal consistency of the test was evaluated using Cronbach alpha coefficient and found to be 0.84, which is an acceptable level of reliability. The analysis of data was carried out using both descriptive statistics (mean, standard deviation) and inferential statistics (analysis of covariance, ANCOVA) using Statistical Package for Social Sciences (SPSS) version 20.0. The post-test score for stoichiometric problem-solving test was subjected to Analysis of Covariance (ANCOVA) using pre-test scores as covariates. The use of ANCOVA analysis was to "statistically control" for influence of confounding variables. A p-value of less than 0.05 was considered to be statistically significant.

FINDINGS

The results of the study are presented based on the research questions and research hypotheses formulated. All hypotheses were tested at 0.05 level of significance.

Research Question one:

What is the difference in the mean achievement scores of students taught with Ashmore, Casey and Frazer (1979) and Selvaratnam and Frazer, (1982) problem-solving models and those taught with the conventional method?

To address this research question, a comparative analysis of the effects of the Selvaratnam-Frazer as well as Ashmore et al. problem solving approaches on Advanced Level students' achievement in Stoichiometry was made. The results of the post-test indicated that the
experimental schools had greatly improved when compared to control schools as shown in tables 1 below.

**Table 1: Mean scores and standard Deviations (SD) of students in Stoichiometry**

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>40.6160</td>
<td>1.15667</td>
<td>250</td>
</tr>
<tr>
<td>Exp- Ashmore et al</td>
<td>56.7179</td>
<td>1.15852</td>
<td>117</td>
</tr>
<tr>
<td>Exp-Selvaratnam-Fraser</td>
<td>56.6949</td>
<td>0.99149</td>
<td>118</td>
</tr>
<tr>
<td>Total</td>
<td>48.4124</td>
<td>8.12678</td>
<td>485</td>
</tr>
</tbody>
</table>

From the data presented in table 1, it was observed that the students in the two experimental groups (Selvaratnam-Frazer and Ashmore et al) had mean scores of 56.6949 and 56.7179 and corresponding Standard deviations of 0.99149 and 1.15852 respectively. The mean score for the students in the control group was found to be 40.6160 and the standard deviation being 1.15667. The observation implied that the use of the two models indicated a positive effect on the students’ achievement in stoichiometry.

The study went on further to statistically test the main effect of Selvaratnam-Frazer and Ashmore et al problem-solving instruction on participants’ overall performance in stoichiometry. In this study, the use of ANCOVA enabled the researcher to isolate the effect of Selvaratnam-Frazer and Ashmore et al problem solving instructional strategies after having statistically removed the effect of the covariate (pre-test scores).

The following null hypotheses (Ho) was tested at 0.05 levels of significance.
Null hypothesis: \( H_0: \) There is no significant difference in the mean achievement scores of students’ taught using the Selvaratnam-Frazer and Ashmore et al problem-solving models and those taught with the conventional method.

Alternate hypothesis: \( H_1: \) There is a significant difference in the mean achievement scores of students’ taught using the Selvaratnam-Frazer and Ashmore et al problem-solving models and those taught with the conventional method.

The results of the hypothesis test are presented in table 2 below.

**Table 2: The test of Between-Subjects Effects; Stoichiometry test**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td>4.312</td>
<td>1</td>
<td>4.312</td>
<td>3.459</td>
<td>.084</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td>31140.261</td>
<td>2</td>
<td>15570131</td>
<td>12491.765</td>
<td>.000</td>
</tr>
</tbody>
</table>

The result in table 2 suggests that the treatment (Selvaratnam-Frazer and Ashmore et al problem-solving models) is a significant factor on students’ achievement in stoichiometry. Thus the hypothesis \( H_0 \) that there is no significant difference is rejected. The implication is that a significant difference exists in the mean scores of subjects exposed to the two problem-solving models and those not exposed.

**Research Question 2**

*To what extent would gender influence the mean achievement scores of students taught with Selvaratnam-Frazer and Ashmore et al problem-solving models in the Stoichiometry Achievement Tests?*
Table 3: Mean Achievement scores of male and female students in the Stoichiometry Achievement Test

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>female</td>
<td>40.9912</td>
<td>1.25519</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>male</td>
<td>40.8613</td>
<td>1.13230</td>
<td>137</td>
</tr>
<tr>
<td>Exp Selvaratnum-fraser</td>
<td>female</td>
<td>51.2542</td>
<td>2.16232</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>male</td>
<td>51.6271</td>
<td>1.63895</td>
<td>59</td>
</tr>
<tr>
<td>Exp- Ashmore et al</td>
<td>female</td>
<td>56.0690</td>
<td>3.28667</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>male</td>
<td>56.5085</td>
<td>1.26454</td>
<td>59</td>
</tr>
</tbody>
</table>

Table 3 shows that the males in the two respective experimental groups had higher mean scores than their female counterparts.

The following hypothesis was tested at the 0.05 levels of significance.

Ho1: There is no significant difference in the performance of male and female chemistry students exposed to Selvaratnam-Frazer and Ashmore et al problem-solving models.

H1: There is a significant difference in the performance of male and female chemistry students taught using Selvaratnam-Frazer and Ashmore et al problem-solving models.

Table 4. ANCOVA summary Table for post-test Performance Scores based on gender

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>21692.770*</td>
<td>6</td>
<td>3615.462</td>
<td>1181.139</td>
<td>.000</td>
<td>.937</td>
</tr>
<tr>
<td>Intercept</td>
<td>5643.119</td>
<td>1</td>
<td>5643.119</td>
<td>1843.557</td>
<td>.000</td>
<td>.794</td>
</tr>
<tr>
<td>pretest</td>
<td>31.654</td>
<td>1</td>
<td>31.654</td>
<td>10.341</td>
<td>.001</td>
<td>.021</td>
</tr>
<tr>
<td>gender</td>
<td>5.743</td>
<td>1</td>
<td>5.743</td>
<td>1.876</td>
<td>.171</td>
<td>.004</td>
</tr>
<tr>
<td>group</td>
<td>21335.570</td>
<td>2</td>
<td>10667.785</td>
<td>3485.071</td>
<td>.000</td>
<td>.936</td>
</tr>
<tr>
<td>gender *group</td>
<td>7.922</td>
<td>2</td>
<td>3.961</td>
<td>1.294</td>
<td>.275</td>
<td>.005</td>
</tr>
<tr>
<td>Error</td>
<td>1463.155</td>
<td>478</td>
<td>3.061</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1103092.000</td>
<td>485</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>23155.926</td>
<td>484</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The data in table 4 indicates that the F-ratio for the gender factor was not significant since 0.05 is less than 0.171 (P>0.05). The conclusion is that there was no significant difference between the mean achievement scores of male and female students taught stoichiometry using the models.

Scheffe’s post hoc analysis

To determine which of the two methods was most effective in teaching stoichiometry, a post-hoc analysis was conducted using Scheffe’s Post Hoc test. The results are summarized in table 5.

*Table 5. Scheffe’s post hoc analysis for students’ performance on the stoichiometry test*

<table>
<thead>
<tr>
<th>group</th>
<th>N</th>
<th>Subset 1</th>
<th>Subset 2</th>
<th>Subset 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>contr</td>
<td>250</td>
<td>40.9200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exp-Selvaratnam-Fraser</td>
<td>118</td>
<td></td>
<td>51.4407</td>
<td></td>
</tr>
<tr>
<td>exp-Ashmore et al</td>
<td>117</td>
<td>1.000</td>
<td>1.000</td>
<td>56.2906</td>
</tr>
<tr>
<td>Sig.</td>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The results in table 5 show that learners in the two experimental groups are significantly different from those in the control group and that their performance was better than those in the control group. Moreover, the Scheffe’s post-hoc test also indicated that there was a significant difference between the two experimental groups (those taught using the Ashmore et al problem-solving model did significantly better than those taught using the Selvaratnam-Frazer problem-solving model.

**DISCUSSION**

Generally, the findings of the study revealed that problem-solving instruction is more effective on improving problem-solving skills of chemistry learners in stoichiometry than the
conventional teaching method. The finding of this study is in consonance with the view of [24, 25] who assert that problem-solving instruction enhances achievement in Chemistry more than conventional lecture method of teaching. This result is in agreement with the results of earlier studies carried out by [26] as well as [27] both of which established the relative efficacy of problem-solving instructional strategies in fostering students’ achievement in school subjects relative to the expository method. The findings are in accord with [28] who noted that the use of problem-solving instruction significantly increased students’ achievement in computer programming.

With reference to the second research question (To what extent would gender influence the mean achievement scores of students taught with problem-solving instructional strategies?), the effect of problem-solving instruction on stoichiometry problem-solving abilities and achievement of female and male students in the treatment group was not found to be statistically significantly different. Literature has reported many findings [29, 30, 31] revealing the exceptional performance of male students than their female counterparts in science. However, in the present study problem-solving instruction reduced the gender gap in stoichiometry problem-solving skills and performance indicating that gender is not a perfect predictor as far as achievement in stoichiometry concerned, whether students are taught using problem-solving approach or the conventional method. This finding was also in consonant with [32] as well as [33] that gender has no effect on students’ performance in chemistry and physics respectively, a position also held by [34] who also found out that gender difference had no influence on students’ performance in chemistry and science examinations.

The findings of men out performing women may perhaps have been perpetuated by gender stereotyping which is commonly based on cultural beliefs. This finding implies that whether a
student is male or female, gender does not make a difference in their academic achievement therefore students’ academic achievement is not a function of gender. All students irrespective of their sexes benefited in about the same margin from the use of problem-solving instructional strategies.

CONCLUSIONS

It can therefore be concluded that the application problem-solving strategies is more effective in helping students improve their problem solving performance than conventional lecture method. This clearly supports the implementation of problem-solving instruction in the chemistry classroom. The implication is that students who were taught using problem-solving strategies had well mastered the strategies of solving stoichiometry and ionic equilibrium problems better than those taught using the conventional method.

The gender difference among students exposed to problem-solving instruction was not significant implying that problem-solving instruction is capable of facilitating learning in similar manner among male and female students in stoichiometry and ionic equilibria.

Recommendations

Based on the major findings of this study, the following recommendations are made:

It is evident from the study that, problem-solving instructional teaching methods are effective in improving students’ achievement in stoichiometry and ionic equilibria. Therefore, chemistry teachers are strongly recommended to use these teaching methods in their lessons to facilitate students’ problem solving performance.
Considering that the goal of chemistry education is to improve problem solving skills of learners, findings from the study suggest need for proper training of pre service teachers in problem solving instruction as well as how to implement effectively problem-solving instruction. Furthermore, in-service training through symposiums and workshops should be organized and made compulsory for practicing chemistry teachers so that they can embrace the skills of the problem-solving strategies for effective implementation of the strategies in teaching chemistry.

REFERENCES


46


UTILIZATION OF LEARNING ACTIVITY PACKAGE IN THE CLASSROOM: IMPACT ON SENIOR SECONDARY SCHOOL STUDENTS’ ACADEMIC ACHIEVEMENT IN ORGANIC CHEMISTRY

1David Agwu Udu and 2Charles .U. Eze
1Department of Science Education, Faculty of Education, Federal University Ndufu-Alike Ikwo (FUNAI) Ebonyi State, Nigeria.

2Department of Science and Computer Education Enugu State University of Science and Technology (ESUT), Enugu
Correspondence Email: daviduduagwu@gmail.com

ABSTRACT
This study examined the impact of the utilization of Learning Activity Package (LAP) in the classroom and its effect on urban and rural students’ academic achievement in organic chemistry. Two research questions and three hypotheses guided the study. The study adopted quasi-experimental design. The population comprised 4,164 senior secondary two (SS2) chemistry students of Afikpo Education zone of Ebonyi State, Nigeria. The sample was 235 students drawn from 4 schools by balloting. The experimental groups were taught with LAP while the control groups were taught with Lecture. The instruments used were Learning Activity Package Manual (LAPM) and Chemistry Achievement Test on Organic Chemistry (CATOC) which were validated by three experts. Reliability index of .82 was obtained for the CATOC using Kuder Richardson’s formula 20 which showed that it was reliable. The data collected were analyzed using the mean, standard deviation and analysis of covariance (ANCOVA). Results of data analysis revealed among others that, utilization of Learning Activity Package in the classroom had greater impact on the students’ academic achievement in organic chemistry than the Lecture method. Furthermore, there was no significant difference in the academic achievement of urban and rural students in chemistry when taught with LAP and Lecture method. The researcher recommended among others things that chemistry teachers should be encouraged to utilize the LAP in their classrooms in order to encourage students’ active engagement in the lesson for enhanced academic achievement. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

The teacher’s role in every teaching and learning process cannot be overemphasised. This is because the pace set by the teacher in the classroom is what determines whether students can learn or not. Moreover, the teaching strategies/methods adopted by the teacher will either enhance or hamper the students’ academic achievement, especially in chemistry. According to [1], methodology is the ways and means by which the teacher presents his materials to the students and engages them in task at hand. Chemistry being a subject most students are perhaps afraid of requires the teachers to use appropriate teaching methods that will arouse the students’ interest and encourage them to develop positive attitude for effective learning outcome.

Generally, science educators have been canvassing for science teachers at all levels to focus on the utilisation of teaching strategies that can enhance students’ conceptual understanding, give them higher levels of performance in scientific thinking, reasoning and problem solving. It is important to point out that chemistry play important roles in the scientific and technological development of nations [2].

Unfortunately, research studies have shown that Nigerian secondary school students’ performance in the subject chemistry in both internal and external examinations have consistently been poor [3,4,5]. Meanwhile, researchers have discovered that the causes of the persistent poor academic performance have been attributed to; ineffective teaching methods/strategies adopted by chemistry teachers [6,7]; apparent difficulty associated to chemistry by students [8]; among others reasons.

Based on these facts, the researcher is of the view that when chemistry teachers utilises appropriate teaching strategies, which are student-centred and activity-oriented, the chemistry concepts would be easily understood by the students. This can lead to improved students’ academic
performance in the subject. There are many student-centred and activity-oriented teaching strategies, but this study focussed on the Learning Activity Package (LAP). Available empirical evidence as documented in the literature review section of this study has shown that the learning activity package (LAP) enhances students’ academic achievement more than the conventional teaching approaches. This present study is poised to investigate the effectiveness or otherwise of LAP in enhancing students’ academic achievement in organic chemistry.

LITERATURE REVIEW

Theoretical framework

The theoretical foundations of LAP grew out of the work of psychologist, Jean Piaget, who in 1926 advanced a theory to explain the development of cognitive abilities in children [9]. Piaget proposed that cognitive development proceeds through an orderly sequence of stages. Piaget’s theory is not only concerned with a child’s mental developmental stages but also recognises the differences in individuals of the same age groups or mental state. He stressed further that recognising the differences that exists among learners’ mental readiness, interest and needs, will enhance the setting of learners on a learning pedestal appropriate to each stage of mental development. The learners will gradually work at their own pace and accomplish the terminal task, irrespective of their speed or educational linkage.

Therefore, Piaget’s idea tallies with learning activity package instructional strategy, which caters for learners’, interests, needs and aspirations. According to Piaget, mental activity of the child is organised into structures. Various mental activities are related to each other and grouped together in clusters, which are known as ‘schemas’ or patterns of behaviour. According to
Woolfolk and Nicolich in [10], the schema is the primary unit of cognitive organisation in the Piagetian system. This means that it is the basic building block of thinking.

Piaget believed that mental activity which is involved in cognitive organisation is a process of adaptation which is divided into two opposing but inseparable processes of assimilation and accommodation. In assimilation, a child fits his new experience into pre-existing mental structures. He interprets his new experience with respect to his old experience. Accommodation involves a change of mental structure due to the influence of the environment which means the modification of self to fit the new materials. The Piagetian theory thus places the child as the principal agent in the teaching/learning situation.

This being the case, the teacher’s job is to provide the individual with situations that encourage experimentation and manipulation of objects and symbols. More so, the theory has direct implication for the use of Learning Activity Package in science teaching, especially in Chemistry. This is based on the fact that the LAP encourages active interaction of the child with his environment because it is student-centred and activity-based. The teacher acting as a facilitator of learning guides the students through series of activities and problems, which enhances achievement. In addition, learning materials are broken into small steps which are sequentially arranged from known to unknown and in an increasing order of difficulty in LAP.

From the foregoing, Learning Activity Package accommodates both fast and slow learners in the classroom. It should therefore be used to teach the concepts in organic chemistry which will help to concretize the apparent abstractness of the concepts and will also help the students to learn. [11] opined that it is essentially important for the students to participate actively rather than merely listen during class lessons.
The Learning Activity Package (LAP)

According to Cardarelli in [10], Learning Activity Package (LAP) is a student-centered and activity-based teaching strategy, where the teacher acts as facilitator of learning, guiding the students through series of activities and problems that may lead to enhanced students’ academic achievement. Contributing, [12] stated that Learning Activity Package is a program of study in printed form which covers a particular aspect of a subject that follows a logical sequence of instructional objectives and activities for implementing the objectives. The student proceeds through the objectives and activities in the LAP at his/her own pace. Continuing, Duke maintained that in LAP, the learning materials are broken down and arranged sequentially into small steps, ranging from the known to the unknown and in an increasing order of difficulty. This implies from the foregoing that in the LAP instructions are individualised.

Furthermore, Learning Activity Package offers a very practical and successful method for individualizing instruction. For instance, it gives students the opportunity to engage actively in the teaching and learning process by engaging in hands-on activities. Unlike the traditional classroom where the teacher talks much and the students go through their textbooks and workbooks, page by page, lock stepped together. Furthermore, in the traditional/conventional method, there is little or no provision for meeting differences in individual learning styles or differences in individual learning rates. But, the LAP provides the students the opportunity to grow in self-discipline, self-motivation and also presents occasions for genuine interaction between the teacher and students, which is lacking in the traditional method of teaching [13].

Contributing, [14] emphasised that the Learning Activity Package is one of the approaches to individualised instruction. There are many other approaches to individualised instructions such as; programmed instruction, computer assisted instruction, independent study, among others.
Some of these approaches have been investigated and found to be effective in enhancing students’ academic achievement but their applications in the teaching and learning process are hindered by several factors in Nigerian schools [15,10]. Hence the need for the use of Learning Activity Package (LAP) which can be readily prepared/constructed by the chemistry teachers.

**Influence of School Location on Students’ Academic Achievement in Chemistry**

For the purpose of this study, the urban schools are those schools located within the Local Government Headquarters, while the rural schools are those located outside the Local Government headquarters. School location refers to the particular place, in relation to other areas/places in the physical environment where a particular school is sited. It could be urban or rural. Basically, environment may have direct or indirect influence on human abilities; it could enhance or inhibit ability to learn [16]. [17] discovered a lot of problems in the teaching and learning of science and technology in the rural environments, such as; high student-teacher ratio, teaching method factor, quality and quantity of science teachers, problem of improvisation, lack of fund for science education and inadequate supervision of rural secondary schools. It is not known whether these factors can contribute to students’ poor academic performance in the rural schools. This study is poised to find out.

From the foregoing, school location could be a factor that can influence students’ achievement in chemistry. [18], found that school location influences student’s academic achievement in chemistry. Specifically, [19,20], revealed that urban students had higher academic achievement than their rural counterparts in chemistry. In addition, [21] found that chemistry students in urban schools performed better than their rural counterparts. On the other hand, [22,16] reported that rural students performed better than their urban counterparts in chemistry. However, [23,24] found no significant influence of school location on students’ academic achievement in
chemistry. It can be established from the above that the influence of school location on students’
academic achievement remains inconclusive and therefore calls for further studies, thereby
justifying this present study.

Related Empirical Studies

Few researchers have examined the effect of Learning Activity Package on students’
academic achievement. A study on the effect of Learning Activity Package (LAP) on male and
female students’ academic achievement in secondary school Biology was carried out by [10] in
Enugu State. The study specifically determined the mean achievement scores of male and female
students in Biology when taught Unit of life with Learning Activity Package and lecture method.
The study found significant difference in the academic achievement of students taught Biology
using LAP and Lecture methods; those students taught with LAP had higher academic
achievement than those taught with Lecture method. The study concluded that students’ academic
achievement will be greatly enhanced when innovative strategies like Learning Activity Package
are employed in the teaching and learning of science subjects. Neboh’s study was on the effects of
LAP and Lecture methods on students’ achievement in Biology but did not consider the effect of
location. Moreover, the study was conducted in Enugu State. This present study was conducted in
Chemistry and considered location as a variable.

In another study on the effectiveness of LAP and Lecture instructional methods of teaching
Biology at the senior secondary level of education in Zaria, Kaduna State, Nigeria [15]. The result
showed that LAP enhanced the students’ achievement in Biology irrespective of their previous
academic standings. The study was only confined to two schools in Zaria Township and no attempt
was made by the researcher to control some extraneous variables that might have constituted a
threat to the validity of the study such as irregular participation of the subjects and inter-group
communication during the experiment. Furthermore, school location was not considered a variable in the study. But, this present study considered school location as variable. Extraneous variables such as teacher effect, subject interaction, Hawthorne effect etc. were controlled. Above all, this study focused on Chemistry and was conducted in Ebonyi State.

More so, studies conducted by [16] on influence of gender and location on students’ achievement in chemical bonding in secondary schools in Nsukka education zone of Enugu State Nigeria, found that school location has significant influence on students’ achievement in chemistry. The study showed that the mean academic achievement score of rural students in chemical bonding was higher than that of their urban counterparts.

Meanwhile, most of the related empirical studies already carried out on the LAP were conducted in Biology. It therefore becomes necessary to conduct this present study in Chemistry. To find out if similar results obtained in Biology could also be obtained in Chemistry.

**STATEMENT OF THE PROBLEM**

Research studies have shown that Nigerian candidates in the West African School Certificate Examinations have been recording consistent poor performance in chemistry [25,26,4,5]. In a bid to identify the possible causes of this persistent poor academic performance, researchers have identified the use of ineffective teaching methods by the teachers and the apparent difficulty associated to chemistry by students, among others reasons that could be responsible. Moreover, students find organic chemistry difficult to understand, this might be as a result of the apparent abstract nature of the concepts and the pedagogic approaches adopted by teachers in presenting it to the students [27]. Meanwhile, research studies have acknowledged the effectiveness of the learning activity package (LAP) in enhancing greater students’ academic
performance in some subject areas as presented in the literature. This present study therefore examined the learning activity package instructional strategy, to find out whether it can as well be effective in enhancing students’ academic performance in organic chemistry.

**PURPOSE OF THE STUDY, RESEARCH QUESTIONS AND HYPOTHESES**

The main purpose of this study is to examine the utilisation of Learning Activity Package (LAP) in the classroom and its impact on students’ academic achievement in organic chemistry. Specifically, this study sought to determine the;

1. Impact of Learning Activity Package on students’ academic achievement in organic chemistry;
2. Influence of teaching methods (LAP and Lecture) on urban and rural students’ academic achievement in organic chemistry.
3. Interaction effect of method and location on students’ academic achievement in organic chemistry.

In order to achieve the purpose of this research work, the study sought answers to the following questions:

1. Is there any significant difference in the academic achievement of students taught organic chemistry with LAP and those taught with conventional (Lecture) method?
2. Does significant difference exist in the academic achievement of urban and rural students taught organic chemistry with LAP and conventional (Lecture) method?

The following null hypotheses tested at 5% level of significance guided the study;

H01. There is no significant difference in the academic achievement of students taught organic chemistry with LAP and those taught with conventional (Lecture) method.
H02. Significant difference does not exist in the academic achievement of urban and rural students taught organic chemistry with LAP and conventional (Lecture) method.

H03. The interaction effect of method and location on students’ academic achievement in organic chemistry is not significant.

METHODOLOGY

Research Design

The researcher adopted quasi-experimental design for the study. The pre-test, post-test, non-equivalent, control group design was the specific quasi-experimental design used. Quasi-experiments are experiments used when a researcher cannot use random assignment of subjects or groups [28]. The design was chosen because the subjects for the study could not be manipulated or randomised. Intact classes were used and the classes were assigned to experimental and control groups.

Area of the Study

The study was carried out in Afikpo Education zone which is one of the three educational zones of Ebonyi State, Nigeria. The zone is made up of five local government areas with 35 senior secondary schools that offer chemistry at WAEC level. The names of the local governments with the numbers of schools are as follows; Afikpo North has 10 schools, Afikpo South has 8 schools, Ohaozara has 6 schools, Onicha has 8 schools while Ivo has 3 schools. The zone was selected for this study because the schools are homogenous and are under the same education authority. Secondly, for ease of access and convenience for effective management of the available financial resources meant for the study. This is because the researcher had to monitor the activities of the
teachers to ensure their agreement with the stipulated plans of the study by visiting the sampled schools regularly during the period of the study.

**Population, Sample and Sampling Techniques**

The population for the study was 4,164 Senior Secondary 2 chemistry students in Afikpo Education zone in the 2015/2016 academic session. This grade of students was chosen because organic chemistry is contained in the SS2 section of the chemistry curriculum in use in Nigerian schools.

Using simple random sampling (balloting) technique, a sample of 235 SSII chemistry students (125 urban and 110 rural) was drawn from 4 co-educational (2 urban and 2 rural) secondary schools in Afikpo Education zone of Ebonyi State, Nigeria. Two intact classes in each of the schools were randomly assigned to experimental groups (120 students) and control groups (115 students). The sampled schools were selected on the bases that there were co-educational and chemistry had been taught in the schools for over ten years. Also, the number of students in each of the classes was not more than 40.

**Instruments for Data Collection, Validation and Reliability**

Two major instruments were used for the study, they are; Learning Activity Package Manual (LAPM) and Chemistry Achievement Test on Organic Chemistry (CATOC). The LAPM was adapted from the works of [29] who constructed the Learning Activity Package that comprised seven basic components/parts; the pre-test, performance objectives, concept, learning activities, self-test/evaluation, mastery/post-test, and enrichment opportunities. The LAP manual covered the following contents in organic chemistry as contained in SS2 chemistry curriculum; Structure and valency of carbon; Hydrocarbon; Homologous series; Saturated and unsaturated hydrocarbons; Isomerism; and Aromatic hydrocarbons.
The CATOC comprised 25 multiple-choice test items drawn from the various organic chemistry units outlined above. The researcher developed the test items using a test blue-print/table of specification to determine number of test items for each topic along three categories of cognitive objective, namely: knowledge (remembering), comprehension (understanding) and application (thinking). Each test item had four response options A - D with only one option as the correct answer while others were distracters.

Both the LAPM and the CATOC were content and face validated by two experts in chemistry education and one expert in measurement and evaluation from the Faculty of Education of Ebonyi State University. The instruments were revised based on the experts’ suggestions. Specifically, the test items of the CATOC were adjusted and evaluated according to the experts’ comments before it was used as pre-test and post-test.

The reliability of the CATOC was determined by pilot-testing the testing it on 40 SS2 chemistry students of Government Technical College, Abakaliki who were not part of the study subjects. Using Kuder-Richardson formula 20 (KR-20) reliability index of .82 was obtained, which confirmed the instrument as being reliable. This was in line with the established standard that any instrument with reliability index of .7 and above is adjudged reliable [30].

**Procedure for Data Collection and Method of Data Analysis**

The researcher organised a 5-day seminar/workshop for the regular chemistry teachers of the sampled schools where they were trained on the use of the learning activity package (LAP) in chemistry lesson delivery. During the seminar/workshop, copies of the LAPM which was derived from the organic chemistry curriculum contents of the students were given to the teachers. They were drilled thoroughly by the researcher on the use of the Learning Activity Package in chemistry instructions. The researcher observed as the teachers utilised the LAPM in delivering the lesson
and made corrections where necessary. The teachers were instructed to teach the control group using the conventional (lecture) method the way they have been using it in their classrooms. After the seminar, the teachers commenced the exercise in their respective schools. On the first day of commencement of the exercise, each of the teachers administered the CATOC to the students, as pre-test for the duration of 50 minutes and recorded their scores.

Experimental group

The treatment was teaching the students using the Learning Activity Package for the duration of four weeks. Four experimental lessons were carried out on different topics in organic chemistry.

Procedure: The teacher distributed the LAP manual to the students. Each student was to carry out the required activities as contained in the manual. The Pre-test was to test the student’s knowledge of the subject matter, note that the pre-test in the LAP differed from the pre-test which was initially administered to the students before the commencement of the experiments. After the pre-test, the performance objectives were identified. The Concept; defined, explained and illustrated the contents of the topic. The students thereafter carried out the learning activities expected of them on individual bases. When through with the learning activities, each student engaged in self-test/evaluation to test their understanding of the material studied. They proceed to mastery/post-test, if they answered the self-test correctly or to enrichment opportunities which entailed studying more materials until they can answer the self-test correctly. Each student progressed on the manual at their own pace. The teacher uses the mastery test to assess each student’s progress to know whether a student can proceed to the next lesson or needed to be drilled more on the particular lesson/topic. At the end of the four weeks’ treatment, a post-test (which was a reshuffled version of the pre-test) was administered to the students and the scores recorded.
Control

The pre-test was first administered to the students. The teacher thereafter taught them four lessons in organic chemistry using the conventional (lecture) method. The lessons were delivered using the chalk and chalkboard. The students were given assignments which the teacher marked and went through the corrections with them. At the end of the four weeks’ duration, the post-test was administered to the students and the scores recorded.

The pre-test and post-test scores of the experimental and control groups were used for data analysis. The research questions were answered by using the results to calculate the mean achievement scores and standard deviations of the groups, whereas the hypotheses were tested with Analysis of Covariance (ANCOVA) using the pre-test scores as covariates.

RESULTS AND DISCUSSIONS

Research question 1: Is there any difference in the academic achievement of students taught organic chemistry with LAP and those taught with conventional (Lecture) method?

Table 1: Mean Achievement Scores and Standard deviations of Students

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>Teaching Method</th>
<th>Test Type</th>
<th>No. Of Subjects (N)</th>
<th>Mean (X)</th>
<th>Standard Deviation (SD)</th>
<th>Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>LAP</td>
<td>Pre-test</td>
<td>120</td>
<td>7.60</td>
<td>3.15</td>
<td>19.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-test</td>
<td></td>
<td>27.15</td>
<td>6.13</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Lecture</td>
<td>Pre-test</td>
<td>115</td>
<td>7.45</td>
<td>3.40</td>
<td>19.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-test</td>
<td></td>
<td>18.15</td>
<td>5.80</td>
<td>10.70</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>235</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 1, the mean scores of the students taught organic chemistry with LAP and Lecture method are 7.60 and 7.45 respectively in the pre-tests. The difference in the pre-test mean scores of the two groups is .15. This shows that the two groups were similar at the beginning of the experiment. The Table 1 further shows that the mean achievement score of the students
taught organic chemistry with LAP in the post-test is 27.15 with standard deviation of 6.13 and mean achievement gain score of 19.55. On the other hand, the mean achievement score of those taught with the Lecture method in the post-test is 18.15 with standard deviation of 5.80 and mean achievement gain score of 10.70. The difference in the mean achievement gain scores of the two groups is 8.85. Therefore, difference exists in the academic achievement of students taught with LAP and those taught with Lecture method. Those students taught with LAP had higher academic achievement than their counterparts who were taught with Lecture method. Moreover, the standard deviations of the two groups in the post-tests are 6.13 and 5.80 for the LAP and Lecture method respectively. This is an indication that the individual scores of the students were clustered around the mean in the Lecture method more than in the LAP.

However, Table 1 did not show whether the observed difference in the mean achievement score of the two groups in the post-test is significant. Therefore, the result was further subjected to inferential testing as shown in hypothesis 1, in order to ascertain whether the observed difference is significance or not.

Hypothesis 1: There is no significant difference in the academic achievement of students taught organic chemistry with LAP and those taught with conventional (Lecture) method.

Table 2: Analysis of Covariance (ANCOVA) of Students’ Overall Achievement Scores by Teaching Method and Location

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Type III Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F-cal</th>
<th>P-value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>658.942</td>
<td>2</td>
<td>329.471</td>
<td>3.675</td>
<td>.013</td>
<td>S</td>
</tr>
<tr>
<td>Intercept</td>
<td>126530.064</td>
<td>1</td>
<td>126530.064</td>
<td>2117.296</td>
<td>.000</td>
<td>S</td>
</tr>
<tr>
<td>Method</td>
<td>658.942</td>
<td>2</td>
<td>329.471</td>
<td>3.675</td>
<td>.013</td>
<td>S</td>
</tr>
<tr>
<td>Location</td>
<td>198.450</td>
<td>1</td>
<td>198.450</td>
<td>3.321</td>
<td>.070</td>
<td>NS</td>
</tr>
<tr>
<td>Method X Location</td>
<td>48.606</td>
<td>2</td>
<td>24.303</td>
<td>.814</td>
<td>.636</td>
<td>NS</td>
</tr>
<tr>
<td>Error</td>
<td>13804.607</td>
<td>231</td>
<td>59.760</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>142066.000</td>
<td>235</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>14463.549</td>
<td>234</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = Significant (P < .05); NS = Not Significant (P > .05)
Table 2 shows that there is a significant difference in the academic achievement of students taught organic chemistry with LAP and those taught with conventional (lecture) method. This is because from the table, the probability value of .013 obtained is lower than the level of .05 at which it was tested. Therefore, the null hypothesis (Ho1) of no significant difference in the students’ academic achievement is rejected at .05 level of confidence. This means that the earlier observed difference in the overall mean achievement scores of students taught organic chemistry with LAP and those taught with conventional (lecture) method, as shown in Table 1 is significant.

Furthermore, the academic achievement of the students taught with LAP having been found to be higher than those taught with the conventional (lecture) method signifies that LAP had greater impact on the students’ academic achievement in the organic chemistry than the lecture method.

Research question 2: Does significant difference exist in the academic achievement of urban and rural students taught organic chemistry with LAP and Lecture method?

Table 3: Mean Achievement Scores and Standard Deviations of Urban and Rural Students

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>Teaching Methods</th>
<th>School location</th>
<th>Test type</th>
<th>No. of subjects (N)</th>
<th>Mean (X)</th>
<th>Standard deviation (SD)</th>
<th>Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>LAP</td>
<td>Urban</td>
<td>Pre-test</td>
<td>64</td>
<td>7.34</td>
<td>3.07</td>
<td>19.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-test</td>
<td>61</td>
<td>26.68</td>
<td>6.66</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Lecture</td>
<td>Urban</td>
<td>Pre-test</td>
<td>56</td>
<td>7.40</td>
<td>2.25</td>
<td>17.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-test</td>
<td>56</td>
<td>18.77</td>
<td>6.05</td>
<td>11.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rural</td>
<td>Pre-test</td>
<td>54</td>
<td>6.58</td>
<td>2.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-test</td>
<td>54</td>
<td>16.72</td>
<td>4.19</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>235</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 shows the mean pre-test and post-test scores of urban and rural students taught organic chemistry with LAP and Lecture method. The Table 3 shows that the urban students taught with LAP has mean achievement gain score of 19.34 while their counterparts in the rural schools
has mean achievement gain score of 17.53. The mean achievement gain score of the urban students taught with LAP (experimental) is 1.81 higher than that of their rural counterparts.

Furthermore, Table 3 shows that the mean achievement gain score of the urban students in the control group taught with Lecture method is 11.37 while that of their rural counterparts is 10.14. From this result, the mean achievement gain score of the urban students taught with Lecture method (control) is 1.23 higher than that of their rural counterparts. These results show that differences exist in the mean achievement scores of urban and rural students taught with LAP and Lecture method. However, it was not shown on the Table whether the observed differences in the urban and rural students’ mean achievement scores in the LAP and Lecture method are significant. Therefore, the result was further subjected to inferential testing in order to ascertain whether the observed difference is significance, as shown in hypothesis 2.

Hypothesis 2: Significant difference does not exist in the academic achievement of urban and rural students taught organic chemistry with LAP and Lecture method.

From Table 2, non-significant difference was found in the Post-achievement test scores of the urban and rural students. This is because the probability value of .070 obtained is greater than the level of .05 at which it was tested. With this result, Ho2 was retained because the observed difference in the academic achievement of urban and rural students in organic chemistry is not significant. Thus, the efficacy of the methods in enhancing students’ achievement in chemistry according to this finding was not influenced by school location.

Hypothesis 3: The interaction effect of method and location on students’ academic achievement in organic chemistry is not significant.

In Table 2, the F-value for the interaction effect of method and location on students’ academic achievement in organic chemistry is .814 with P-value of .636 which is greater than .05
set for the study. With this result, Ho3 was retained. Hence, the two-way interaction of method and location has no significant effect on students’ academic achievement in organic chemistry. Meanwhile, since method is significant while the interaction with location is not, it therefore shows that method does not depend on school location to be effective.

**SUMMARY OF MAJOR FINDINGS**

1. There is a significant difference in the academic achievement of students taught organic chemistry with learning activity package and those taught with conventional (lecture) method.

2. The Learning Activity Package enhances students’ academic achievement in organic chemistry more than the conventional (lecture) method. This implies that LAP has more impact on students’ academic achievement than the conventional (lecture) method.

3. There is no significant difference in the academic achievement of urban and rural students in organic chemistry.

4. The two-way interaction effect of method and location on students’ academic achievement in organic chemistry is not significant.

**DISCUSSION**

The findings of this study have shown that students taught with Learning Activity Package (LAP) had higher academic achievement than those taught with conventional (lecture) method. The LAP therefore has greater impact on students’ academic achievement in organic chemistry than the Lecture method. This finding agrees with the findings of previous researchers, [10,15] that Learning Activity Package (LAP) is more effective than the Lecture method in enhancing students’ academic achievement in science. Meanwhile, the relative effectiveness of LAP over the
Lecture method in enhancing students’ academic achievement could be attributed to the fact that LAP is a student-centred and activity-based method of instruction which provided the students the opportunity to have direct contact with the materials of study. Given the different approaches by which the two methods (LAP and Lecture) were utilised, it is not surprising that the LAP had greater impact on students’ academic achievement than the lecture method.

This study further found no statistically significant difference in the academic achievement of urban and rural students in organic chemistry. Although the mean achievement scores of urban students were higher than that of their rural counterparts in the LAP and Lecture method, the differences were not statistically significant. These shows that the efficacy of the teaching methods in enhancing students’ achievement was not influenced by school location. This finding agrees with the findings of [23,24] that there is no significant influence of school location on students’ academic achievement. The finding also agrees with [3] that there is no significant difference in the academic achievement of urban and rural students in physics. However, the finding of this study disagrees with the findings of [21,31] that chemistry and mathematics students in urban schools performed better than their rural counterparts. The finding also disagrees with [16] that there is significant difference in the academic retention of urban and rural students; the urban students’ academic achievement was higher than that of their rural counterparts.

The finding of this study also established no significant interaction effect of method and school location on students’ achievement in organic chemistry. This finding agrees with [22] that there is no statistically significant interaction effect of method and location on students’ academic achievement in chemistry. The fact that this present study found no significant interaction effect of method and location on students’ academic achievement in organic chemistry is a proof to the fact that method do not depend on school location to be effective.
CONCLUSION

The major causes of students’ poor academic performance in chemistry have been attributed to, among other things; the use of ineffective teaching methods/strategies by teachers and the apparent difficulty associated to organic chemistry by students. These have resulted to persistent poor academic performance being recorded in both internal and external examinations by the chemistry students in Nigeria.

This therefore calls for an improvement on the mode and methods of teaching and learning of the subject, which necessitated this present study to try other alternative strategies of teaching chemistry, different from the conventional method. Moreover, this study lends empirical support to the fact that students’ achievement in organic chemistry could be greatly improved when taught with the Learning Activity Package (LAP) which is an individualised method of instruction, among other innovative, student-centred and activity-based teaching methods. These innovative teaching methods have been proven to be effective in facilitating students’ academic achievement in chemistry better than the lecture method, as supported by the findings of this study. The findings further revealed no significant influence of school location on students’ academic achievement in organic chemistry, thereby establishing the fact that when chemistry teachers expose the students to LAP, their academic achievement could be greatly improved irrespective of their school location. This study has lent empirical support to the fact that when chemistry teachers individualises instructions in the classroom, students’ academic achievement will be greatly enhanced.

The researcher therefore advocates for the chemistry teachers to imbibe the use of student-centred and activity-based teaching methods such as the Learning Activity Package, and de-emphasize the use of lecture method in chemistry teaching and learning. Because, effective
teaching arising from the use of Learning Activity Package, had positive impact on students’ understanding of chemistry concepts and gave rise to higher achievement in the subject.

RECOMMENDATIONS

The researcher recommends as follows;

1. Chemistry teachers should be encouraged to utilise the Learning Activity Package in their lesson deliveries in order to encourage active engagement and self-motivation among learners for enhanced academic achievement.

2. The Learning Activity Package should be incorporated into the chemistry curriculum of teacher training tertiary institutions, so as to popularize its use among the teacher trainees in order to bring about enhanced achievement in chemistry in the secondary schools.

3. Secondary school chemistry curriculum should be reorganised in such a way as to incorporate the LAP into the system. This will enable the students to identify problems, stimulate their thinking ability and allow them to individually approach and solve chemistry problems.

4. Chemistry teachers should be encouraged to attend regular workshops and seminars to acquire the requisite skills to enable them make effective use of the Learning Activity Package in their lesson delivery.

REFERENCES


**APPENDICES: SUPPLEMENTARY MATERIALS**

**Appendix A: LEARNING ACTIVITY PACKAGE MANUAL**

**LEARNING ACTIVITY PACKAGE MANUAL FOR SENIOR SECONDARY SCHOOL TWO (SSII) STUDENTS ON ORGANIC CHEMISTRY**

**INSTRUCTIONS:**

This Learning Activity Package Manual (LAPM) is specifically designed to expose you to contents and activities in organic chemistry, for effective learning. You will be provided with all necessary information to enable you achieve the purpose. You will go through the package step by step at your own pace. You will also be required to complete each learning activity, record your observations and thereafter respond to the questions that follow. You
are free to request for assistance from your teacher on areas you might experience some difficulties during the lesson.

The performance objectives of each topic are stated at the beginning of each lesson to enable you have a focus of what you are required to achieve by the end of the lesson. You are expected to keep good record of your work.

**WEEK 1: Lessons One**

**TOPIC:** Organic Chemistry

**Sub-topic:** Structure and valency of carbon

**Duration:** 4 periods (40 minutes per period)

**Pre-Test:**

Answer the following questions;

1. List 4 different forms in which carbon can exist?
2. What is the valency of carbon?
3. Give 4 reasons why carbon can combine with many substances?
4. Draw the tetrahedral structure of carbon?

**Performance Objectives**

By the end of the lesson, you should be able to;

1. List the different forms carbon can exist;
2. Determine the valency of carbon;
3. Explain why carbon can combine with many substances;
4. Draw the tetrahedral structure of carbon.

**Concept**

**Carbon**

Carbon is the name for the element with atomic number 6 and is represented by the symbol C. Carbon has 6 protons, 6 neutrons and 6 electrons. It is a non-metal that belong to group 4 in the periodic table. It occurs naturally as diamond and graphite in a pure form. Carbon also occurs in an impure form as coal; it occurs in the combined state as petroleum, wood and natural gases. Other sources that contain carbon are mineral deposits of metallic trioxocarbonates(iv) eg. Calcium trioxocarbonate(iv), limestone, and Magnesium trioxocarbonate(iv), dolomite; Carbon(iv)oxide in air and water; Charcoal which is of various forms or types eg. Wood charcoal, animal charcoal, sugar charcoal, etc; Coke, which is obtained by heating coal in the absence of air to a very high temperature otherwise known as the destructive distillation of coal; and finally soot or carbon black (lamp black).

**Structure and valency of carbon:**
The carbon atom has four unpaired valence electrons in its outermost (L) shell. This enables the carbon atom to form four single covalent bonds by sharing electrons with neighbouring atoms, which may be carbon atoms or atoms of other elements, so that the outermost shell of its atom is completely filled. The four covalent bonds of carbon are directed symmetrically in space at an angle of 109.5° to one another, i.e. they are arranged in a tetrahedral form, so that they point towards the corners of a regular tetrahedron when the carbon atom is placed in its centre.

![Tetrahedron Diagram](image)

Reasons why carbon can form numerous stable organic compounds:
1. Catenation: this is the ability of atoms of the same element to form long chains or rings. Carbon is unique in its ability to form very long chains, branched chains or ring compounds.
2. Multiple bonds: carbon is the only element in group (iv) which forms stable double and triple bonds to itself and to oxygen, sulphur and nitrogen.
3. When carbon has filled shell, it has no lone pair of electrons and cannot act as donor, because strong bonds are formed and this results in lack of reactivity of many carbon compounds.
4. The ease with which carbon combines with hydrogen, nitrogen and the halogens.
5. The ability of carbon atoms to form single, double or triple bonds and the strong carbon-carbon bonds formed.

**Learning Activity 1.1**

**Construction of 3 dimensional model/structure of Carbon Atom**

**Materials:** Coloured (Styrofoam) balls, poster board/cardboard paper, compass, glue, plasticine, pair of scissors and string.

**Method/Procedure**

1. Get 12 styrofoam balls of different colours (6 of one colour for the protons and 6 of another colour for the neutrons) and 6 small plasticine balls for the electrons.
2. Glue the six protons and six neutrons into a ball, alternating between protons and neutrons as you glue.
3. Cut a small ring and a large ring out of cardboard paper. Use string to tie these rings in concentric circles around the nucleus.
4. Glue/place two electrons to the inner circle and four to the outer circle.
5. Attach string to the outer circle for hanging.

**Learning Activity questions**

Answer the followings questions;

a. Why did you glue the protons and neutrons together?
b. Why did you not glue the electrons together with the proton and neutron?
c. What charge has the proton, neutron and electron?
d. What does the small and large cut cardboard paper rings represent?
Self-Test / Evaluation
Answer the following questions;
1. Give 4 reasons why carbon can combine with many substances?
2. Draw the tetrahedral structure of carbon?
3. List 4 different forms in which carbon can exist?
4. What is the valency of carbon?

Mastery / Post-test;
Answer the following questions;
1. What is carbon?
2. Draw the electronic structure of carbon?
3. What are the forms in which carbon can exist in the pure state?

Enrichment Opportunities
Also study pages 136 – 137 of Science Teachers Association of Nigeria (STAN) Chemistry for Senior Secondary Schools.

WEEK 2: Lesson Two

TOPIC: Organic Chemistry
Sub-topic: Hydrocarbons, Isomerism, Homologous series, Functional groups and Nomenclature

Duration: 6 periods (40 minutes per period)

Pre-test:
Answer the following questions;
1. What are hydrocarbons?
2. Define the term isomerism and give 3 examples?
3. What is homologous series?
4. Define functional groups and give 4 examples?
5. What are the procedures for naming an organic compound?

Performance objectives
By the end of the lesson, you should be able to;
1. Explain the meaning of hydrocarbons;
2. Give the definition of isomerism and some examples;
3. Explain the meaning of homologous series;
4. Define the term functional groups and give some examples;
5. Outline the procedures for naming organic compounds.
Concept

Hydrocarbons

Hydrocarbons are organic compounds composed only of two elements, carbon and hydrogen, just as their name imply. They are among the simplest organic compounds. They have the general molecular formula of \( \text{C}_x\text{H}_y \), where \( x \) and \( y \) are whole numbers. The hydrocarbons are among the simplest organic compounds. Some examples are; Methane \( \text{CH}_4 \), Propane \( \text{C}_3\text{H}_8 \), Pentane \( \text{C}_5\text{H}_{12} \), Benzene \( \text{C}_6\text{H}_6 \), etc.

The hydrocarbons are classified into two main groups; Aliphatic and Aromatic hydrocarbons.

*The Aliphatic hydrocarbons*

These are organic compounds composed of carbon-carbon chains. They could be straight chain, branched chain or in the form of a ring.

They are sub-divided into two, based on the structure; Acyclic and Cyclic aliphatic hydrocarbons.

In the Acyclic aliphatic hydrocarbons, the carbon atoms are joined together to form long straight or branched chains.

In the Cyclic aliphatic hydrocarbons, the carbon chains join together at the ends to form a ring.

*The Aromatic Hydrocarbons*

Aromatic hydrocarbons are special class of cyclic compounds based on benzene, \( \text{C}_6\text{H}_6 \), a 6-carbon ring compound. All other aromatic compounds are derivatives of benzene, e.g phenylamine (aniline) and phenol. Some derivatives may also contain straight carbon chains as side chains.

Learning Activity 2.1

Making 3D Models of Hydrocarbons

Materials Needed/Apparatus:

Black coloured plasticine, White coloured plasticine, match stick or tooth pick.

Method / Procedure / Instructions

1. Roll pieces of plasticine into balls, the balls represents atoms.
2. The black plasticine balls will represent carbon atoms while the white plasticine balls will represent hydrogen atoms.
3. The match stick or toothpick will serve as bond.
4. Push single stick into the carbon atom at 4 different positions making sure that the bonds are tetrahedrally oriented.
5. Push hydrogen atom (white ball) into each of the bonds (stick).
6. Using the above method, make models of the following hydrocarbons
   i. Methane (\( \text{CH}_4 \)), ii. Propane (\( \text{C}_3\text{H}_8 \)), iii. Pentane (\( \text{C}_5\text{H}_{12} \)).

Isomerism

Isomerism is the existence of two or more compounds that have the same molecular formula (the same number and types of atoms) but possessing different molecular structure (structural formula) and different properties. There are structural isomers, geometric isomers, optical isomers and stereoisomers.
Example; Butane (C\textsubscript{4}H\textsubscript{10}) and 2-methylpropane (C\textsubscript{4}H\textsubscript{10}) are isomers; the structures are as shown below:

Butane (C\textsubscript{4}H\textsubscript{10})

2-methylpropane (C\textsubscript{4}H\textsubscript{10})

**Learning Activity 2.2**

**Making 3D models of the Isomers of Butane (C\textsubscript{4}H\textsubscript{10})**

Using the same materials you used in learning activity 2.1, construct 3 dimensional structures of the 2 Isomers of Butane; N-Butane and 2-methylpropane.

**Homologous series**

A homologous series is a family of organic compounds which follows a regular structural pattern, in which each successive member differs in its molecular formula by – CH\textsubscript{2} – group. It is also a series of compounds in which each member differs from the next by a specific number and kind of atoms. They show similar chemical properties and have physical properties that change regularly as the molar mass increases.

With the homologous series, the numerous organic compounds can be grouped into a comparatively small number of families of compounds. Each member of the series is known as a homologue. For instance, the alkanes are the simplest homologous series with a general molecular formula of C\textsubscript{n}H\textsubscript{2n+2} where n is a whole number equal to or greater than 1. Other examples of homologous series will include; Alkenes (C\textsubscript{n}H\textsubscript{2n}), Alkynes (C\textsubscript{n}H\textsubscript{2n-2}), Alkanols (C\textsubscript{n}H\textsubscript{2n+1}OH), Carboxylic or Organic acids (C\textsubscript{n}H\textsubscript{2n+1}COOH), etc.

Characteristics of homologous series are;

i. All members conform to a general molecular formula as shown in the examples above.

ii. Each homologue differs from the next in molecular formula by – CH\textsubscript{2} – and in its relative molecular mass by an increase in 14.

iii. All members show similar chemical properties.

iv. They posses similar method of preparation.

v. The physical properties of members such as boiling point change gradually as the number of carbon atoms increases.

The homologous series is very useful in organic chemistry because, it helps in the study of numerous organic compounds under limited number of families thereby saving us the energy and time with which we would have been studying the compounds singly. This is because knowing the homologous series, the properties of a compound could be predicted.
Learning Activity 2.3
Making 3D Structures of examples of homologous series

Materials Needed/Apparatus:
Different colours of plasticine, match stick or tooth pick.

Method / Procedure / Instructions
1. Roll pieces of plasticine into balls, the balls represents atoms.
2. The black balls for carbon atoms, white balls for hydrogen atoms, brown ball for oxygen atom.
3. The match stick or toothpick for bonds.
4. Using the atoms (plasticine balls) and bonds (match sticks or tooth picks), construct a model of the following members of homologous series;
   i. Alkene (Eg. Ethene, H₂C = CH₂)
   ii. Alkanol (Eg. Ethanol, H₃C – CH₂OH)
   iii. Carboxylic acid (Eg. Ethanoic acid, H₃C – COOH) note that in the structure, 1 oxygen is double bonded to the carbon while the other oxygen is single bonded to carbon and hydrogen.

Functional group

A functional group is an atom, a radical or bond common to a homologous series and which determines the main chemical properties of the series. If there are two or more functional groups in one molecule of a compound, the properties of one are often modified or influenced by the presence of the other.

Examples of functional groups will include; Hydroxyl group – OH, Amino group – NH₂, Carboxyl group – COOH, Amides – CONH₂, Double bonded carbon atoms C = C, etc.

The functional groups determine the basic chemistry of a compound, i.e. it is the functional group that determines the chemical behaviour or characteristics of an organic compound. The functional group is based on the principle that, the chemical properties of a homologous series will change when a functional group is attached to a homologue and that the chemical properties of such homologue will be reflecting the chemical properties of the functional group attached. For instance, if a halogen is attached to an alkane homologous series, the series will change to haloalkane homologous series and the chemical properties of the haloalkane homologous series will be different from those of the alkane homologous series.

IUPAC Nomenclature of Hydrocarbons (IUPAC – International Union of pure and applied chemistry)

The IUPAC has put forward a system of naming the organic compounds which relates the name of the compound to its molecular structure. In this system of nomenclature, every name consists of; a root, suffix, and as many prefixes as necessary.

1. The root name is generally an aliphatic hydrocarbon. The systematic name of a compound is formed from the root hydrocarbon by adding a suffix and prefixes to denote the substitution of the hydrogen atoms by an alkyl, functional groups or multiple bonds.
2. The suffix(es) is/are added to the root to indicate the presence of the principal substituent which is usually also the principal functional group in the molecule. Compounds that have the same functional groups such as those belonging to the same homologous series, would carry a common suffix at the end of their names. Examples are; Alkanes end with – ane eg. Methane (CH₄), Ethane (C₂H₆) etc.; Alkenes end with – ene eg. Ethene (C₂H₄), Propene (C₃H₆) etc.; Alkanols end with – ol, eg. Methanol (CH₃OH), Ethanol (C₂H₅OH) etc.

Note that a suffix is a sound or syllable(s) added at the end of a word to make another word.

3. The prefix(es) are syllable(s) added in front of the root name of an organic compound.

Cyclic compounds can be indicated by adding the prefix cyclo – to the names of the corresponding aliphatic compounds eg. Cyclopentane, Cyclohexane, Cyclobutane etc.

4. Prefixes also used to indicate the presence of substituted alkyl or functional groups other than the principal group, as well as the positions of the substituents in the carbon chain. When more than one of the same substituent group is present, the multiplying prefixes such as di – for 2, tri – for 3, tetra – for 4 etc. are used. If more than one prefix is needed, they are placed in alphabetical order.

5. The positions of the substituent groups and the multiple bonds in the carbon chain of a compound are indicated by the number of the carbon atom or atoms to which they are attached. In numbering the carbon atoms, number all the carbon atoms in the longest chain starting from the end which is closest to the branch chain or other modifications of the simple alkane structure.

**Rules of Naming Organic Compounds**

i. Take the longest continuous carbon chain as the root hydrocarbon and name it according to the number of carbon atoms it contains, adding the appropriate suffix to indicate the principal substituent group.

ii. Number the carbon atoms in the root hydrocarbon from the end which will give the lowest number to the suffix and then the prefix(es).

iii. Indicate the other substituents by prefixes preceded by numbers to show their positions on the carbon chain.

**Examples of IUPAC names of Organic Compounds**

i. CH₃ - CH₂- CH(CH₃)-CH = CH₂  
   3-Methylpent-1-ene  

ii. CH₃CH₂-C(CH₃)=CH-CH₃  
   3-Methylpent-2-ene  

iii. Cl-CH₂-CH₂-CH₂-OH  
   3-Chloropropan-1-ol  

iv. H-C(Cl,Cl)-CH(Cl,Cl)  
   1,1,2,2 Tetrachloroethane

**Learning Activity 2.4**

**Making 3D Models of Organic Compounds**

**Materials Needed/Apparatus:**

Different colours of plasticine, match stick or tooth pick.

**Method / Procedure / Instructions**
1. Using the different atoms (Plasticine balls) and the sticks, make 3 dimensional models of the following organic compounds:
   i. 3-methylpent-1-ene   ii. 3-methylpent-2-ene   iii. 3-chloropropan-1-ol
   iv. 1,1,2,2 Tetrachloroethane

**Self-Test / Evaluation**

Answer the following questions:
1. What is homologous series?
2. What are the procedures for naming an organic compound?
3. Define functional groups and give 4 examples?
4. Define the term isomerism and give 3 examples?
5. What are hydrocarbons?

**Mastery / Post-test;**

Answer the following questions;
1. Draw the structure of Cyclohexane  ii. Draw the structure of Ethanoic acid

**Enrichment Opportunities**


Also study page 137 of Science Teachers Association of Nigeria (STAN) Chemistry for Senior Secondary Schools.

**WEEK 3: Lesson Three**

**TOPIC:** Hydrocarbons

**Sub-topic:** Saturated and Unsaturated hydrocarbons, Aliphatic hydrocarbons (Alkanes; properties, preparation and uses)

**Duration:** 6 periods (40 minutes per period)

**Pre-test:**

Answer the following questions;
1. When is a hydrocarbon compound said to be saturated?
2. Give 3 examples each of saturated and unsaturated hydrocarbons?
3. What is the general formula of the Alkanes?
4. Outline 3 properties of the Alkane homologous series?
5. Explain two methods of preparing the Alkanes?
6. List 5 uses of the Alkanes?
Performance objectives

By the end of the lesson, you should be able to;
1. define saturated and unsaturated hydrocarbons;
2. give examples of hydrocarbons which are saturated and those which are unsaturated;
3. give the general formula of the Alkanes;
4. list all the properties of the Alkane homologous series;
5. explain the methods of preparing the Alkanes in the laboratory; and
6. identify the uses of the Alkanes.

Concept

Saturated and Unsaturated Hydrocarbons

A saturated hydrocarbon is a compound in which the carbon atoms are joined together by single covalent bonds. They are hydrocarbons that contain only single carbon-carbon bonds. They are called the Alkanes (Eg. Methane (CH\textsubscript{4}), Ethane (C\textsubscript{2}H\textsubscript{6}), Propane (C\textsubscript{3}H\textsubscript{8}) etc).

An unsaturated hydrocarbon is a compound which contains carbon atoms joined together by double or triple covalent bonds. Unsaturated hydrocarbons contain double or triple carbon-carbon bonds. They are the Alkenes (Eg. Ethene (C\textsubscript{2}H\textsubscript{4}), Propene (C\textsubscript{3}H\textsubscript{6}), etc.) and the Alkynes (Eg. Ethyne (C\textsubscript{2}H\textsubscript{2}), Propyne (C\textsubscript{3}H\textsubscript{4}), etc.).

Aliphatic Hydrocarbons – The Alkane homologous series

The alkanes are aliphatic hydrocarbons whose molecules have very similar structures to each other. They form a homologous series of saturated hydrocarbons whose general molecular formula can be represented as C\textsubscript{n}H\textsubscript{2n+2}, where n is an integer greater than or equal to +1.

The alkanes are hydrocarbons in which the constituent carbon atoms are tetrahedrally bonded by single covalent bonds to the hydrogen atoms and other carbon atoms.

Below are molecular formula, structural formula and names of some members of the alkane homologous series, including the isomers. They are arranged in increasing molecular weight.

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Structural Formula and Isomers</th>
<th>Name</th>
</tr>
</thead>
</table>
| CH\textsubscript{4} | \begin{center} 
H 
\Hline 
H–C–H 
\Hline 
H 
\end{center} | Methane       |
| C\textsubscript{2}H\textsubscript{6} | \begin{center} 
H 
\Hline 
H–C–C–H 
\Hline 
H 
\end{center} | Ethane        |
| C\textsubscript{3}H\textsubscript{8} | \begin{center} 
H 
\Hline 
H–C–C–C–H 
\Hline 
H 
\end{center} | Propane       |
Properties of Alkanes

Combustion; the alkanes burn in oxygen (air) to give out heat, carbon(iv) oxide and steam.

\[ C_xH_y + 2O_{2(g)} \rightarrow yH_2O + xCO_2 \]

Eg. \[ CH_4(g) + 2O_{2(g)} \rightarrow 2H_2O(g) + CO_2(g) \]

Other reactions of alkanes;

Alkanes are generally unreactive because their molecules are non-polar and contain single covalent bonds. But the only reaction they undergo is the substitution reaction, in which another atom substitutes a hydrogen atom from the alkane compound. Eg. In the reaction between methane and chlorine, an atom of chlorine is substituted for a hydrogen atom in the methane molecule as shown below;

\[ CH_4(g) + Cl_{2(g)} \rightarrow CH_3Cl(l) + HCl(g) \] Chloromethane
\[ CH_3Cl(l) + Cl_{2(g)} \rightarrow CH_2Cl_2(l) + HCl(g) \] Dichloromethane
\[ CH_2Cl_2(l) + Cl_{2(g)} \rightarrow CHCl_3(l) + HCl(g) \] Trichloromethane
\[ CHCl_3(l) + Cl_{2(g)} \rightarrow CCl_4(l) + HCl(g) \] Tetrachloromethane

Methods of Preparation

The alkanes can be prepared in the following methods;

1. All the alkanes can be obtained by the fractional distillation of crude oil. Although the main source of methane is natural gas.
2. They can also be prepared in the laboratory by de-carboxylation (removal of CO\(_2\)) of the appropriate carboxylic acid.
3. They can also be prepared by heating an appropriate sodium salt with soda-lime.

Uses of Alkanes
The alkanes are used mainly as fuels. For instance, CH₄ is the main component of natural gas while butane is the main component of camping gas and lighter fuel. Octane is an important component of petrol.

They are also used to produce very useful unsaturated hydrocarbons such as ethane (C₂H₆) through the process of cracking.

Methane is used for making hydrogen, carbon black, carbon(iv)sulphide, alkynes, hydrocyanic acid, trichloromethane (chloroform, an anaesthetic used in surgical operations), dichloromethane (CH₂Cl₂ used for dissolving paints) and tetrachloromethane (an important organic solvent used for removing grease stains.

**Learning Activity 3.1**

**Materials Needed/Apparatus:**
Black coloured plasticine balls (Carbon atoms), White coloured plasticine balls (Hydrogen atoms), match stick or tooth pick.

**Method / Procedure / Instructions**
1. Using the carbon and hydrogen atoms (Plasticine balls) and the sticks, make 3 dimensional models of the following alkane compounds;
   i. Propane
   ii. Butane
   iii. 2-methylpropane
2. Draw the structural formula of the following alkane compounds;
   i. Pentane (C₅H₁₂)
   ii. 2-methylbutane (C₅H₁₂)
   iii. 2,2-dimethylpropane (C₅H₁₂)

**Self-Test / Evaluation**

Answer the following questions;
1. List 5 uses of the Alkanes?
2. What is the general formula of the Alkanes?
3. Explain two methods of preparing the Alkanes?
4. Outline 3 properties of the Alkane homologous series?
5. Give 3 examples of saturated and unsaturated hydrocarbons?
6. When is a hydrocarbon compound said to be saturated?

**Mastery / Post-test;**

Answer the following questions;
1. What is substitution reaction in alkanes?
2. Give 3 differences between saturated and unsaturated hydrocarbons?
3. Give 3 examples each of acyclic and cyclic aliphatic hydrocarbons?

**Enrichment Opportunities**

Also study page 137 – 140 of Science Teachers Association of Nigeria (STAN) Chemistry for Senior Secondary Schools.
WEEK 4: Lessons Four and Five

TOPIC: Hydrocarbons

Sub-topic: Alkenes and Alkynes (properties, preparations and uses)

Duration: 6 periods (40 minutes per period)

Pre-test:
Answer the following questions;

1. What are the general molecular formula of the alkenes and alkynes?
2. Why are alkenes and alkynes said to be unsaturated?
3. List the methods of preparing the alkenes and the alkynes?
4. Draw the structures of 4 examples of alkene homologous series?
5. Draw all the isomers of hexyne?

Performance objectives
By the end of the lessons, you should be able to;

1. write the general molecular formula of the alkenes and alkynes;
2. explain unsaturation in the alkenes and alkynes;
3. explain the methods of preparing alkenes and alkynes;
4. identify the structures of alkene homologous series; and
5. explain isomerism in hexyne.

Concept
Lesson Four:
The Alkene homologous series

The alkenes are homologous series of hydrocarbons with a general molecular formula of \( C_nH_{2n} \), where \( n \) is a positive integer equal to or greater than 2. They contain 2 hydrogen atoms less than the alkanes. The alkenes are unsaturated hydrocarbons which contain a carbon-carbon double bond as well as single bonds. The alkenes are given names similar to the alkanes depending on the number of carbon atoms in the molecule. The -ane of the corresponding alkane is replaced by -ene.

Below are molecular formula, structural formula and names of some members of the alkene homologous series, including the isomers. They are arranged in increasing molecular weight.

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Structural Formula and Isomers</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_2H_4 )</td>
<td>[ \begin{array}{c} \text{H} \text{H} \ \text{H} \text{C} = \text{C} \text{H} \end{array} ]</td>
<td>Ethene</td>
</tr>
</tbody>
</table>
Properties of Alkenes

Combustion:

The alkenes burn to give carbon(iv)oxide and water, with a smoky and luminous flame because of the high proportion of carbon.

Eg. \[ \text{C}_2\text{H}_4(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

Other reactions of alkenes;

The alkenes are generally more reactive than the alkanes because of the double bond in their structure which make them unsaturated compounds.

Addition Reactions of Ethene (\(\text{C}_2\text{H}_4\)) and Propene (\(\text{C}_3\text{H}_6\)) with Bromine.

Due to their unsaturated nature, the alkenes react by addition, which means specie is simply added on as shown in the following examples;

1. Addition Reactions of Ethene and Propene with Bromine;

   a. \(\text{C}_2\text{H}_4(\text{g}) + \text{Br}_2(\text{g}) \rightarrow \text{H} - \text{C} - \text{C} - \text{H} \)

      Ethene \(\rightarrow 1,2\)-dibromoethane

   b. \(\text{C}_3\text{H}_6(\text{g}) + \text{Br}_2(\text{g}) \rightarrow \text{H} - \text{C} - \text{C} - \text{C} - \text{H} \)

      Propene \(\rightarrow 1,2\)-dibromopropane
Polymerisation:
The alkenes undergo polymerisation especially ethane and its derivatives to form important compounds such as polyethylene, polychloroethene, etc.
Polymerisation is a process whereby many simple molecules known as monomers are linked to form a much larger molecule known as a polymer.

Methods of Preparation:
1. The main commercial source of the alkenes is from the thermal or catalytic cracking of larger alkane molecules. In the process, mixtures of alkenes are obtained which are separated by fractional distillation. Eg. $\text{C}_{12}\text{H}_{26} + \text{C}_{4}\text{H}_{8} \rightarrow \text{C}_{8}\text{H}_{18} + \text{C}_{5}\text{H}_{12} + \text{C}_{3}\text{H}_{6}$
2. Another method used in the preparation of alkenes involves dehydration of the appropriate alcohol. Eg. Ethene can be prepared by heating ethanol with conc. tetraoxosulphate (vi) acid ($\text{H}_2\text{SO}_4$).

\[
\text{C}_2\text{H}_5\text{OH}(l) \rightarrow \text{C}_2\text{H}_4(g) + \text{H}_2\text{O}(l)
\]

Uses of Alkenes:
1. The cracking of petroleum produces large quantities of ethane for industrial uses such as polyethylene products.
2. Propene is used to produce plastics such as Perspex.
3. Buta-1,3-diene is used in synthetic rubber manufacture.

Learning Activity 4.1

Materials Needed/Apparatus:
Black coloured plasticine balls (Carbon atoms), White coloured plasticine balls (Hydrogen atoms), match stick or tooth pick.

Method / Procedure / Instructions
1. Using the carbon and hydrogen atoms (Plasticine balls) and the sticks, make 3 dimensional models of the following alkene compounds:
   i. Ethene  ii. But-1-ene  iii. 2-methylprop-1-ene
2. Draw the structural formula of the following alkene compounds:
   i. Hex-2-ene ($\text{C}_6\text{H}_{12}$)  ii. Hept-3-ene ($\text{C}_7\text{H}_{14}$)  iii. 3,3-dimethylhept-1-ene ($\text{C}_9\text{H}_{18}$)

Lesson Five:
The Alkyne homologous series

The alkyynes are groups of hydrocarbons which belong to the same homologous series. They have a general molecular formula of $\text{C}_n\text{H}_{2n-2}$, where $n$ is a positive integer equal to or greater than 2. Each alkyne molecule contains four (4) hydrogen atoms less than the corresponding alkane and two (2) hydrogen atoms less than the corresponding alkene. The alkyynes are unsaturated hydrocarbons which contain a carbon-carbon triple bond as well as single bonds in each molecule. They show a higher degree of unsaturation than the alkenes and are therefore more reactive than the alkenes and the alkanes. The alkyynes are given names similar to the alkanes depending on the
number of carbon atoms in the molecule. The -ane of the corresponding alkane is replaced by -yne.

Below are molecular formula, structural formula and names of some members of the alkyne homologous series, including the isomers. They are arranged in increasing molecular weight.

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Structural Formula and Isomers</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂H₂</td>
<td>H– C ≡ C – H</td>
<td>Ethyne</td>
</tr>
<tr>
<td>C₃H₄</td>
<td>H – C ≡ C – C – H</td>
<td>Prop-1-yne</td>
</tr>
<tr>
<td>C₄H₆</td>
<td>H – C ≡ C – C – C – H</td>
<td>But-1-yne</td>
</tr>
<tr>
<td></td>
<td>H – C – C ≡ C – C – H</td>
<td>But-2-yne</td>
</tr>
</tbody>
</table>

**Properties of Alkynes**

Combustion:

1. The alkynes (ethyne) burns in air to give a very smoky and luminous flame to form carbon(iv)oxide and water.
   
   Eg. \(2\text{C}_2\text{H}_2(g) + 5\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 2\text{H}_2\text{O}(l)\)

2. If ethyne is used in a special burner with an extra oxygen supply, it burns brilliantly giving the very hot oxy-acetylene (oxy-ethyne) flame which is capable of cutting through metals.

3. When a sample of ethyne is tested with a lighted taper, it burns with a yellow, sooty flame owing to its high carbon content and carbon is deposited.

   \(2\text{C}_2\text{H}_2(g) + \text{O}_2(g) \rightarrow 4\text{C}(s) + 2\text{H}_2\text{O}(g)\)

Other reactions of alkynes:

Addition Reactions:

Alkynes are highly unsaturated, containing carbon-carbon triple bond in its structure. They undergo addition reactions combining with a maximum of four (4) univalent atoms or radicals per molecule to form addition products. The addition reactions take place in two stages:

a. The first stage yields a product with a carbon-carbon double bond ie. Alkenes.

b. The second stage converts this into a fully saturated compound with only carbon-carbon single bonds ie. Alkanes.
Examples
1. Addition reaction of Alkyne (Ethyne) with Hydrogen

\[
\begin{align*}
\text{C}_2\text{H}_2 + \text{H}_2 & \rightarrow \text{C}_2\text{H}_4 + \text{H}_2 \\
\text{Ethyne} & \quad \text{Ethene} \quad \text{Ethane}
\end{align*}
\]

2. Addition reactions of Alkyne (Ethyne) with Halogens (Bromine, Br\(_2\))

\[
\begin{align*}
\text{C}_2\text{H}_2 + \text{Br}_2 & \rightarrow \text{C}_2\text{H}_2\text{Br}_2 + \text{Br}_2 \\
\text{Ethyne} & \quad 1,2\text{-dibromoethene} \quad 1,1,2,2\text{-tetrabromoethane}
\end{align*}
\]

Chlorine reacts explosively with ethyne producing carbon and hydrogen chloride gas

\[
\begin{align*}
\text{C}_2\text{H}_2(g) + \text{Cl}_2(g) & \rightarrow 2\text{C}(s) + 2\text{HCl}(g) \\
\text{Ethyne} & \quad \text{1,1,2,2-tetrabromoethane}
\end{align*}
\]

Ethyne reacts with Chlorine and Bromine in the presence of a catalyst (metallic halide) to yield halogenated compounds at room temperature.

Polymerisation
Alkynes also polymerises especially, ethyne which polymerises to form the aromatic hydrocarbon, benzene (C\(_6\)H\(_6\)) when it is passed through a hot tube containing a complex organo-nickel catalyst.

\[
3\text{C}_2\text{H}_2(g) \rightarrow \text{C}_6\text{H}_6(g)
\]

Methods of Preparation:
1. Alkynes can be prepared in the laboratory by the action of alcoholic potassium hydroxide on dibromoalkanes.

Eg. \[\text{CH}_2\text{BrCH}_2\text{Br} \xrightarrow{\text{KOH}/\text{C}_2\text{H}_5\text{OH}} \text{C}_2\text{H}_2 + 2\text{HBr} \]

2. However, ethyne can be prepared in the laboratory conveniently by the action of cold water on calcium carbide.

ie. \[\text{CaC}_2(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{H–C} = \text{C–H} \]

Uses of Alkynes:
1. Ethyne is used as the starting material for the production of Polyvinylchloride (PVC), 1,1,2,2-tetrachloroethane (a solvent for grease and oils), artificial or synthetic fibres and ethanoic acid.
2. Ethyne is used in the oxyacetylene torch and in lamps.

**Learning Activity 4.2**

Materials Needed/Apparatus:
Black coloured plasticine balls (Carbon atoms), White coloured plasticine balls (Hydrogen atoms), match stick or tooth pick.

Method / Procedure / Instructions
1. Using the carbon and hydrogen atoms (Plasticine balls) and the sticks, make 3 dimensional models of the following alkyne compounds;


2. Draw the structural formula of the following alkyne compounds;
i. Pent-2-yne (C₅H₈). ii. Hex-3-yne (C₆H₁₀). iii. 3,5-dimethylhept-1-ene (C₉H₁₆).

**Self-Test / Evaluation**

Answer the following questions:

1. What are the general molecular formula of the alkenes and alkynes?
2. Why are alkenes and alkynes said to be unsaturated?
3. List the methods of preparing the alkenes and the alkynes?
4. Draw the structures of 4 examples of alkene homologous series?
5. Draw all the isomers of hexyne?

**Mastery / Post-test;**

Answer the following questions:

1. What are aromatic hydrocarbons?
2. Draw the resonating structures of benzene?
3. In a tabular format, distinguish between the alkanes, alkenes and alkynes?

**Enrichment Opportunities**


Also study page 149 – 154 of Science Teachers Association of Nigeria (STAN) Chemistry for Senior Secondary Schools.

**Appendix B: Chemistry Achievement Test on Organic Chemistry (CATOC)**

**Section A**

Name of school:...................................................................................................

Name of student:...................................................................................................

Class:...............................................

Sex: Male ☐ Female ☐ (Tick ✓)

**Section B**

Instructions

a. Choose and tick ✓ only the correct answer from options a - d
b. Erase completely any answer made in error
c. Do not cheat in any form 

d. Time allowed is 1.30 hrs
e. Answer all the questions.

**Questions**

1. The following are general characteristics of carbon except?
   a. covalent nature and non-polar.  
   b. low melting and boiling points
   c. low reactivity with other elements except oxygen and the halogens
   d. hydrogen bond in petrol

2. Exceptional large number of carbon compounds is essentially due to the ability of?
   a. carbon to catenate liberally  
   b. various groups to catenate
c. nitrogen, hydrogen, phosphorous and the halogens to catenate with themselves
d. hydrocarbons to dominate other groups
3. What is the name of C(CH₃)₄?
a. butane    b. tetramethyl butane. c. methyl propane.   d. 2,2-dimethyl propane
4. What is the name of the homologous series with the general formula shown below?
   \[
   \text{R - C} = \text{NH}_2
   \]
a. amine.    b. amino acids.   c. oxy-amines.   d. amides.
5. Which is not among the characteristics of functional groups in organic compounds?
a. determine the chemical properties of the homologous series
b. does not modify the other when they are more than one in a molecule
c. have a general formula which may include the functional group
d. are responsible for the physical properties
6. The IUPAC name of ClCH₂-Ch₂-CH₂OH is?
a. 1-chloropropan-3-ol.    b. 3-chloropropan-1-ol.   c. 1-chloropropanol.
d. 3-chloropropanol.
7. Which of these compounds is not a hydrocarbon?
a. benzene    b. ethane    c. ethanol    d. butyne
8. What is the name given to the compound shown below?

   \[
   \text{H}_2\text{C} \quad \text{CH}_2 \quad \text{H}_2\text{C} \quad \text{CH}_2
   \]
a. benzene    b. hexane    c. cyclohexane    d. hydrobenzene
9. When two or more compounds have the same molecular formula but different structures they are known as?
a. allotropes.   b. tantamerism.   c. mirror isomers.   d. structural isomers.
10. Which is not among the uses of Petroleum?
a. fuels only.    b. fuels and money.    c. fuels and pollutants.
d. fuels and petrochemical raw materials
11. The main natural sources of hydrocarbons are from fossil fuels and these include except?
a. natural gas    b. coke    c. coal    d. petroleum
12. Alkenes and Alkynes reacts the same, except with?
a. ammoniacal AgNO₃ solution.   b. oxygen.    c. bromine water.
d. acidified KMnO₄ solution.
13. Functional group for the alkanol is?
a. -OH.    b. CnH₂n-2    c. COOH    d. OH
14. What is this compound CH₃(CH₂)₂CONH₂ called?
a. methyl amine.   b. butyl amine.   c. butyl amide.    d. Urea.
15. Which among the following is an aromatic hydrocarbon?
a. cyclopentane b. toluene    c. pentanal    d. ethane
16. What is the product formed when methane reacts with chlorine; CH₄ + Cl₂ → ?
a. CH₃Cl₂ + H₂   b. CH₃Cl + HCl   c. CH₂Cl + 2HCl    d. CH₂Cl₂ + H₂
17. Which of the following compounds is an alkane?
   a. \( C_2H_2 \)  
   b. \( C_3H_6 \)  
   c. \( C_4H_6 \)  
   d. \( C_6H_{14} \)

18. What type of reaction takes place when ethane reacts with hydrogen bromide?
   a. oxidation reaction  
   b. substitution reaction  
   c. addition reaction  
   d. polymerisation reaction

19. Which of the following molecules is the most unsaturated?
   a. ethyne  
   b. methane  
   c. ethene  
   d. propane

20. Write the general formula for the alkenes?
   a. \( C_nH_{2n} \)  
   b. \( C_nH_{2n+2} \)  
   c. \( C_nH_{2n-2} \)  
   d. \( C_nH_{2n-n} \)

21. Hydrocarbons are organic compounds that contain....?
   a. carbon and oxygen only.  
   b. carbon, hydrogen and oxygen only.  
   c. carbon and sulphur only.  
   d. carbon and hydrogen only.

22. Which method is often used in separating the hydrocarbons found in petroleum?
   a. catalytic cracking  
   b. polymerisation  
   c. fractional distillation  
   d. hydrogenation

23. Which of the following compounds do not exhibit isomerism?
   a. \( C_2H_6 \)  
   b. \( C_4H_8 \)  
   c. \( C_6H_{14} \)  
   d. \( C_5H_8 \)

24. What is the name of the compound \( C_2H_5COOH \)?
   a. ethanoic acid.  
   b. propanoic acid.  
   c. butanoic acid.  
   d. methanoic acid.

25. What is the general molecular formula of the alkene homologous series?
   a. \( C_nH_n \)  
   b. \( C_nH_{2n+2} \)  
   c. \( C_nH_{2n} \)  
   d. \( C_nH_{2n-2} \)
Appendix C: CATOC Marking Guide

1.  d
2.  a
3.  d
4.  d
5.  b
6.  b
7.  c
8.  c
9.  d
10. c
11. b
12. b
13. a
14. c
15. b
16. b
17. d
18. b
19. a
20. c
21. d
22. c
23. a
24. b
25. c
Appendix D: TEST BLUE PRINT FOR THE CATOC

<table>
<thead>
<tr>
<th>Content</th>
<th>Knowledge (Remembering)</th>
<th>Comprehension (Understanding)</th>
<th>Application (Thinking)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure and Valency of Carbon - 10%</td>
<td>A 1</td>
<td>B 1</td>
<td>C 1</td>
<td>T_a 3</td>
</tr>
<tr>
<td>Hydrocarbons (Saturated, Unsaturated, Alkanes, Alkenes and Alkynes) - 45%</td>
<td>D 5</td>
<td>E 3</td>
<td>F 3</td>
<td>T_b 11</td>
</tr>
<tr>
<td>Isomerism, Homologous series, Functional groups) - 25%</td>
<td>G 3</td>
<td>H 2</td>
<td>I 1</td>
<td>T_c 6</td>
</tr>
<tr>
<td>IUPAC Nomenclature - 20%</td>
<td>J 2</td>
<td>K 2</td>
<td>L 1</td>
<td>T_d 5</td>
</tr>
<tr>
<td>Total</td>
<td>T_e 11</td>
<td>T_f 8</td>
<td>T_g 6</td>
<td>25</td>
</tr>
</tbody>
</table>

Calculations:

Total number of items = 25

From the table above, ‘Structure and valency of carbon’ was allotted 10%; ‘Hydrocarbons (saturated, unsaturated, alkanes, alkenes and alkynes)’ had 45%, ‘Isomerism, Homologous series and Functional groups’ had 25%; while IUPAC nomenclature was allotted 20%. Likewise, Knowledge was allotted 40%, Comprehension 35% and Application 25%.

Calculating the totals, T_a to T_g;

\[ T_a = \frac{10}{100} \times 25 = 3 \]
\[ T_b = \frac{45}{100} \times 25 = 11 \]
\[ T_c = \frac{25}{100} \times 25 = 6 \]
\[ T_d = \frac{20}{100} \times 25 = 5 \]
\[ T_e = \frac{45}{100} \times 25 = 11 \]
\[ T_f = \frac{30}{100} \times 25 = 8 \]
\[ T_g = \frac{25}{100} \times 25 = 6 \]

Calculating the number of items/questions for each cell, A to L;

\[ A = \frac{11}{25} \times 3 = 1 \]
\[ B = \frac{8}{25} \times 3 = 1 \]
\[ C = \frac{6}{25} \times 3 = 1 \]
\[ D = \frac{11}{25} \times 11 = 5 \]
\[ E = \frac{8}{25} \times 11 = 3 \]
\[ F = \frac{6}{25} \times 11 = 3 \]
\[ G = \frac{11}{25} \times 6 = 3 \]
\[ H = \frac{8}{25} \times 6 = 2 \]
\[ I = \frac{6}{25} \times 6 = 1 \]
\[ J = \frac{11}{25} \times 5 = 2 \]
\[ K = \frac{8}{25} \times 5 = 2 \]
\[ L = \frac{6}{25} \times 5 = 1 \]
RE-STRUCTURING SECONDARY SCHOOL CHEMISTRY EDUCATION FOR SUSTAINABLE DEVELOPMENT IN NIGERIAN DEVELOPING ECONOMY

Olufunmilayo D. Ayodele
Oduduwa University Ipetumodu, Ile-ife, Osun-State, Nigeria
Email: olufunmilayopapers@gmail.com

ABSTRACT
Chemistry Education is considered as a key agent of development, either as a way of developing human capacity, increasing the skilled workforce for modernization, or as a matter of personal freedom, developing capability and empowerment. Nigeria, as a nation, is still wadding in a muddy pull in seeking the right way to terminate her total dependence on foreign nations for technological expertise in fields of Science and Technology. The nation has produced many scientists, engineers and technologist yet we import services and goods in these fields from other countries which resulted in a recessed economy. This paper therefore discussed the loopholes in the present secondary school chemistry education and recommended the way forward in terms of restructuring the curriculum themes to produce a functional chemistry education, restructuring the chemistry practical activities to integrate improvisation with locally available materials and chemical processes designed to meet the need of the society (and not just rote learning of titration and cation/anion analysis of procured chemical compounds), introduction of remedial teaching plan for mastery learning strategy, introducing Science Mini Project (SMP) for Senior Secondary Students using available local materials as part of SSCE formative assessment scores. This would build a solid foundation that would usher in a new era of creative and innovative students who are prepared for post- secondary industrial work and at the same time could proceed with higher confidence and adequate creative potential and practical skills to higher education in any science and technological field. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

Chemistry education is the study of the teaching and learning of chemistry in all schools, colleges and universities. Chemistry education also includes the understanding of how students learn chemistry, how best to teach chemistry, and how to improve learning outcomes by changing teaching methods and appropriate training of chemistry instructors [1]. Moreover, Chemistry Education has been identified to be one of the major bedrock for the transformation of a nation’s economy. It is needed for the production of the needed technologists, technicians, engineers, medical practitioners who are required to turn the nation’s economy around and usher in the desired technological advancement which is very much required for sustainable development.

Chemistry has been defined as a branch of pure and basic science which deals with the study of nature, composition, properties (physical and chemical) and uses of matter, and the changes matter would undergo under different conditions [2]. Chemistry in its entirety has a central role to play in promoting sustainable development through basic research skills, chemical innovations and technology.

Sustainable development has been defined as a development that meets the need of the present without compromising the ability of the future generation to meet their need. The concept of sustainable development emphasizes that education should be geared to prepare students to learn how to take responsibility for both themselves and their society for today and in the future [3, 4, 5]. All educational domains and all school subjects need to contribute to education for sustainable development including secondary school chemistry.

The position of Chemistry and the chemical industry in a nation play core roles in achieving sustainable development. Chemical knowledge is necessary to understand issues that threaten the sustainability of our planets (global warming, ozone depletion acid rain formation, among others).
Moreover, the chemical industry provides most of the raw materials necessary for every other type of business or endeavour. Chemistry is also the basis of a modern energy supply, agriculture, innovative materials, communication, biotechnology and Pharmaceuticals [6].

Researchers reported negative attitude of students generally to science subjects such as Chemistry, they opined that the lack of interest in Chemistry subject is majorly as a result of the content of the syllabus [7]. Also, secondary school students perceived Chemistry syllabus as being too wide and involving too many calculations and Chemistry as being too abstract [8]. Moreover, over the years the pass rates in Chemistry for most part have fallen below 50% [9]. This poor performance could be as a result of lack of interest in the content and ineffective teaching methods used by the teachers.

According to [10], there is a significant positive relationship between interest and effort, if the students have interest in the subject, they would make effort to perform well in the subject. There is therefore a need to re-awaken the interest of secondary school students in chemistry to secure a solid foundation for vocations like health fields, pharmaceuticals, petroleum and petrochemical industries, agriculture, food and chemical engineering and so on.

Nigeria has dwelt in the realm of underdeveloped economy for too long, though the Nigerian economy is now referred to as a developing economy, yet Nigeria as a nation is still swaying in a blurry pool in seeking the right way to reduce or end her total reliance on foreign nations for goods and services in fields of Science and Technology. Nigeria needs to produce more graduates in these fields who are competent and have been adequately grilled with relevant curriculum tailored towards innovative and sustainable developmental goals in their respective fields of Science and Technology. Chemistry is a core science subject taught in the secondary school as prerequisite course for admission into tertiary institutions in these fields.
Qualitative functional chemical knowledge is practical and useful but the Nigerian formal education has not provided school learners with functional education. The secondary school chemistry curriculum taught over the years has lost its relevance in this aspect.

Most Chemistry students from secondary schools are not able to apply principles taught or how to relate the theories with the practical everyday living or see Chemical knowledge as a tool for wealth creation. There is therefore a need to review the curriculum for teaching Chemistry in the secondary school, to create a functional and relevant Chemistry curriculum that would meet the societal demand, awaken interest for the subject in students and aid the sustainability of scientific and technological development in the country.

It is therefore necessary to position secondary education in a developing economy, curricular emphasis in secondary school context refers to the degree of vocationalization of the curriculum ranging from purely academic to pre-vocational training [11]. They advised that for optimal positioning, planners and political leaders should hope to fit secondary schools rationally into this matrix to prepare youths for full wage-sector jobs and also raise the proficiencies of aspiring university candidates and to reinforce nation building

It is on this premise that this paper proposes the re-structuring of the secondary school chemistry curriculum and education in terms of the objectives, themes and topics, practical syllabus and assessment. The paper highlights the loopholes in the Nigerian secondary school chemistry curriculum, it extrapolates the secondary school chemistry curriculum of the two most populous and technologically viable nations; china and India with that of Nigeria. The paper also proposed the way forward in terms of restructuring the themes, topics, method of instruction, content, scope and practical chemistry syllabus and also made some salient recommendations.
OBJECTIVES OF THE STUDY

- To identify loopholes in the Nigerian Secondary School Chemistry curriculum,
- To compare the curricula of China and India with that of Nigeria,
- To propose ways of re-structuring the Secondary School Chemistry curriculum
- To give appropriate recommendations.

THE LOOPHOLES IN THE NIGERIAN SECONDARY SCHOOL CHEMISTRY CURRICULUM

Loopholes in the Nigerian Secondary School Chemistry Objectives

A sustainable development involves those activities, processes put in place to meet the need of the present, at the same time not sabotaging the future. China and India are the two most populous countries with high reliance on a lot of homemade chemical products and innovative technologies. Hence, the Nigerian secondary school chemistry curriculum is taken side by side with India in terms of objectives, and China in terms of themes and the three are contrasted in terms of practical syllabus in order to identify the loopholes in the Nigerian secondary school chemistry curriculum.

The Objectives of Chemistry Education in Nigeria National Curriculum for Senior Secondary Schools and that of India Secondary School Chemistry Curriculum are presented in the table below.
Table 1: Objectives of Secondary Chemistry Education in India and Nigeria

<table>
<thead>
<tr>
<th>INDIAN SECONDARY SCHOOL CHEMISTRY CURRICULUM OBJECTIVES</th>
<th>NIGERIAN SECONDARY SCHOOL CHEMISTRY CURRICULUM OBJECTIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To promote understanding of basic facts and concepts in chemistry while retaining the excitement of chemistry.</td>
<td>• Facilitating a transition from secondary to tertiary level of education in the use of scientific concepts and techniques acquired in chemistry.</td>
</tr>
<tr>
<td>• To make students capable of studying chemistry in academic and professional courses (such as medicine, engineering, technology) at tertiary level.</td>
<td>• Providing the students with basic knowledge in chemical concepts and principles, through efficient selection of content and sequencing.</td>
</tr>
<tr>
<td>• To expose the students to various emerging new areas of chemistry and apprise them with their relevance in future studies and their application in various spheres of chemical sciences and technology.</td>
<td>• Showing chemistry in its relationship with other subjects.</td>
</tr>
<tr>
<td>• To equip students to face various challenges related to health, nutrition, environment, population, weather, industries and agriculture.</td>
<td>• Showing chemistry and its links with industry, everyday life, hazards and benefits.</td>
</tr>
<tr>
<td>• To develop problem solving skills in students.</td>
<td>• Providing a course which is complete for its pupils not proceeding to higher education while it is at the same time, a reasonably adequate foundation for a post-secondary course.</td>
</tr>
<tr>
<td>• To expose the students to different processes used in industries and their technological applications.</td>
<td></td>
</tr>
<tr>
<td>• To apprise students with interface of chemistry with other disciplines of science such as physics, biology, geology, engineering etc.</td>
<td></td>
</tr>
<tr>
<td>• To acquaint students with different aspects of chemistry used in daily life.</td>
<td></td>
</tr>
<tr>
<td>• To develop an interest in students to study chemistry as a discipline.</td>
<td></td>
</tr>
</tbody>
</table>

Source: [12, 13]

The chemistry curriculum objectives as presented in the table above revealed the inadequacy of the Nigerian objectives when compared with those of Indian secondary school chemistry curriculum. The India objectives are more relevant and designed to meet the societal needs while Nigeria objectives seemed ambiguous in comparison. According to [14], University undergraduate science students perceived that the secondary school chemistry curriculum was
adequate and relevant as a foundation for university chemistry. However, the question is; ‘Are these objectives sufficient for a sustainable development?’

According to [15], though Nigeria is rich in human and natural resources, there are so many unemployed youths because the educational system does not equip them for self-reliance. Teaching of chemistry should be practically oriented to develop skills needed for entrepreneurial development and at the same time for movement to higher education.

The objectives stated in the secondary school chemistry curriculum, did not make provision for relating chemistry to; nature and society, wealth creation, health and daily living and so on. Post-secondary chemistry students are not trained to engage in small scale analysis and production of household chemical products useful and relevant to the society. In Nigeria we import materials like paper, tissue, liquid soap, air freshener and so on? Most of the ones produced are by local entrepreneurs who have no chemistry foundation, hence could not meet up to required standards and are exposed to hazards they are not informed about. There is need to review the objectives of the present chemistry curriculum in Nigeria to enable students relate chemistry to nature and society, to equip students with adequate practical skills for functional chemistry that would make them work effectively as industrial technicians or chemical artisans for those who may not be opportune to proceed to tertiary education.

**Loopholes in the themes**

The table below presents the themes of the secondary school curriculum of China and our nation Nigeria.
Table 2: Secondary School Chemistry Curriculum Themes for China and Nigeria

<table>
<thead>
<tr>
<th>CHINESE SECONDARY CHEMISTRY CURRICULUM</th>
<th>NIGERIAN SECONDARY CURRICULUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course Themes</td>
<td>Themes</td>
</tr>
<tr>
<td>Chemistry 1</td>
<td>Knowing Chemistry as a science</td>
</tr>
<tr>
<td></td>
<td>Basics to Chemical experiments</td>
</tr>
<tr>
<td></td>
<td>Common Inorganic Elements and compounds and their applications</td>
</tr>
<tr>
<td></td>
<td>Chemical World</td>
</tr>
<tr>
<td></td>
<td>Periodic table, Chemical reactions, particulate nature of matter, gas laws, chemical combinations, qualitative and quantitative analysis</td>
</tr>
<tr>
<td>Chemistry 2</td>
<td>Particulate Structure of Substances</td>
</tr>
<tr>
<td></td>
<td>Chemical Reaction and Energy</td>
</tr>
<tr>
<td></td>
<td>Chemistry and sustainable social development</td>
</tr>
<tr>
<td></td>
<td>Chemistry and environment</td>
</tr>
<tr>
<td></td>
<td>Separation techniques, acids bases and salts, non-metals and their compound.</td>
</tr>
<tr>
<td>Chemistry and Daily lives</td>
<td>Chemistry and Personal Health</td>
</tr>
<tr>
<td></td>
<td>Materials in Daily Lives</td>
</tr>
<tr>
<td></td>
<td>Chemistry and Environmental Protection</td>
</tr>
<tr>
<td></td>
<td>Chemistry and industry</td>
</tr>
<tr>
<td></td>
<td>Chemical industry, redox reactions and electrolysis, metals and their compounds, petroleum / crude oil</td>
</tr>
<tr>
<td>Chemistry and Technology</td>
<td>Chemistry and Exploitation and Application of Natural Resources</td>
</tr>
<tr>
<td></td>
<td>Chemistry and Manufacture and application of Materials</td>
</tr>
<tr>
<td></td>
<td>Chemistry and Industrial and Agricultural production</td>
</tr>
<tr>
<td></td>
<td>Chemistry of life</td>
</tr>
<tr>
<td></td>
<td>Carbon and its compound, Hydrocarbons, fats and oils, soap and detergents, giant molecules.</td>
</tr>
<tr>
<td>Particulate structure and Properties of Substance</td>
<td>Atomic Structure and Elements</td>
</tr>
<tr>
<td></td>
<td>Chemical Bonds and properties of substances</td>
</tr>
<tr>
<td></td>
<td>Intermolecular Forces and properties’ of Substances</td>
</tr>
<tr>
<td></td>
<td>Values of Investigating</td>
</tr>
</tbody>
</table>
Students should learn how to take responsibility for both themselves and their society for today and the future [3, 4]. Chemistry education must contribute to developing a balanced and well-informed society as citizens responsible for how the present shapes the future. There is need to infuse themes and topics in the chemistry curriculum content, teaching and practice, so as to reveal the link of Chemistry to nature, society and everyday living. Also, directing the themes to subsume topics targeted at achieving a functional chemistry education for the good of the individual and the society at large.

According to [5], chemistry education that would achieve a sustainable development must focus on general educational skills for societal participation, it should deal with the impacts of development related to chemistry and technology on the ecology, the economy, and society at the local, regional and global level and develop skills in students to actively handle these aspects in the future.
Practical syllabus

Restructuring chemistry education towards a sustainable development in Nigeria requires a shift in not only the theoretical content but also the contextual approaches in teaching chemistry practical skills. The Secondary School Chemistry Practical syllabus for Nigeria, India and china are presented below:

Table 3: Comparison of Chemistry Practical Syllabus

<table>
<thead>
<tr>
<th>INDIA</th>
<th>CHINA</th>
<th>NIGERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Surface Chemistry</strong>&lt;br&gt; (a) Preparation of one lyophilic and one lyophobic sol Lyophilic sol - starch, egg albumin and gum Lyophobic sol - aluminium hydroxide, ferric hydroxide, arsenous sulphide.&lt;br&gt; (b) Dialysis of sol-prepared in (a) above.&lt;br&gt; (c) Study of the role of emulsifying agents in stabilizing the emulsion of different oils.</td>
<td><strong>D. Chemical Equilibrium</strong>&lt;br&gt; One of the following experiments:&lt;br&gt; a) Study the shift in equilibrium between ferric ions and thiocyanate ions by increasing/decreasing the concentration of either of the ions.&lt;br&gt; b) Quantitative Estimation i) Using a chemical balance. ii) Preparation of standard solution of Oxalic acid. iii) Determination of strength of a given solution of Sodium Hydroxide by titrating it against standard solution of Oxalic acid. iv) Preparation of standard solution of Sodium Carbonate. v) Determination of strength of a given solution of Hydrochloric acid by titrating it against standard Sodium Carbonate solution.</td>
<td>1. Acid-base titration&lt;br&gt; 2. Water of crystalization&lt;br&gt; 3. Thermochemistry&lt;br&gt; 4. Qualitative analysis involving cations Pb²⁺, Cu²⁺ A1³⁺, Fe³⁺, Mn²⁺, Zn²⁺, Co₂⁺Ca₂⁺, Ba₂⁺, Mg²⁺, and anions SO₄²⁻, SO₃²⁻, NO₃⁻, CO₃²⁻, Cl⁻, Br⁻, I⁻. Test for gases: CO₂, NO₂, H₂, O₂, SO₂, NH₃ and H₂S.</td>
</tr>
<tr>
<td><strong>B. Chemical Kinetics</strong>&lt;br&gt; (a) Effect of concentration and temperature on the rate of reaction between Sodium Thiosulphate and Hydrochloric acid.&lt;br&gt; (b) Study of reaction rates of any one of the following: (i) Reaction of Iodide ion with Hydrogen Peroxide at room temperature using different concentration of Iodide ions. (ii) Reaction between Potassium Iodate, (KIO₃) and Sodium Sulphite: (Na₂SO₃) using starch solution as indicator (clock reaction).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### C. Thermochemistry
Any one of the following experiments

i) Enthalpy of dissolution of Copper Sulphate or Potassium Nitrate.

ii) Enthalpy of neutralization of strong acid (HCl) and strong base (NaOH).

iii) Determination of enthalpy change during interaction (Hydrogen bond formation) between Acetone and Chloroform.

### D. Electrochemistry
Variation of cell potential in Zn/Zn2+||Cu2+/Cu with change in concentration of electrolytes (CuSO4 or ZnSO4) at room temperature.

### E. Chromatography

i) Separation of pigments from extracts of leaves and flowers by paper chromatography and determination of Rf values.

ii) Separation of constituents present in an inorganic mixture containing two cations only (constituents having large difference in Rf values to be provided).

### F. Preparation of Inorganic Compounds

i) Preparation of double salt of Ferrous Ammonium Sulphate or Potash Alum.

ii) Preparation of Potassium Ferric Oxalate.

### G. Preparation of Organic Compounds
Preparation of any one of the following compounds

i) Acetanilide

ii) Di-benzal Acetone

iii) p-
Nitroacetanilide iv) Aniline yellow or 2 - Naphthol Aniline dye.

**H. Tests for the functional groups present in organic compounds**: Unsaturation, alcoholic, phenolic, aldehydic, ketonic, carboxylic and amino (Primary) groups.

**I. Characteristic tests of carbohydrates, fats and proteins** in pure samples and their detection in given food stuffs.

**J. Determination of concentration/ molarity** of KMnO₄ solution by titrating it against a standard solution of: i) Oxalic acid, ii) Ferrous Ammonium Sulphate (Students will be required to prepare standard solutions by weighing themselves).

**K. Qualitative analysis**

Determination of one cation and one anion in a given salt. Cation- Pb²⁺, Cu²⁺ As³⁺, Al³⁺, Fe³⁺, Mn²⁺, ZnCu²⁺, Co²⁺, Ni²⁺, Ca²⁺, Sr²⁺, Ba²⁺, Mg²⁺, Anions- 2⁻ 2⁻ 2⁻ - - - - 3⁺ 2⁻ - 3 4 2 2 4 4 , S , S , S , NO , C, Br, I , PO , C , O , CH COO⁻

---

**WAY FORAWRD**

**Rephrasing the Objectives**

Chemistry education should deal with the impact of chemistry on nature, environment, society at the local, regional and global level and also enlighten students on the impact of all these on the economy. We need our schools, universities and lifelong learning programs to focus their
objectives on science and technology with innovative, economic, environmental and social perspectives.

Rephrasing the objectives to include the following:

- To provide Chemistry education that focuses on general chemical skills for societal participation.
- To impact the knowledge of chemistry that deals with nature, environment and society at the local, regional and global level.
- To enlighten students on the impact of all chemical compounds and processes on human health and the economy of the Nation.

Revising Themes and Topics

*Proposed revised theme*

- Chemistry and nature
- Chemical world and our environment; including topics like green chemistry, effect of gas flaring, effect of chemical and nuclear weapons, should be subsumed under environmental pollution and preservation.
- Chemical industries (textile industry, petroleum, polymer chemistry; topics like industrial effluent and its treatment or disposal should be taught,
- Chemistry in everyday life; in medicine (Chemicals in medicines - analgesics, tranquilizers antiseptics, disinfectants, antimicrobials, antifertility drugs, antibiotics, antacids, antihistamines. Chemicals in food - preservatives, artificial sweetening agents, elementary idea of antioxidants. Cleansing agents- soaps and detergents, cleansing action.), in food, in agriculture, in technology, in our homes.
- Chemistry of life;
Chemistry and health; effect of various chemicals on health, precautions in handling chemicals at home (e.g. fuels like kerosene, petrol, alcohols, gases etc) school and in the industries (fine and heavy chemicals).

Moreover, separate studies [8, 18, 19] have identified some difficult topics in the current curriculum which make chemistry to be too abstract for the students to comprehend. Thus, topics in the secondary chemistry curriculum should be reviewed.

**Functional Practical Chemistry**

It was reported that the present science and technology taught in Nigerian schools do not prepare learners to function well in a society undergoing transition from a rural economy to a modern economy [20]. According to them, learners should be taught to connect school learning with the world of work where the subject is applied. That is the skills should be aimed at readiness for the world of work and economic responsibilities. There is much inconsistency between the formal chemistry curriculum and the present day market and industrial demands. Chemistry practical should therefore be utilitarian by identifying chemical processes of practical application in the society.

Practical topics should be drawn from topics taught in the syllabus like dilution and standardization of chemical solutions, neutralization, rates of reaction, solubility, thermochemistry, treatment of hard water, simple inorganic analysis; water analysis, soil analysis, identification of cations and anions in food substances and drinks, esterification, saponification, identification of functional groups.

The practical questions for the SSCE or NECO could be drawn from the above listed topics using locally available materials e.g.

- Analysis of impure samples or mixtures like alum, ink or dye, ferrous sulphate tablet
- Standardization of battery water.
- Determination of pH of common drinks
- Oxalate ions in fruits
- Study of reaction rates
- Effect of temperature on some food preservatives
- Separation of pigments from extracts of leaves and flowers by paper chromatography and determination of Rf values, and other relevant experiments.

**Improvisation**

Improvisation and the use of locally available materials for practical experiments should be encouraged. The Nigerian chemistry curriculum could integrate improvisation on materials used. That is locally available chemicals could be used for some practical experiments. This would also create awareness of the chemical substances available around us, for example juices of unripe citrus fruits like unripe oranges, lemon e.t.c as sources of organic acids, potassium hydroxide from wood ashes, dyes of local plants (e.g Hibiscus sabdariffa; known as Zobo) as indicators for acid base titration, and so on. These materials could be used in acid-base titration, standardization and dilution processes.

**Science Mini Project (SMP)**

Introduction of Science Mini Project (SMP) for Secondary School leaving Chemistry Students. The secondary school Chemistry curriculum for India and china both include chemistry projects on topics given to students to reveal the knowledge gained by the students in terms of application of principles and chemical procedure in analyzing or producing simple chemical compounds.
This could be adapted in our secondary curriculum. A mini project could be given to students as part of the formative assessment score of the SSCE. e.g.

- Determination of pH in different water samples, juices, beverage drinks and the implication.
- Production of soft soap from a locally available ester.
- Extraction of essential oils and carrier oils from seeds, leaves and flowers and other project topics suggested by the students and teachers.

**Introduction of Remedial Teaching Plan (Mastery Learning Strategy) for SSI and SSII**

There has been various research into reforming the dynamics of the classrooms and according to Caroll (1963) cited by [21], every learner can attain mastery in any subject if given enough engaged-time. He opined that the difference in academic achievement is not just the IQ (intelligent quotient), but the amount of time students spends actively engaged on a given task. Hence, a Remedial Teaching plan in form of Summer revision classes should be organized for SS1 and SS2 students who could not meet 50% pass mark in chemistry.

This paper proposes a remedial teaching plan for SS1 students and SS2 student who could not meet up to 50% in their summative assessment in a particular subject. The remedial teaching could be for a month during the long holidays with the teachers acting as facilitators while the students are given revision exercises to work with and ask questions when clarifications are needed.

**CONCLUSION**

Chemistry is a major pillar needed to sustain the nation’s growth in science and technology. The chemistry curriculum in Nigeria is not structured for a functional chemistry education that
could transform and sustain development in science and technology. Hence, there is an undeniable need to re-structure our chemistry curriculum starting from secondary education.

Re-structuring the chemistry curriculum would re-awaken the interest of students and reposition their attitude towards the learning and practice of chemical principles and concepts. This would definitely improve the standard of chemistry education in Nigeria and prepare the platform for economic growth and sustainable development.

RECOMMENDATIONS

- Curriculum planners should come together to re-structure the chemistry curriculum in Nigeria starting from secondary schools.
- There should be inputs of institute of chartered chemists, representatives of chemical industries and chemical educators in the curriculum restructuring.
- Funding of secondary school laboratories should be a public/private partnership.
- Chemical industries should invest in the training of students for future relevance in the industries. All multinational co-operations and firms employing up to 60 chemistry specialists should be required by law to contribute 5% of their pre-tax profit to an endowment for equipping Chemistry laboratories in both secondary and tertiary institutions.
- Re-training of teachers; you cannot give what you don’t have. Teachers should be retrained on how to use indigenous chemicals and improvisation with locally available materials to conduct some practical procedures.
- Use of local materials and improvisation in practical curriculum.
• The curriculum should be geared to elicit the interest of students, motivate students, foster creativity, reward ingenuity relate practical activities with everyday real life experiences that would meet societal needs.

• Constant review of chemistry curriculum to meet the challenges and demand of the nation industrial and or entrepreneurial development.

• Monitoring committees should be constituted to oversee the science laboratory facilities in secondary schools they would also validate the science mini project of each school.

• Adoption of mastery learning strategy

REFERENCES
READABILITY OF SOME TOPICS IN SELECT CURRENT ORDINARY LEVEL CHEMISTRY TEXTBOOKS AND NIGERIAN STUDENTS’ PERCEPTION ABOUT DIFFICULTY OF THE TOPICS

Macson Joshua AHIKAkWO and Godsgrace Chiagaweye ENE
Department of Science Education, Rivers State University, Port Harcourt, Rivers State, Nigeria
Email: mcsahia@yahoo.com

ABSTRACT
The purpose of the study was to determine the readability of some topics in chemistry and to find out the perception of students about the topics. One hundred and forty-five year 3 senior secondary chemistry students in a university demonstration school who have just concluded their SSCE for 2014/2015 constituted the study sample. These students have also read the five commonly used chemistry textbooks investigated in the study. Flesch readability formula was used to assess the readability of the chemistry topics while a perception rating scale was used to determine the students’ perception of the chemistry topics. Overall findings of the study revealed that readability indices ranging between 51.2 and 87.0 indicated that the topics were readable by 7th to 12th grade students in the selected chemistry books. It was also observed in the study that over 50% of the students perceived rates of chemical reaction and acids, bases and salts difficult to learn. In all there was no significant relationship between the readability score and the difficult indices of the topics chosen from the commonly read textbooks in the schools. These findings and their implications were discussed in the study. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

Despite all the attempts made by good chemistry teachers to improve the performance of their students, chemical educators keep reporting that students’ performance in chemistry is dwindling [1][2][3]. According to the Chief Examiners’ Report [4] for November/December 2013 chemistry examination, the raw mean score of 29 and standard deviation of 12.69 poorer than that of November/December, 2012 results with a raw mean score of 34 and standard deviation of 17.29 was obtained. Till date students’ results in both internal and external examinations in chemistry have followed the same trend.

Chief Examiners [4] have continuously complained about students’ non-adherence to instructions, poor expression and presentation of facts, poor mathematical skills, inability to use appropriate technical terms in definition and explanation of concepts and inability to interpret the demands of the questions to mention a few.

Blames have gone to chemistry teachers’ methods and strategies as regards the poor performance of the students. It is believed that the students have problems with the learning of chemical concepts, theories and principles. Of recent, attention has shifted to the chemistry textbooks recommended by Ministry of Education for use in the secondary schools [5][6]. Some students have reported that some of the chemistry books used in Nigerian Secondary Schools are at the frustration level, difficult to understand for the students.

For example, [7] evaluated the readability by students of five chemistry textbooks, namely (i) New school chemistry for senior secondary schools’ students by Osei Yaw Ababio (ii) Senior Secondary Chemistry BK3 by S.T. Bajah & Onwu, G.O.M (iii) Chemistry for senior secondary school certificate by V.I. Oyeyiola (iv) Pure chemistry for West African Schools by B.C. Oluba and (v) A New certificate chemistry by Holderness, A and Lambert, J. The findings of the study
revealed among others that out of the five chemistry textbooks only two (New school chemistry for senior secondary schools students by Osei Yaw Ababio and A new certificate chemistry 7th edition by Holderness and Lambert) attained up to 50% readability score.

One other important observation that was made in the study of [7] was that concerning the perception of the teachers about the chemistry textbooks. It was found that the teachers agreed that the textbooks were helpful to the students and therefore within the acceptance range for use as recommended by Ministry of Education. However, the teachers failed to score the books high.

Having considered the teachers’ perceptions about the textbooks, it would have been necessary to also probe the students’ perception, not only the textbooks but the topics they learn in the textbooks. How readable are some of the chemistry topics in the textbooks? Readability of chemistry topics and students’ perception about the difficulty they encounter in learning are central to the present study.

According to [9], readability is

“The sum total (including all the interactions) of all those elements within a given piece of printed material that affect the success of a group of readers……. The success is the extent to which they understand it, read it at an optimal speed, and find it interesting”

Rahma and Gunadi [6] have noted that textbooks are important resources for teachers in assisting students to learn subjects, including chemistry at school. A good reading material should be in the right level of the students’ competence. If it is too difficult, the students will be easily discouraged and if it is too easy, it will make them simply bored [10].

In the past [11][12][13] studies have shown that students’ perception about difficulty of topics in chemistry helped teachers’ lesson delivery. Teachers applied caution in very difficult to
learn topics. Teachers have re-strategized by way of teaching and re-teaching to ensure mastery of such topics.

One question that need to be addressed is that having to do with the reconciliation between students’ readability of chemistry topics and their perception about the topics. This is of interest in this study.

RESEARCH QUESTIONS AND HYPOTHESIS

The following research questions guided the study, namely,

1. What is the readability of topics in select chemistry books commonly used in Rivers State Secondary Schools?
2. What is the difficulty perceived by the students in learning the chemistry topics in the select textbooks?
3. What is the relationship between the readability indices and the difficulty indices of the chemistry topics in the select chemistry textbooks?

The following null hypothesis was stated and tested at 5% level of significance, namely, H01: There is no significant relationship between the readability indices and the difficulty indices of the chemistry topics in select chemistry textbooks.

METHODOLOGY

The population of the study is all the year three SS3 Senior Secondary Students in Rivers State that use select chemistry textbooks in teaching and learning chemistry.

One hundred and forty-five (145) year 3 chemistry Senior Secondary Students in a University Demonstration School who have just concluded their SSCE for 2014/2015 session made up the

**Instruments**

Two instruments were used for the study, namely,

1) Students’ perception rating scale (SPRS), and

2) Readability test

SPRS was used to find out how the students perceived “how difficult” or “how easy” they learnt such topics as air pollution, chemical combination, nature of matter, energy and chemical changes, acids, bases and salts, hydrogen and its compounds, rates of chemical reaction, kinetic theory of matter and gas laws, carbon and its compounds and types of reaction.

For each topic the students were provided with a rating scale ranging from very difficult (5), difficult (4), moderate (3), easy (2), to very easy (1). In addition, students were requested to support their choice of the rating of a topic with a reason.

The readability test involved the use of a readability formula, namely Flesch in [14]
Scoring techniques of the Instruments

Students’ perception rating scale (SPRS) was scored by carrying out a frequency distribution of the response labels. Each response label was scored 1 point.

Difficulty index (DI) for each topic investigated was calculated using the formula:

\[
DI = \frac{\sum (VD_f + D_f)}{T_f}
\]

Where \( VD_f \) = frequency distribution of “very Difficult” responses, \( D_f \) = frequency distribution of “difficult” responses, \( T_f = \sum \left( (VD_f + D_f + M_f + E_f + VE_f) \right) \), \( M_f \) = frequency distribution of “moderate” responses, \( E_f \) = frequency distribution of “Easy” responses, \( VE_f \) = frequency distribution of “Very Easy” responses.

Flesch readability formula was applied in estimating the readability of the chemistry topics in the select textbooks. The Flesch Reading Ease formula:

\[
(RE) = 206.835 - (1.015 \times ASL) - (84.6 \times ASW),
\]

where \( RE \) = Readability ease, \( ASL \) = Average Sentence Length (ie the number of words divided by the number of sentences), \( ASW \) = Average number of syllables per word (ie the number of syllables divided by the number of words) [14].

Mean Score Ranges and Readability Interpretations

<table>
<thead>
<tr>
<th>%</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 – 100</td>
<td>Very easy</td>
</tr>
<tr>
<td>80 – 89</td>
<td>Easy</td>
</tr>
<tr>
<td>70 – 79</td>
<td>Fairly easy</td>
</tr>
<tr>
<td>60 – 69</td>
<td>Standard</td>
</tr>
<tr>
<td>50 – 59</td>
<td>Fairly difficult</td>
</tr>
<tr>
<td>30 – 49</td>
<td>Difficult</td>
</tr>
<tr>
<td>20 – 29</td>
<td>Very confusing</td>
</tr>
</tbody>
</table>
DATA ANALYSIS AND RESULTS

Data were analyzed and presented according to the research questions and hypothesis set in the study. Thus, the study first addressed the readability of topics in select chemistry books commonly used in Rivers State, followed by the difficulty perceived by the students in learning the topics. Finally, the relationship between the readability indices and the difficulty indices of the chemistry topics were calculated using the Pearson’s product moment correlation coefficient formula (r). Results are presented in Tables 1, 2 and 3.

Table 1: Calculated Readability Indices of Five Textbooks used by Senior Secondary Students in Nigeria

<table>
<thead>
<tr>
<th>S/N</th>
<th>Topics</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air pollution</td>
<td>53.5</td>
<td>50.6</td>
<td>45.6</td>
<td>52.0</td>
<td>66.2</td>
</tr>
<tr>
<td>2</td>
<td>Chemical combination</td>
<td>58.5</td>
<td>87.0</td>
<td>66.1</td>
<td>61.3</td>
<td>62.9</td>
</tr>
<tr>
<td>3</td>
<td>Nature of matter</td>
<td>53.6</td>
<td>51.5</td>
<td>52.2</td>
<td>56.1</td>
<td>45.5</td>
</tr>
<tr>
<td>4</td>
<td>Energy and chemical changes</td>
<td>58.9</td>
<td>54.7</td>
<td>53.8</td>
<td>56.2</td>
<td>53.6</td>
</tr>
<tr>
<td>5</td>
<td>Acids, bases and salts</td>
<td>52.6</td>
<td>53.0</td>
<td>53.9</td>
<td>51.2</td>
<td>54.7</td>
</tr>
<tr>
<td>6</td>
<td>Hydrogen and its compounds</td>
<td>52.3</td>
<td>56.5</td>
<td>51.8</td>
<td>53.2</td>
<td>55.3</td>
</tr>
<tr>
<td>7</td>
<td>Rates of chemical reaction</td>
<td>51.2</td>
<td>38.1</td>
<td>50.0</td>
<td>47.1</td>
<td>49.4</td>
</tr>
<tr>
<td>8</td>
<td>Kinetic theory of matter and gas laws</td>
<td>43.4</td>
<td>44.5</td>
<td>47.6</td>
<td>43.0</td>
<td>50.7</td>
</tr>
<tr>
<td>9</td>
<td>Carbon and its compounds</td>
<td>51.8</td>
<td>41.8</td>
<td>49.3</td>
<td>56.4</td>
<td>47.0</td>
</tr>
<tr>
<td>10</td>
<td>Types of reactions</td>
<td>42.0</td>
<td>46.1</td>
<td>48.3</td>
<td>40.3</td>
<td>45.3</td>
</tr>
</tbody>
</table>

Table 1 revealed that the mean score, ranges of readability indices of the topics 2, 4, 5, 6 chemistry (CHS) Books 1, 2, 3, 4, and 5 were between 51.2 and 87.0 indicating that they were readable by 7th to 12th grade students.

A readability score of less than 48.3% was estimated for Topic 10 – types of reactions for all the chemistry textbooks. This shows that senior secondary students encountered difficulty in reading and understanding the content in all the textbooks.

Table 2: Difficulty Indices (DI) of the Topics in Chemistry

<table>
<thead>
<tr>
<th>S/N</th>
<th>Chemistry Topics</th>
<th>Difficulty indices (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Air pollution</td>
<td>27.7</td>
</tr>
<tr>
<td>2.</td>
<td>Chemical combination</td>
<td>22.5</td>
</tr>
<tr>
<td>3.</td>
<td>Nature of matter</td>
<td>35.0</td>
</tr>
<tr>
<td>4.</td>
<td>Energy and chemical changes</td>
<td>49.6</td>
</tr>
<tr>
<td>5.</td>
<td>Acids, bases and salts</td>
<td>54.4</td>
</tr>
<tr>
<td>6.</td>
<td>Hydrogen and its compounds</td>
<td>26.4</td>
</tr>
<tr>
<td>7.</td>
<td>Rates of chemical reaction</td>
<td>50.0</td>
</tr>
<tr>
<td>8.</td>
<td>Kinetic theory of matter and gas laws</td>
<td>44.5</td>
</tr>
<tr>
<td>9.</td>
<td>Carbon and its compounds</td>
<td>40.3</td>
</tr>
<tr>
<td>10.</td>
<td>Types of reactions</td>
<td>29.4</td>
</tr>
</tbody>
</table>

Table 2 revealed that over 50% of the students perceived topic 7 (rates of chemical reaction) and topic 5 (acids, bases and salts) difficult to learn. Less than 50% of the students perceived the remaining topics difficult to learn.

Table 3: Calculated r for readability of Books’ Topics and Difficulty Indices

<table>
<thead>
<tr>
<th>Readability/Difficulty of topics</th>
<th>r</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHS Book 1 x DI</td>
<td>-0.083</td>
<td>ns</td>
</tr>
<tr>
<td>CHS Book 2 x DI</td>
<td>+0.16</td>
<td>ns</td>
</tr>
<tr>
<td>CHS Book 3 x DI</td>
<td>-0.22</td>
<td>ns</td>
</tr>
<tr>
<td>CHS Book 4 x DI</td>
<td>+0.06</td>
<td>ns</td>
</tr>
<tr>
<td>CHS Book 5 x DI</td>
<td>+0.003</td>
<td>ns</td>
</tr>
</tbody>
</table>

CHS = Chemistry; ns = not significant
The relationship between the readability scores of chemistry books 1, 3 and the difficult indices as perceived by the students was negative (with $r = -0.083$ and $-0.22$ respectively). The relationship for books 2, 4 and 5 between readability scores and difficulty indices was positive. In all there is no significant relationship between the readability scores and the difficulty indices of the topics chosen from the commonly read textbooks in the schools.

**DISCUSSION OF FINDINGS**

Good textbooks are important tools in the hands of the students which to a large extent help the teacher in doing his/her work. A teacher can make the students to learn from the textbooks before, during and after the lesson delivery periods. For this to be effective, student as an independent learner must be able to read and understand what he/she is reading from the textbooks.

Once this is done, the teacher’s work is made simple. If the students cannot understand what they read, then there is problem. The investigation carried out in this study in connection with the readability of chemistry topics and students’ perception can be done in other disciplines or subjects offered in the schools.

The findings of this study are of general interest in learning and teaching. However, with respect to the chemistry topics and books under investigation, the topics are within the learning range of not difficult to read (Table 1). Chemistry is a science subject that present to the students’ conceptual difficulties. There are abstract concepts that require some level of maturity on the part of the students. For example, type of reactions (topic 10) with readability index of less than 50% across the chemistry textbooks present some difficulty to the senior secondary three (SS3) students.
Chemical reactions involve breaking and making of bonds between, atom, molecules and ions. In chemical reactions, there are also acceptance, transfer and sharing of elections. All these, the learner is unable to see and so difficult to concretize. Even the chemistry teachers do not have the experiences to share with the students. So teachers pass on their ignorance to the students. The textbooks writers are also as ignorant as the teachers. Information they have concerning the conceptual nature of chemical reactions is obtained from foreign or local literature. The students are left with their faith to accept what they read from the chemistry textbooks.

This seems to account for part of the difficulty students have in learning chemistry. After all, chemistry is a study of the interaction between matter. Again, topic 8 kinetic theory of matter is essential in understanding the other topics 1, 2, 3, 4, 5, 6, 7 and 9 (Table 1). They all have link with chemical reactions. We have to understand the nature of the forces between the particles in the gas, liquid and solid so as to understand why chemical reactions occur.

Textbook writers try as much as possible to simplify these chemical ideas in an attempt to help students read and understand. But students’ performance in chemistry do not seem to show that students are neither understanding what they read nor benefit from teachers’ instructions in the classroom and laboratory. This is further corroborated by the various levels of difficulty chemistry students perceive of the topics (Table 2). It was only in the case of acids, bases and salts (topic 5) with difficulty index of 54.4% that the students do not seem to perceive much difficulty. This could be purely because of the descriptive nature of these concepts in the textbooks at the level of the students used for the study.

One aspect of the findings of the study is the relationship between the readability indices of the chemistry topics in the selected textbooks and the students’ perception about the topics. Calculated r for chemistry books 1 and 3 showed negative relationship while that of books 2, 4
and 5 revealed positive relationship. These relationships are found not to be significant at 5% level. This seems to suggest that while the students agree with the readability of the topics in some chemistry textbooks as measured by Flesch indices, they (students) do not agree with readability of the topics in other textbooks.

The implication of this findings is that, the Ministry of Education recommending chemistry textbooks for the students, should go beyond looking at the textbooks, publishers and quality of production and also consider the relevance and explicitness of the topics as related to chemistry curriculum.

In conclusion, chemistry teachers should form part of the committee that recommends textbooks for the students, since they (teachers) teach the students and they know where the “shoe is pinching” them.

REFERENCES


KITCHEN CHEMISTRY: PRACTICAL CHEMISTRY WITH SIMPLE EQUIPMENT AND READILY AVAILABLE MATERIALS

Stephen H. Ashworth (The Kitchen Chemist)
University of East Anglia, Norwich Research Park, Norwich, NR4 7TJ
Email: S.Ashworth@uea.ac.uk
info@kitchenchemistry.eu, www.kitchenchemistry.eu

ABSTRACT

The Kitchen Chemistry Science Show uses readily available materials and unsophisticated equipment. The development of the show is outlined and each of the demonstrations is described in detail. For each demonstration there is an explanation of the demonstration and, where appropriate, a suggestion for an extension to a whole class activity. Indications of safety precautions are also discussed. Further development of the Kitchen Chemistry Outreach Project is then outlined with a description of future plans. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

The original Kitchen Chemistry Science Show was developed in partnership with Scifest Africa: South Africa’s National Science Festival [1]. In 2006 I was collaborating with Prof. Mike Cook, a colleague at UEA on the photophysics of phthalocyanines.[2,3] Prof. Cook was simultaneously collaborating with Prof. Tebello Nyokong from Rhodes University in South Africa. Prof. Nyokong was at that time on the Advisory Committee of the National Science Festival – Scifest Africa. When she learned of my various demonstration lectures I was invited to take part.

I performed at Scifest in 2008 and 2009 using demonstration lectures developed with a grant from the Engineering and Physical Sciences Research Council (EPSRC), part of a pilot program to encourage EPSRC funded researchers to communicate their research to the public. My application was for a grant to develop portable demonstration lectures which would illustrate aspects of my research.

After my appearances at these Festivals the then Director of Scifest Africa encouraged me to develop a chemistry show using readily available materials and unsophisticated equipment. This took inspiration from Lorelly Wilson’s “Chemistry with Cabbage” [4] and other science shows that I had seen. The show was first performed as “Kitchen Chemistry” at Scifest Africa 2011 but elements had been already performed in front of audiences as “The Chemistry Show”, such as part of the Mauritius Science Week in 2010 at the Rajiv Gandhi Science Centre.

Kitchen Chemistry was not only performed at Scifest in 2011 it was also taken on tours of the Western Cape in South Africa funded by the Embassy of the Kingdom of the Netherlands in South Africa. The Systemic Extra-Mural Education Development and Support (SEEDS) project, of which this was a small part, was made up of eleven different partners each with different
interventions in rural and township schools throughout the Western Cape over a four-year period [5,6].

In 2013 I was awarded a sabbatical from teaching and from early January until mid-April I toured South Africa giving shows and workshops in schools and science centers. The whole event was coordinated by Scifest Africa as part of its outreach offering. Not only was I able to demonstrate directly to learners, I had the opportunity to train both educators and science centre staff. Travel, accommodation and consumables were covered by charging science centres for the science shows and workshops that I provided. Appearances at schools, however, were free.

During the 100 days I spent in South Africa, which included the week of Scifest, I was involved in over 120 events and drove over 11,000 km. The shows were not just Kitchen Chemistry, I also had a couple of physics demonstration lectures (“The Sound of Science” and “Lasers: the light fantastic”) along with a version of the Royal Society of Chemistry’s Spectroscopy in a Suitcase [7].

Since 2011 I have contributed Science Shows and workshops to Scifest Africa every year, and have also served on the Advisory Committee.

Figure 1: The Kitchen Chemist surrounded by his equipment.
KITCHEN CHEMISTRY: THE ACTIVITIES

The original Kitchen Chemistry show itself is made up of a number of different demonstrations linked by a narrative about what a chemist might end up doing. The first part serves to illustrate that the molecules a chemist works with are very small, but they influence the properties of the matter around us. From there we look at simple color changes to indicate something about the nature or contents of a solution. Where possible one or more new substances are made, and then we look at how materials can be decomposed into their components.

For the shows I have specially built one or two pieces of equipment. This is generally so that they are a suitable size for a large audience to see well. In all cases there is a readily available alternative which can be used instead. Equally, the quantities used are relatively large, again to enable the experiments to be visible to a large audience. These quantities can often be scaled down if one is adapting a demonstration to turn it into a classroom activity or to use as a demonstration in front of a small group.

This is a science show and the demonstrations are chosen and practiced so that they are slick and they are put together so that there is a certain pace to the show. It will not take too much to adapt some of these to involve the whole class in a practical activity. The show runs with the demonstration as follows.

Cartesian Diver

To attract the audience’s attention and get them a little off balance to start with I have a Cartesian Diver in a 2 L soda bottle. I divide the audience in two and each half has an opportunity to “push” the diver to the bottom of the bottle using their minds alone. Of course, the first group does not manage, where the second group does. If appropriate I explain the principle of action, or simply suggest that it might be a good question for later.
The diver itself must float but it is best to ensure that it only just floats. The demonstrator may then manipulate the bottle in such a way that it is not obvious the bottle is being squeezed. I usually use a vinegar packet from a fast food outlet for my diver for visibility. There are, however, many alternatives – a plastic pipette or a straw blocked at one end. If a diver is used that is open at one end and it is transparent or translucent the compression of the air inside the diver is easy to observe. This could then be carried out as a whole class activity and the class encouraged to observe the compression of the air.

**Number of molecules**

To get across the mind-boggling size of the number of molecules in my Cartesian Diver bottle I have a series of laminated cards which make up the number. I invite members of the audience to join me on stage to hold up the cards, and make a play of how big the number is. An alternative method is to write the number on a long strip of paper which can then be slowly unrolled. In this way it would be possible to have indicators of other big numbers, such as the population of a capital city, the population of China, the world population, the number of seconds since the Universe began etc.

**Newspaper ripping**

Having established that molecules are very small we then see that their size and shape dictates the properties of materials around us. How these molecules interact and fit together determines whether a material is hard, or soft.

A newspaper, or any other sheet of paper can be used for this. In one direction a tear is neat and relatively clean, a tear in the perpendicular direction is more ragged, and often ends up tearing in the other direction. This comes about because the fibers that make up paper are composed of long thin molecules. This, in turn, means that the fibers are long and thin – just like fibers that
make up cloth. In the process of making paper the fibers are aligned – they tend to be brushed in one direction. Tearing the paper in a direction parallel to these fibers gives a clean, straight tear, but in the perpendicular direction the tear is jagged and not at all clean.

This could be used in class to start an investigation of materials, what properties they have and whether they are the same in all directions.

**Dissolution**

I then usually move on to describe a “magic trick” that I have been practicing. I tell the audience that I have been trying to make people disappear, but when I do they do not return (at least not uninjured). So what I do instead is show how I practice, with salt. Having made a big show with magical “passes” I take a glass of water and dissolve the salt.

Of course the salt has not “gone away” it is still in the water. This could be a way to start a class discussion on dissolution which might range as far as weathering of rocks and the change in the pH of the ocean as carbon dioxide is absorbed.

**Evaporation**

The salt has dissolved and not gone away, so this is the time to talk about evaporation. If we left the water for long enough the salt could be recovered as the water will evaporate. This I demonstrate using expanded polystyrene balls as “water” and colored solid polystyrene balls as “salt”. The expanded polystyrene may be blown out (and a show made of an imaginary piece of polystyrene being stuck in one’s mouth) or alternatively a hairdryer could be used to generate a stream of air for the same effect. This demonstration makes rather a mess, but is a very visual demonstration of evaporation, and the particulate nature of matter.

**Dissolution**

I continue the dissolution theme by showing that expanded polystyrene may be “dissolved” in acetone. It might be possible to use nail polish remover for this, but the high water content of some formulations prevents them from working. I like to use long thin polystyrene sheets. The length means that the effect is particularly impressive, however, any expanded polystyrene will do.
The material one often finds in packaging will work, but take care to use polystyrene as packaging also comes with starch “popcorn” these days. Polystyrene cups work too, which lends itself to a demonstration where two unsuspecting volunteers are asked each to fill a polystyrene cup to see how quickly they can do it. One, however, is given acetone, and the other water. Obviously the cup disintegrates when acetone is poured in so some care must be taken to ensure that any spillage is contained.

**Density – water and air**

After a short description of the particulate nature of solids, liquids and gases there is a demonstration of the effect of density using hot (coloured) and cold (not coloured) water. Again a great deal is made of the need to turn one of the glasses upside down on the other, until two offset CDs are used to make a lid / seal that enables one glass to be inverted without too much spillage. When slid together to line up the holes allow liquid to pass from one glass to the other. A good example of the final state of this demonstration can be seen in Figure 2. On the left the cold water was in the lower glass and on the right the cold water was in the upper.

This does take some practice and care should be taken when handling hot liquids. The CDs do not always slide smoothly, and that is when liquid tends to be lost.

The same effect can be obtained with a bag of air. The best bags to use are thin, crinkly bin liners. The air inside can be warmed above a toaster. Care must be taken to ensure that the bag does not melt or drop into the toaster. This can also be done with large black bin bags but it will take considerably longer to warm up the air inside than a smaller bin liner. It is good practice to trim excess plastic from the bottom and add some tape to the opening to weight it a little. This helps to prevent the bag inverting when it starts to float.
This demonstration might be made into an investigation to determine the lifting power of air. There are many interesting questions that arise. How would one determine the force produced? How might the temperature of the air in the bag be determined? What is the volume of the bag? If one was simply determining the lifting power of air all of these questions would have to be answered. More interesting still is to transfer the scenario to a hot air balloon. Then the gas mixture in the balloon envelope is no longer simply air: it will contain water and carbon dioxide from the combustion of the fuel.

**Indicators – vinegar and washing soda**

Many colored materials act as acid-base indicators. One of the best is red cabbage water, but this can be difficult to keep for long periods, especially in warm climates, as it tends to develop a variety of bacterial cultures. When I am on the road my choice is either grape juice, which involves no preparation, or fruit teas, such as blackcurrant, cranberry etc. as they may be stored dry and made up on site. The active ingredient in all of these are anthocyanins which turn green in a basic (alkaline) solution, purple at neutral pH and pink when acidic.

My chosen base is washing soda (sodium carbonate) and the acid is distilled, or spirit vinegar. The absence of color in the vinegar enables the color changes to be observed more readily. It is, of course, possible to use other bases with these indicators.

These simple indicators allow a variety of analytical experiments to be carried out. First, there is the qualitative determination of whether a substance, which might be a substance found in the house, such as toothpaste, were acidic or basic (alkaline). Second, one might consider using the indicators to show the endpoint of a titration, where either an acid or base is neutralized. If burettes are not available for these sorts of experiments the number of drops from an eye-dropper, or pipette could be counted and calibrated.
Indicators – milk of magnesia

I then use milk of magnesia (a suspension of magnesium hydroxide) to demonstrate the use of an indicator. I explain that we might ask whether this material is acidic or basic. The milky solution when a little milk of magnesia is added to water turns the indicator green, so it can be seen to be a basic (alkaline) mixture.

This mixture may also be used to demonstrate equilibria, because when acid is added the mixture turns the indicator back to pink. The concentration of dissolved hydroxide ions has thus gone down. The result is that more magnesium hydroxide dissolves and over time the indicator regains its green color. The equilibrium will continue to be re-established on addition of acid until all the solid has dissolved. A process which I liken to using up the charge in a battery.

Indicators – iodine starch and vitamin C

Not all indicators need to be highly colored. A few drops of tincture of iodine in water produces a pale yellow solution. When starch indicator is added to this a deep blue color forms. The starch indicator should be prepared in advance. I take a small amount (half a teaspoon) of cornstarch (Maizena) and pour a small amount of boiling water onto it. I then boil that for a while. At home I do it in the microwave, and at a venue I mix it in a polycarbonate glass and put the glass in a kettle that is one third full of water and let that boil (with the lid open) for a little while. Care must be taken when taking the glass out of the kettle unless everything is allowed to cool first. Having made the deep blue color, addition of vitamin C will remove the color. The vitamin C is an anti-oxidant, or reducing agent. It reduces the iodine to iodide. This is a quantitative reaction and can be used for analyzing the amount of vitamin C in a solution. This was the basis of the Royal Society of Chemistry’s global experiment in 2013 [8].
Water into wine

At this point I often step away from the readily available chemicals and do a classic “Water into Wine” demonstration. I pour myself a large “gin” or “vodka” from a suitably labelled bottle, then explain how I was not meant to drink hard liquor on stage, so I pour it into another glass to turn it into “juice”. Then it occurs to me that that white wine is not hard liquor so by pouring into a third glass I produce some white wine. I go to drink this (but do not, of course) and realise that it should be chilled, so I decide that red wine can be drunk at room temperature, and produce this by pouring into another glass. Before I get to drink that I “remember” that I should not be drinking alcohol as I have to drive, so take my bottle and a final glass, and produce some “milk”.

The mixture in the bottle is water, phenolphthalein and salt. In the first glass I have nothing (gin), the second glass contains a few drops of sodium carbonate solution to turn the phenolphthalein pink (juice), the next glass has a few drops of concentrated iron (III) chloride, which is acidic (to remove the color of the phenolphthalein) and produces a yellow solution (white wine), and the next glass has some ammonium thiocyanate, which reacts with the iron to produce a deep red color. For my “milk” I have a few drops of silver nitrate solution in the glass, which reacts with the sodium chloride in the gin bottle. It is best to use wine glasses for this as the liquid tends to be disguised by the glass where the bowl joins the stem.

Given the length of the show, I use this demonstration less frequently now. It also simplifies the logistics and transport, as I do not have to worry about my solutions leaking in transit.

Holey bottle

I then show a bottle of water which I “discover” has two wooden kebab skewers stuck through it. The audience is asked to predict, just like a scientist would, what will happen when the skewers are removed. I then “do the experiment” and remove the skewers and explain that
everything is balanced, air pressure, water pressure etc. By opening the lid of the bottle very satisfying streams of water can be produced.

I have found the key to making this successful is to have the holes at the same height in the bottle. It does mean that the skewers have to be distorted a little when setting the bottle up, but bamboo kebab skewers are sufficiently flexible, especially if they have been immersed in water for a while.

It would be possible to involve the whole class in this if the effect were not explained, but set as an open-ended problem. There are a number of factors which contribute, the reduced pressure of air inside the bottle, the external air pressure balancing the hydrostatic pressure and the surface tension of the water. Depending on the level of study one might also consider the effects of increasing the size of the holes – is there any hole size at which the effect would no longer work?

**Three cup trick**

Finally, I get my drink of water, but I use three identical polystyrene cups for this. One has been prepared with some super-absorber (sodium polyacrylate). This I usually buy from a garden center. It is slightly slower to absorb water than the material found in nappies, but much easier to handle and less hazardous: the crystals in nappies are very fine and easy to inhale.

This I frame as a test of the power of observation of the audience members. I ensure that they know where some water is to start with, then proceed to swap cups round. Having done this, I ask the audience which cup contains the water. I generally pour the water into the cup with the absorber for the third set of swaps. I can prolong this sufficiently that the water has been absorbed nicely and when the cup chosen by the audience appears to be empty I am careful to say that the water does not “come out” of the cup.
This can be made very theatrical but I always try to make the point that not only should a scientist be able to make accurate observations, but they should also be very precise with language. When I said the water did not “come out” of the cup, it did not mean that the water was no longer in the cup.

**New material**

The absorbent material is a new material made by chemists, so at this point I generally make a new material. If the washing soda (sodium carbonate) solution is nice and clear it may be added to a solution of Epsom salts at which point it forms a precipitate. The milky appearance of this mixture may be linked back to the milk of magnesia. Both are milky because of finely divided solids scattering light, because they are suspensions, not solutions.

If it is possible to get some borax, another new material may be made by adding borax to PVA glue. I generally dilute the glue with some water and emphasize how runny it is. Then add a few drops of a borax solution to produce slime.

This can form a great class experiment. Slime can be made in small batches and tested. There are a variety of tests that are possible on slime. One is to see how far a sample will stretch under its own weight without breaking. Another is to see how quickly it will flow through a funnel (which can be made out of the top of a drinks bottle). Another is to measure how quickly it flows from one concentric circle to another. It is best to put the paper with the concentric circles inside a clear plastic wallet for this. The participants can then determine how to modify their recipe to make their slime quicker or slower, for example.

**Fire extinguisher**

Having put some things together to make new materials I then take a look at taking things apart. The first thing to try is sodium bicarbonate (bicarbonate of soda, sodium hydrogen
carbonate) and acid. I explain that any carbonate material plus an acid will liberate carbon dioxide. Once the audience has confirmed for me that carbon dioxide is a gas I then ask them what we might observe. My analogy here is that if a solid (me) is sitting in a bath full of water (a liquid) and I produced a gas, what would I observe? In this case the solid is the bicarbonate, the liquid is vinegar and we should see bubbles – which we do.

This gas can then be used to extinguish a candle, by pouring it from one container into another container where there is a lighted candle. This can be made more impressive by using an intermediate container. We can explain this as carbon dioxide is denser than air so displaces air from the bottom of our containers. This can be related back to the earlier experiment with density. This is a nice, low cost, reaction that can be used to experiment to find reliable ways to measure gas release from a reaction. You might use the gas to produce a foam by adding a little dishwashing liquid (washing-up liquid). The time it takes your foam to move between two marks on a standard container (say a drinks bottle) would give an approximate idea of the speed at which the gas has been evolved and thus how quickly the reaction is taking place.

It may also be used to look at the concept of a limiting reactant, and is a nice example of an endothermic reaction.

**Hydrogen peroxide with yeast**

Another nice decomposition reaction is the so-called “elephant’s toothpaste”. I would normally have mixed some dried yeast with water prior to the start of the show and this is the source of the peroxidase enzymes that are required for this experiment. One can use blood, liver, celery, or some inorganic salts for this, but dried yeast is easy to store and transport. It also has the advantage that it will foam, which has been useful for me when I have forgotten to bring, or ask for, washing-up liquid, which helps to catch the bubbles of oxygen.
Not only is this a nice decomposition reaction, one can mention that we make hydrogen peroxide just by breathing, that it is breaking down slowly all the time and the yeast will simply speed up the reaction. At a suitable level one can use this to talk about enzymes and catalysts. This can be used for a whole class investigation looking at the effect of particle size on reaction rate, and also on concentration on reaction rate, especially if a gas measuring technique has been developed.

In the first case one can use a piece of freshly cut potato to decompose the hydrogen peroxide. If this is large, like a fat French fry, the gas forms slowly as there is a relatively small amount of surface area in contact with the peroxide solution. If the same amount of potato is cut up, there is more surface area and the gas bubbles form more quickly. Finally mash up the same amount of potato and the gas should be produced more quickly again.

To look at reaction rates one can use potato, celery or yeast, to add to different concentrations of peroxide. Alternatively, different amounts of yeast added to the same concentrations of peroxide.

Of course when working with peroxide suitable safety precautions need to be taken. Even low concentrations of peroxide will bleach skin temporarily and cause a pricking sensation. Any spillage should be treated with copious quantities of water which should then be run to waste.

**Whoosh bottle**

I link this to the previous demonstration by noting that the “elephant’s toothpaste” generates some heat during the reaction. We can thus use chemistry to make heat and one of the simplest ways is to burn a fuel. In this case we take a water cooler bottle and add some methylated or surgical spirits. I make sure that the inside is fully coated with liquid, give it a bit of a cuddle to
warm up the bottle, and pour away any excess liquid. Always use a splint on a stick or a long barbeque lighter to light the bottle. The results of this experiment can be seen in Figure 3.

These bottles can be expensive to get hold of. I have found, however, that the water cooler companies are happy to supply bottles, which they are taking out of service, free of charge. These bottles would otherwise only have been sent for recycling. Even if they cannot be used to supply potable water for humans they are generally plenty good enough for this demonstration.

Immediately after the demonstration the bottle has depleted its reserve of oxygen. If the experiment is repeated without refreshing the air in the bottle the alcohol will only burn at the neck of the bottle which will discolor and melt the bottle. (Yes, it has happened to me.) This can be avoided by blowing into the bottle, or simply leaving the bottle with the neck down in an environment where the carbon dioxide can settle, and diffuse away. If the bottle is to be reused
quickly the oxygen may also be replenished by half-filling the bottle with water, and tipping the water out. In this case, however, the bottle should be rinsed with excess fuel to ensure that any residual water has been removed.

**Cornflour flame**

The final flourish is a demonstration to show the energy there is in food. Cornflour (cornstarch, Maizena) may be blown out of a funnel and ignited with a variety of sources. My preference is to use a funnel on the end of a fairly rigid plastic tube. I blow in the end of the funnel and ignite the flame with a blowtorch as shown in Figure 4.

![Figure 3: A cornflour flame](image-url)
There are many alternative ways of setting this up. For example, the funnel can be clamped in place, as can the blowtorch and a stomp rocket pump may be used to expel the cornflour from the funnel. Instead of cornflour, custard powder may be used. This gives a markedly more intense flame, but the sugar and egg content of the custard powder means that it is slightly less straightforward to clear up.

HINTS, TIPS AND SAFETY

Many of these demonstrations benefit from practice. Sometimes this can be done in a kitchen or lab, other times there is no substitute for trying it out in front of an audience. There are a number of hints and tips on the Kitchen Chemistry website [9] and a forum [10] which I would encourage readers to use to exchange ideas and suggestions.

Please refer to the website safety page [11] and the pages for each individual experiment for specific details of safety advice.

All the glasses I have referred to here are polycarbonate glasses from an internet supplier. Not only are these rigid, and stand up to heat, they are also essentially unbreakable and, therefore, very useful when travelling. The large containers I use for the indicator experiments and other aqueous solutions are manufactured to be vases. Only colored or patterned vases seem to be available on the internet at the moment so I ordered in bulk from China. If you would like to purchase these containers, please contact me through the website or by email. They can easily be dispatched by post, but international postage might incur a surcharge.
FURTHER DEVELOPMENT OF THE KITCHEN CHEMISTRY OUTREACH PROJECT

There is now a second show Kitchen Chemistry: Second helpings, which has a different set of demonstrations but maintains the theme of readily obtainable materials and unsophisticated equipment. If readers are interested I would be happy to describe those demonstrations as I have done here in a further publication. Many of them are already on the website. I am also gathering material and making preparations for there to be a third.

The variety of experiments that I have available now can be used to generate a selection for bespoke events. For example, I spent one week in January 2017 working with the British Council in France on their “Science in Schools” initiative. This was a combination of parts of the Kitchen Chemistry show and the RSC Global experiment [8]. The audience was able to experience part of the science show but also get some hands-on experience of chemistry experiments. All the sessions were delivered in English.

I have also used some of the demonstrations to put on a “Science of Santa” demonstration lecture, with a colleague, Maxine Rushton. This was first performed as the Christmas Lecture for Young Children at the UEA in 2014, and was chosen to be part of the UK delegation for the “Science on Stage” conference which took place in London in 2015. We use demonstrations to put forward the hypothesis that Santa is not a magician, he is simply a scientist. A link to the poster and a recording of the lecture are both available from reference [12].

I have recently extended my work in Southern Africa. The Kitchen Chemistry Outreach Project in South Africa is helping me put to extend my activities to Johannesburg and the Durban area, with the inaugural Umjikelezo We-Science festival [13,14] in 2017. I have also started visiting schools in the Maputo area of Mozambique with Kitchen Chemistry shows.
I am continually looking for opportunities to work with partners or to attract funding to extend the reach and impact of Kitchen Chemistry. The shows and educator workshops are especially useful in areas of the world where specialized chemicals and well-equipped laboratories are not readily available.

If you think that something from Kitchen Chemistry could work for you, then please go ahead, adapt it for your needs, and use it. Very few of the demonstrations I do are original, I have merely adapted them to fit with my own requirements. Often the same demonstration may be used in a variety of ways to illustrate different points. If you need help or advice then please contact me directly, or ask on the Forum.

If you would like Kitchen Chemistry to visit you, then please get in touch. I am happy to travel, and if we can come to some mutually convenient arrangement that fits around my day job, I will be happy to oblige.

Email: Info@KitchenChemistry.eu
Website: http://www.kitchenchemistry.eu
Twitter: @Kitchen_Chem
Facebook: http://www.facebook.com/KitchenChem

ACKNOWLEDGEMENTS
I would like to acknowledge the contributions which have led to Kitchen Chemistry reaching its current position. I would like to acknowledge the Engineering and Physical Sciences Research Council for a grant in the pilot Partnerships for Public Understanding round and the follow-on funding (GR/R78886). I would also like to thank Lorelly Wilson, and her Chemistry with Cabbage, for inspiring the development of Kitchen Chemistry. I would also like to thank Scifest Africa and especially the former Director, Anja Fourie, for support, encouragement, and assistance. The extended 2013 tour of South Africa would not have been possible without their organisation and support. Finally I would like to acknowledge the support of the School of Chemistry at the University of East Anglia, which has not only enabled me to arrange time to travel, but has also supported Kitchen Chemistry financially.

REFERENCES

4. L. Wilson, http://www.lorelllywilson.co.uk/, (Last Accessed 02/01/2018)


INNOVATIVE MNEMONICS IN CHEMICAL EDUCATION: REVIEW ARTICLE

Arijit Das
Department of Chemistry, Ramthakur College, Agartala, Tripura, India
Corresponding Author Email: arijitdas78chem@gmail.com, arijitdas_chem@rediffmail.com

ABSTRACT
In this review article, formulae based innovative mnemonics have been discussed to create interest and remove phobia of students in the field of chemical education. Educators can use these numerous mnemonics in their teaching style in the classroom lectures after discussing conventional methods to make chemistry intriguing. Here, I have tried to focus some time economic mnemonics by including thirty-three (33) new formulae in the field of chemical education. It will encourage students to solve multiple choice type questions (MCQs) at different competitive examinations in a time economic ground. This review article emphasizes chemical education in the light of a variety of mnemonic techniques to make it metabolic, time economic and intriguing for students because the use of mnemonics in classroom lectures is an essential tool to become a distinguished educator. [African Journal of Chemical Education—AJCE 8(2), July 2018]
INTRODUCTION

The conventional methods for determination of hybridization of simple molecules including heterocyclic compounds, bond order of diatomic species having (1-20)e’s using M.O.T., bond-order of oxide based acid radicals, prediction of spin state using spin multiplicity value, aromatic and anti-aromatic behavior of organic compounds including heterocyclic compounds, evaluation of magnetic behavior of diatomic species having (1-20)e’s with M.O.T., calculation of number bonds in olefinic hydrocarbons and alkynes etc. is time consuming [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19].

Keeping this in mind, in this pedagogical review article, I have introduced some innovative mnemonic techniques to make chemistry metabolic, time economic and interesting [20,21,22,23,24,25,26,27]. Here, I have tried to discuss them abruptly.

METHODOLOGY

2.1. Innovative mnemonics for predicting hybridization state of simple molecules or ions:

Hybridization state theory

Prof. Pauling (1931), first developed the Hybridization state theory in order to explain the structure of molecules such as methane (CH₄) using atomic orbitals [1, 2]. This concept was developed for simple chemical systems but this one applied more widely later on and from today’s point of view it is considered an operative empirical for excusing the structures of organic and inorganic compounds along with their related problems.
Conventional method for prediction of hybridization state

Hybridization state for a molecule can be calculated by the formula 0.5 (V+H−C+A), Where, V = Number of valance electrons in central atom, H = Number of surrounding monovalent atoms, C = Cationic charge, A = Anionic charge

2.1.1. Prediction of sp, sp\(^2\), sp\(^3\) Hybridization state:

Hybridization is nothing but the mixing of orbital’s in different ratio and the newly mixed orbitals called hybrid orbitals. The mixing pattern is as follows:

- \(s + p (1:1)\) - sp hybrid orbital;
- \(s + p (1:2)\) - sp\(^2\) hybrid orbital ;
- \(s + p (1:3)\) - sp\(^3\) hybrid orbital

Formula: prediction of sp, sp\(^2\), and sp\(^3\) hybridization state

Power on the Hybridization state of the central atom \((P_{Hyb}) = (T_{SLP}) − 1\)

where, \(P_{Hyb}\) = Power on the Hybridization state of the central atom,

\(T_{SLP} = (\text{Total no of } \sigma \text{ bonds around each central atom} + \text{LP})\)

From the Lewis structure of a molecule, first of all, predict the number of sigma bonds (\(\sigma\)-bonds), pi bonds (\(\pi\)-bonds) and the lone pair of electrons (LP) if any. All single (\(-\)) bonds are the \(\sigma\) bond, in the double bond (\(=\)) there is 1\(\sigma\) and 1\(\pi\), in triple bond (\(≡\)) there is 1\(\sigma\) and 2\(\pi\) (exclude \(\pi\) bond). In addition to these each Co-ordinate bond (\(→\)) can be treated as 1\(\sigma\) bond. This formula is applicable up to four (04) \(T_{SLP}\). If the power of the hybridization state \((P_{Hyb})\) will be 03, 02 and 01 then the hybridization state will be sp\(^3\), sp\(^2\) and sp respectively [21, 24, 26].
2.1.2. Prediction of \( sp^3d, sp^3d^2, sp^3d^3 \) Hybridization state:

In case of \( sp^3d, sp^3d^2 \), and \( sp^3d^3 \) hybridization state there is a common term \( sp^3 \) for which four (04) TSLP is responsible. So, with four (04) TSLP, for each additional TSLP (additional sigma bond or lone pair of electron), added one d orbital gradually as follows:

- \[ 5 \text{TSLP} = 4 \text{TSLP} + 1 \text{additional TSLP} = sp^3d \text{hybridization} \]
- \[ 6 \text{TSLP} = 4 \text{TSLP} + 2 \text{additional TSLP} = sp^3d^2 \text{hybridization} \]
- \[ 7 \text{TSLP} = 4 \text{TSLP} + 3 \text{additional TSLP} = sp^3d^3 \text{hybridization} \]

In case of cationic species, requisite electron/electrons must be removed from the outermost orbit of the central atom and in case of anionic species, added requisite electron with the outermost electrons of the central atom [21, 24, 26].

2.2. Innovative mnemonic for Predicting hybridization state of hetero atom in different heterocyclic compounds:

Classification of Lone Pair of Electrons in heterocyclic compounds

Lone Pair of electrons can be generally classified into two types as Delocalized lone pair of electron (DLP) and Localized lone pair of electron (LLP) as follows:

i) Delocalized lone pair of electron (DLP): When lone pair of electron of hetero atom undergo delocalization through conjugation then it is to be treated as delocalized lone pair of electron (DLP). Hetero atom (atom containing lone pair of electron) which is directly attached with single bonds only from all ends is to be considered as DLP containing hetero atom and its lone pair is to be treated as (DLP).
Eg. In Pyrrole lone pair of N atom is to be treated as DLP because it is directly attached with three single bonds only.

ii) **Localized lone pair of electron (LLP):** When lone pair of electron of hetero atom does not undergo delocalization through conjugation then it is to be treated as Localized lone pair of electron (LLP). Hetero atom (atom containing lone pair of electron) which is directly attached with single and double bonds with the ring system is to be considered as LLP containing hetero atom and its lone pair is to be treated as localized lone pair of electron (LLP).

Eg. In Pyridine lone pair of N atom is to be treated as LLP because it is directly attached with double and single bonds with the ring system.

**Planarity of Heterocyclic Compounds**

Planarity is one of the vital features for prediction aromatic, anti-aromatic and non-aromatic behavior of heterocyclic compounds or other organic compounds. For aromatic and anti-aromatic behavior, the compound must be planar, whereas, non-planar compound is non-aromatic in nature [12,13,14,15,16,17,18]. Planarity of heterocyclic compounds depends on the nature of the hybridization state of carbon and hetero atoms present in it. When all atoms (carbon and hetero) in the heterocyclic compounds having sp² hybridized then it is planar but when there is a mixing of sp² and sp³ hybridization state then it is treated as non-planar.
2.2.1. Prediction of \( \text{sp}^2 \) and \( \text{sp}^3 \) Hybridization state

**Formula: prediction of \( \text{sp}^2 \) and \( \text{sp}^3 \) hybridization state**

Power on the Hybridization state of the hetero atom \((P_{\text{Hyb}})\) = \((T_{\text{SLLP}}) - 1\)

where, \(P_{\text{Hyb}}\) = Power on the Hybridization state of the hetero atom, \(T_{\text{SLLP}}\) = (Total no of \(\sigma\) bonds around each central atom + LLP), LLP = Localized lone pair of electron.

If the power of the hybridization state \((P_{\text{Hyb}})\) will be 03, 02 and 01 then the hybridization state will be \(\text{sp}^3\), \(\text{sp}^2\) and \(\text{sp}\) respectively. All single (-) bonds are \(\sigma\) bond, in double bond (=) there is one \(\sigma\) and one \(\pi\). In addition to these each localized lone pair of electron (LLP) can be treated as one \(\sigma\) bond [27].

2.2. Predicting the Bond-Order of Diatomic Species

Bond-order usually predicted from the Molecular Orbital Theory. Molecular Orbital Theory (M.O.T.) was first proposed by Friedrich Hund and Robert Mulliken in 1933 [3, 4]. They developed an approach to covalent bond formation which is based upon the effects of the various electron fields upon each other and which employs molecular orbital rather than atomic orbital. Each such orbital characterizing the molecule as a whole is described by a definite combination of quantum numbers and possesses relative energy value.

First of all, classify the molecules or ions having (1-20)e-s into the following four (4) types based on total number of electrons present in them [21, 24, 25, 26].

2.2.1. Molecules and ions having total no of electrons within the range (2-6):
In such case Bond order = \(n/2\)

2.2.2. Molecules and ions having total no of electrons within the range (2-6):
In such case Bond order = \((1 + \text{mod} n \text{ I}) / 2\)

2.2.3. Molecules and ions having total no of electrons within the range (6-14):
In such case Bond order = \((18 - \text{mod} n \text{ I}) / 2\)

2.2.4. Molecules and ions having total no of electrons within the range (14-20):
In such case Bond order = \((20 - \text{n}) / 2\), [Where \(n = \text{Total no of electrons, ‘I I’ indicates Mod function i.e. the value of bond order is always positive}\]
2.3. Prediction of Bond-Order of oxide based acid radicals:

Bond order of oxide based acid radicals can be calculated from the simple molecular formulae of the acid radicals in the following way [21, 24, 26].

In case of oxide based acid radicals

\[ \text{Bond Order (B.O.)} = \text{Valency of the peripheral atom} + \left( \frac{\text{Charge on Acid Radical}}{\text{Total number of peripheral atoms}} \right) \]

\[ = 2 + \left( \frac{\text{Charge on Acid Radical}}{\text{Total number of peripheral atoms}} \right) \]

2.4. Prediction Magnetic Behavior of Diatomic Species

The present study involves three new formulae by just manipulating the number of unpaired electrons \( n \) using mod function (based on Applied Mathematics) and by means of these \( n \) values one can easily stumble the magnetic moment values in Bohr-Magneton using spin only formula \( \mu_s = \sqrt{n(n+2)} \text{B.M.} \), where B.M. = Bohr Magneton = unit of magnetic moment, \( n \) = number of unpaired electrons [21, 24, 25, 26].

First of all, we classify the molecules or ions depending on the total number of electrons present in them in the following three (03) sets.

Set-1: Molecules or ions having (1-3)e’s, (3-5)e’s, (5-7)e’s, (7-10)e’s, (13-16)e’s

Set-2: Molecules or ions having (10-13)e’s and (16-19)e’s

Set-3: Molecules or ions having 20 e’s

Then for different set we have to use three different formulae to calculate the number of unpaired electrons and thus magnetic moment (\( \mu_s \) in B.M.) can be evaluated in the following way:

2.4.1. F-1(For Set-1) - for the determination of number of unpaired electrons \( n \) of molecules or ions having total number of electrons (1-3), (3-5), (5-7), (7-10) and (13-16)e’s:

\[ n = \lfloor I \left( ND - \text{total e’s} \right) \rfloor \]
Here, ND = next digit i.e. digit next to minimum digit and ‘I I’ indicates mod function.

Eg: Molecules or ions having (1-3)e’s, in this case ND = 2 because here minimum digit is 1.

For the molecules or ions containing (3-5)e’s, (5-7)e’s, (7-10)e’s, and (13-16)e’s the ND value will be 4, 6, 8 and 14 respectively.

Hence, the value of \( n = \left\lfloor \frac{I(4-\text{total e's})}{I} \right\rfloor; \left\lfloor \frac{I(6-\text{total e's})}{I} \right\rfloor; \left\lfloor \frac{I(8-\text{total e's})}{I} \right\rfloor \) and \( \left\lfloor \frac{I(14-\text{total e's})}{I} \right\rfloor \) respectively.

### 2.4.2. F-2 (For Set-2) - for the determination of number of unpaired electrons \( n \) of molecules or ions having total number of electrons (10-13) and (16-19):

In this case, the number of unpaired electrons \( n = \left\lfloor \frac{PD-\text{total e's}}{I} \right\rfloor \)

Here, PD = Penultimate electron digit (i.e. before last electron).

For the molecules or ions containing (10-13) and (16-19)e’s the PD value will be 12 and 18 respectively.

Hence, the value of \( n = \left\lfloor \frac{12-\text{total e's}}{I} \right\rfloor \) and \( \left\lfloor \frac{18-\text{total e's}}{I} \right\rfloor \) respectively.

### 2.4.3. F-3 (For Set-3) - for the determination of number of unpaired electrons \( n \) of molecules or ions having total number of electrons 20:

In this case, the number of unpaired electrons \( n = \left\lfloor \frac{20-\text{total e's}}{I} \right\rfloor \)

### 2.5. Evaluating Spin Multiplicity

Spin-multiplicity value and its corresponding spin state was first discovered by Friedrich Hund in 1925. The formula which is generally used for the prediction of spin multiplicity value is \( [(2S+1), \text{where } S = \Sigma s = \text{total spin quantum no}] \) is time consuming [6]. To keep the matter in mind a simple innovative method has to be introduced for calculation of spin-multiplicity value and thus its corresponding spin state in the easiest way by ignoring the calculation of total spin quantum number \( (S = \Sigma s) \).
First of all we should classify the species (atoms, molecules, ions or complexes) for which spin multiplicity value should be evaluated into three types based on the nature of alignment of unpaired electrons present in them [21, 24, 26].

2.5.1. Species having unpaired electrons in upward alignment (↑):

In this case, \( \text{spin multiplicity} = (n+1) \); where \( n \) = number of unpaired electrons

2.5.2. Species having unpaired electrons in downward alignment (↓):

In this case \( \text{spin multiplicity} = (-n+1) \); Here (-ve) sign indicate downward arrow.

2.5.3. Species having unpaired electrons in both mixed alignment (↑)(↓) :

In this case \( \text{spin multiplicity} = [(+n) + (-n) + 1] \);

where, \( n \) = number of unpaired electrons in each alignment. Here, (+ve) sign and (–ve) sign indicate upward and downward alignment respectively.

2.6. Innovative Mnemonics for Identifying Aromatic and Anti-Aromatic Organic Compounds

It was first devised by Huckel in 1931 [12,13,14,15,16,17,18]. The present study will be an innovative method involving two formulae by just manipulating the number of \( \pi \) bonds within the ring system and delocalized electron pair (excluding \( \pi \) electron pair within the ring system) with one (01) [20, 21, 24].

Conventional methods:

Aromatic nature of organic compound

1. Cyclic molecule,
2. Planer molecule in which all bonded atoms lie in same plane (having sp\(^2\) hybridized)
3. Conjugated molecule with conjugated \( \pi \)-electron system,
4. Contains \( (4n + 2) \) \( \pi \) electrons, where, \( n \) is a positive integer (\( n = 0,1,2,3 \) etc.)
**Anti-Aromatic nature of organic Compound:**

1. Cyclic molecule,
2. Planer molecule in which all bonded atoms lie in same plane (having sp\(^2\) hybridized)
3. Conjugated molecule with conjugated \(\pi\)-electron system,
4. \(4n\pi\) electrons, where, \(n\) is a positive integer (\(n = 0, 1, 2, 3\) etc.)

**Non Aromatic Nature of organic Compound:**

If a compound violates any one of the above three conditions (1 or 2 or 3) then it is non aromatic in nature.

**2.6.1. Prediction of Aromatic behavior:**

In the first case, the compound must be cyclic, planar (i.e. all the carbon atoms having same state of hybridization) and conjugated with **even number** of \(A\) value, where \([A = \pi b + e^- p + 1](\text{constant})\], here \(\pi b\) = number of \(\pi\) bonds with in the ring system and \(e^- p\) = number of electron pair outside or adjacent to the ring system i.e. if the ring contains hetero atoms (atoms containing lone pair of electrons) which can undergo delocalization and each negative charge if present may be treated as one pair of electrons.

If the value of ‘\(A\)’, for a certain organic compound comes out as even number then this compound will be treated as aromatic compound.

**2.6.2. Prediction of Anti-aromatic behavior:**

In the second case, the compound must be cyclic, planar (i.e. all the carbon atoms having same state of hybridization) and conjugated with **odd number** of \(A\) value, where \([A = \pi b + e^- p + 1](\text{constant})\], here \(\pi b\) = number of \(\pi\) bonds with in the ring system and \(e^- p\) = number of electron pair outside or adjacent to the ring system i.e. if the ring contains hetero atoms which can undergo delocalization and each negative charge if present, may be treated as one pair of electrons.
If the value of ‘A’, for a certain organic compound comes out as odd number then this compound will treat as anti-aromatic compound.

2.6.3. General Condition for Non-aromatic behavior of Organic Compounds:

Any compound that lacks one or more of the above features i.e. it may be acyclic / non-planar, is to be treated as non-aromatic. But in this case, ‘A’ value may be even or odd number. It is always to be noted that if the ring contains hetero atom like N, O, S etc, in this case we must count that electron pair in the evaluation of ‘A’ value which can undergo delocalization. We never count localized electron pair.

2.7. Innovative Mnemonics for the Prediction of Aromatic, Anti Aromatic behavior of Heterocyclic Compounds with DLP:

The present study will be an innovative mnemonic involving calculation of ‘A’ value by just manipulating the no of π bonds within the ring system and delocalized lone pair of electron (DLP) with one (01) [27].

The heterocyclic compound having cyclic, planar, conjugated (i.e. all the carbon atoms having same state of hybridization, sp²) with even number of ‘A’ value will be treated as aromatic in nature and with odd number of ‘A’ value will be treated as anti-aromatic in nature.

*Formula: Evaluation of A Value to predict Aromatic and Anti Aromatic Nature*

\[
A = \pi b + DLP + 1(\text{constant}) = \begin{cases} \text{even no} = \text{Aromatic} \\ \text{odd no} = \text{Anti Aromatic} \end{cases}
\]

where, \( \pi b \) = number of π bonds with in the ring system;

\( DLP \) = Delocalized lone pair of electron.

In case of a multi hetero atom based heterocyclic compound, containing both DLP and LLP hetero atoms, Aromatic and Anti Aromatic behavior should be predicted with respect to DLP based
hetero atom only. But when heterocyclic compounds contain both LLP based hetero atoms then
Aromaticity should be predicted with respect to that hetero atom which contains lowest possible
position number as per IUPAC nomenclature or any one of the hetero atom.

2.8. Calculating of π-bonds, σ-bonds, single and double bonds in Straight Chain and
Cycloalkene Systems

The molecular formula which defines a very large number of chemical structure, in this
particular case, it is a herculean task to calculate the nature and number of bonds. Earlier
Badertscher et al studied a novel formalism to characterize the degree of unsaturation of organic
molecules [19]. But no such work has not been taken till now to calculate the number and types
of bonds in open chain olefinic system having complex molecular formulae like \( C_{176}H_{250} \),
\( C_{2000}H_{2000} \).

Keeping this in view, a rapid innovative method has been proposed for the calculation of
number of π-bonds, σ-bonds, single and double bonds with the help of following 06 (six) completely
new formulae for certain aliphatic unsaturated open chain and cyclic olefinic hydrocarbons [21, 23, 24].

2.8.1. For Open Chain Aliphatic Hydrocarbons

(i) Calculation of π-bonds and double bonds (P):

The number of π bonds or double bonds for a straight chain olefin is \( P = [(2X - Y)/2] + 1 \);
Where, \( X \) = number of carbon atoms; \( Y \) = number of hydrogen atoms and \( P \) = number of π
bonds/double bonds.

(ii) Calculation of σ-bonds (S):

The number of σ bonds for a straight chain olefin is \( S = [X + Y - 1] \); where, \( X \) = number
of carbon atoms; \( Y \) = number of hydrogen atoms and \( S \) = number of sigma bonds (σ-bonds).
(iii) Calculation of Single bonds (A):

The total number of single bond for a straight chain olefin is $A = [(3Y/2)-2]$; where $A =$ number of single bonds and $Y$ is number of hydrogen atoms.

2.8.2. For Cyclic aliphatic olefinic hydrocarbons

(i) Calculation of $\pi$-bonds and double bonds ($P_c$):

The number of $\pi$ bonds or double bonds for an aliphatic cyclic olefin is $P_c = [(2X-Y)/2]$;

Where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $P_c =$ number of $\pi$ bonds or double bonds in the cyclic olefinic system.

(ii) Calculation of $\sigma$-bonds ($S_c$):

The number of $\sigma$ bonds for an aliphatic cyclic olefin is $S_c = [X + Y]$; Where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $S_c =$ number of sigma bonds ($\sigma$-bonds) in cyclic olefinic system.

(iii) Calculation of Single bonds ($A_c$):

The total number of single bonds in aliphatic cyclic olefin can be calculated by using the formula $A_c = [3Y/2]$; where $A_c =$ number of single bonds and $Y =$ number of hydrogen atoms in aliphatic cyclic olefin.

2.9. Calculation of $\pi$-bonds, $\sigma$-bonds, single and triple bonds in Straight Chain Alkyne and Cycloalkyne Systems:

$Cycloalkyne$ Systems:

The number and types of bonds in open chain and cycloalkynes having complex molecular formula is a Herculean task. Keeping this in view, a rapid innovative method has been proposed for the calculation of number of $\pi$-bonds, $\sigma$-bonds, single and triple bonds with the help of following 08 (eight) completely new formulae by just manipulating the number of carbon and
hydrogen atoms by using some factors for certain aliphatic unsaturated open chain and cycloalkynes [21, 22, 24].

2.9.1. Open Chain Aliphatic Alkynes

(i) Calculation of $\pi$-bonds ($P$):

The number of $\pi$ bonds for an aliphatic open chain alkyne, where there is one or more than one triple bonds is $P = \left\{ \frac{(2X-Y)}{2} + 1 \right\}$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $P =$ number of $\pi$ bonds.

(ii) Calculation of $\sigma$-bonds ($S$):

The number of $\sigma$ bonds for an aliphatic open chain alkyne, where there is one or more than one triple bonds is $S = \left\{ X+Y-1 \right\}$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $S =$ number of $\sigma$ bonds.

(iii) Calculation of Single bonds ($A$):

The total number of single bond for an aliphatic open chain alkyne, where there is one or more than one triple bonds is $A = \left\{ \frac{(2X+5Y)}{2} - 3 \right\}/2$; where, $A =$ number of single bonds, $X =$ number of carbon atoms and $Y =$ number of hydrogen atoms.

(iv) Calculation of Triple bonds ($T$):

In the first case, we have to count the number of carbon atoms ($X$) and the number of hydrogen atoms ($Y$) in a given unsaturated hydrocarbon containing triple bonds. The formula to calculate the number of triple bonds for an aliphatic open chain alkyne, where there is one or more than one triple bonds is

$T = \left\{ \frac{(2X-Y)}{2} + 1 \right\}/2$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $T =$ number of triple bonds.
2.9.2. Cycloalkynes

(i) Calculation of π-bonds ($P_c$):

In the first case, we have to count the number of carbon atoms ($X$) and the number of hydrogen atoms ($Y$) in the given unsaturated cycloalkyne. The formula to calculate the number of π bonds for an aliphatic cycloalkyne is $P_c = \frac{(2X - Y)}{2}$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $P_c =$ number of π bonds in the cycloalkyne system.

(ii) Calculation of σ-bonds ($S_c$):

The number of σ bonds for an aliphatic cycloalkyne is $S_c = [X + Y]$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $S_c =$ number of sigma bonds (σ-bonds) in cycloalkyne system.

(iii) Calculation of Single bonds ($A_c$):

The total number of single bond for an aliphatic cyclo alkyne is $A_c = \frac{[(2X + 5Y)/2]}{2}$; where, $A_c =$ number of single bonds in cycloalkyne, $X =$ number of carbon atoms and $Y =$ number of hydrogen atoms.

(iv) Calculation of Triple bonds ($T_c$):

The number of triple bond is $T_c = \frac{[(2X - Y)/2]}{2}$; where, $X =$ number of carbon atoms; $Y =$ number of hydrogen atoms and $T_c =$ number of triple bond.

RESULTS AND DISCUSSION

*Prediction of the hybridization state (sp, sp$^2$ & sp$^3$) of simple molecules and ions can be well explained in the following way*

Eg.:
a) NH₃: In NH₃, central atom N is surrounded by three N-H single bonds i.e. three (03) sigma (σ) bonds and one (01) lone pair (LP). So, T_{SLP} = 4, in NH₃, hence, power on the hybridization state of N in NH₃, \( P_{Hyb} = (T_{SLP}) - 1 = (3+1) - 1 = 3 \) i.e. hybridization state = sp³.

b) H₂O: In H₂O, central atom O is surrounded by two O-H single bonds i.e. two (02) sigma (σ) bonds and two (02) lone pairs. So, in this case, power on the hybridization state of O, \( P_{Hyb} = (T_{SLP}) - 1 = (2+2) - 1 = 3 \), i.e. hybridization state of O in H₂O = sp³.

c) H₃BO₃: In H₃BO₃, B has (Fig.1), three (03) σ bonds only (no LPs) and oxygen has two (02) σ bonds and two (02) lone pair of electrons, so, in this case, power on the hybridization state of B, \( P_{Hyb} = (T_{SLP}) - 1 = (3+0) - 1 = 2 \) i.e. B is sp² hybridized in H₃BO₃. On the other hand, the power of the hybridization state of O, \( P_{Hyb} = (T_{SLP}) - 1 = (2+2) - 1 = 3 \) i.e. hybridization state of O in H₃BO₃ is sp³.

d) I-Cl: In I-Cl, I and Cl both have one (01) σ bond and three (03) lone pair of electrons, so, in this case, power on the hybridization state of both I and Cl, \( P_{Hyb} = (T_{SLP}) - 1 = (1+3) - 1 = 3 \) i.e. hybridization state of I and Cl both are sp³.

e) CH₂ = CH₂: In C₂H₄, each carbon (Fig.1), is attached with two (02) C-H single bonds (2 σ bonds) and one C=C bond (1σ bond), so, altogether there are 3 sigma bonds. So, in this case, the power on the hybridization state of both C, \( P_{Hyb} = (T_{SLP}) - 1 = (3+0) - 1 = 2 \) i.e. hybridization state of both carbons are sp².

![Fig. 1 Structure of H₃BO₃ and C₂H₄](image-url)
f) O₃: Ozone (O₃) exists as a stable form of cyclic ozone (Fig.2) and its structure is equilateral triangle [2, 5]. In which each center O atom has two (02) O-O single bonds (2σ bonds) and two (02) lone pair of electrons. So, in this case, power on the hybridization state of central O atom 

\[ P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3 \text{ i.e. hybridization state of center atom O in cyclic O}_3 \text{ is sp}^3. \]

But the resonance description of ozone involves two structures (Fig.3), in which, central oxygen atom of ozone will have sp² hybridization state. In this case, the central O atom has two (02) σ bonds and one (01) lone pair of electron (LP = 01), hence, power on the hybridization state of central O atom in resonance hybrid of ozone, 

\[ P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+1) - 1 = 2 \text{ (sp}^2). \]

\[ \text{Fig. 2 Equilateral triangle structure of cyclic ozone (O}_3\text{)} \]

\[ \text{Fig. 3 Resonating structures of Ozone (O}_3\text{)} \]

g) S₈: The ordinary form of sulfur (orthorhombic sulfur, yellow crystals) contains octatomic molecules (S₈), in which, S can form single covalent bonds with two other S atoms in a zigzag fashion (Fig.4), into a long chain. In this case, each sulfur atom attached with two (02) adjacent σ bonds and two (02) lone pair of electrons (LP = 2). Hence, power on the hybridization state of any S atom 

\[ P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3 \text{ i.e. hybridization state of S atoms in S}_8 \text{ is sp}^3. \]

h) P₄: In P₄, the four P atoms are arranged at the corners of a regular tetrahedron (Fig.4). Here, each P atom forms three covalent bonds (3σ bonds) and one lone pair of electron (LP = 1).
Hence, power on the hybridization state of any P atom \((P_{Hyb}) = (T_{SLP}) - 1 = (3+1) - 1 = 3\) i.e. hybridization state of P atoms in \(P_4\) is \(sp^3\).

\[
(P_{Hyb}) = (T_{SLP}) - 1 = (3+1) - 1 = 3
\]

**Fig. 4 Zigzag structure of \(S_8\) and Tetrahedron structure of \(P_4\)**

i) \(CO_3^{2-}\) : In the valence bond structure of carbonate ion \((CO_3^{2-})\), the central carbon atom does not contain any lone pair of electron \((LP = 0)\) but it has three \((03)\) \(\sigma\) bonds (**Fig.5**). Hence, power on the hybridization state of central C atom in carbonate ion, \((P_{Hyb}) = (T_{SLP}) - 1 = (3+0) - 1 = 2\) \((sp^2)\). But in resonance hybrid of \(CO_3^{2-}\) (**Fig.6**), carbon atoms are in \(sp^2\) hybridization state due to 3 \(\sigma\) bonds and no lone pair of electrons \((LP = 0)\).

\[
\begin{align*}
&\text{O} = C \quad \text{O} &
&\text{O} = C \quad \text{O}
\end{align*}
\]

**Fig. 5 Valence bond structure of carbonate ion \((CO_3^{2-})\)**

\[
\begin{align*}
&\text{O} \quad \text{C} \quad \text{O} &
&\text{O} \quad \text{C} \quad \text{O}
\end{align*}
\]

**Fig. 6 Resonance hybrid of \(CO_3^{2-}\)**
Prediction of the hybridization state (sp$^3$d, sp$^3$d$^2$ & sp$^3$d$^3$) of simple molecules and ions can be well explained in the following way

Eg:-

a) I$_3^-$: In Tri iodide ion (I$_3^-$), central I atom has 2σ bonds and 3 lone pair of electrons (LP = 3) (Fig.7). Hence for central I, there is 5 T$_{SLP}$ So, 5 T$_{SLP}$ = 4 T$_{SLP}$ + 1 additional T$_{SLP}$ = sp$^3$d hybridization.

\[
\text{Fig. 7 Linear structure of tri iodide ion (I}_3^-\text{)}
\]

b) IF$_4^+$: In IF$_4^+$ (Fig.8), I have 7 e$^-$s in its outermost shell, so, in this case, subtract one e$^-$ from 7 i.e. 7 – 1 = 6. So, out of 6 electrons, 4 electrons form four (04) I-F σ bonds and there is one (01) LP. So, altogether there are 5 T$_{SLP}$. So, 5 T$_{SLP}$ = 4 T$_{SLP}$ + 1 additional T$_{SLP}$ = sp$^3$d hybridization.

c) XeF$_4$: In XeF$_4$ (Fig.8), Xe, an inert gas, consider 8 e$^-$s in its outermost shell, four (04) of which form four (04) Xe-F sigma bonds and there are two (02) lone pair of electrons, so, altogether there is 06 T$_{SLP}$ = 4 T$_{SLP}$ + 2 additional T$_{SLP}$ = sp$^3$d$^2$ hybridization.

\[
\text{Fig. 8 Structure of IF}_4^+\text{ and XeF}_4
\]

a) IF$_7$: In IF$_7$, there is seven (07) I-F single bonds i.e. 7σ bonds and no lone pair of electron (LP), so, altogether there is 07 T$_{SLP}$ = 4 T$_{SLP}$ + 3 additional T$_{SLP}$ = sp$^3$d$^3$ hybridization.

162
In case of determination of the hybridization state by using the above method, one must have a clear idea about the outermost electrons of different family members in the periodic table as follows:

<table>
<thead>
<tr>
<th>Family</th>
<th>Outermost electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon family</td>
<td>04</td>
</tr>
<tr>
<td>Nitrogen family</td>
<td>05</td>
</tr>
<tr>
<td>Oxygen family</td>
<td>06</td>
</tr>
<tr>
<td>Halogen family</td>
<td>07</td>
</tr>
<tr>
<td>Inert gas family</td>
<td>08</td>
</tr>
</tbody>
</table>

The geometry of simple molecules or ions

In absence of lone pair of electrons (LPs) a molecule or ion exhibit regular geometry (Fig.9). For sp, sp², sp³, sp³d, sp³d² and sp³d³ hybridization state, geometry will be linear, trigonal planar, tetrahedral, trigonal bipyramid, octahedral and pentagonal bipyramid respectively, whereas for the same hybridization state in presence of the lone pair of electrons they exhibit subnormal geometry (Fig.10) [8, 9, 10].
(Trigonal bipyramidal, sp^{3}d, LP=0) (Octahedral, sp^{3}d^{2}, LP=0) (Petntagonal bipyramidal, sp^{3}d^{3}, LP =0)

Fig. 9 Regular / Normal Molecular Geometry without Lone pair of electrons

(Bent or V shape, sp^{2}, LP = 01) (Pyramidal, sp^{3}, LP=01) (Bent or V shape, sp^{3}, LP=02) (Linear,sp^{3},LP=03)

(See Saw, sp^{3}d, LP=01) (T shape, sp^{3}d, LP=02) (Linear,sp^{3}d,LP=03)

(Square Pyramidal, sp^{3}d^{2}, LP=01) (Square planar, sp^{3}d^{2}, LP=02)

(Pentagonal Pyramidal, sp^{3}d^{3}, LP=01)

Fig. 10 Sub-normal Molecular Geometry with Lone pair of electrons
Prediction of the hybridization state (sp² & sp³) of hetero atom in heterocyclic compounds can be well explained in the following way

Hybridization state of hetero atom in heterocyclic compounds can be calculated from the total number of σ bonds around hetero atom and number of localized lone pair of electrons (T_{SLLP}) on the hetero atom and subtract one (01) from this total value of T_{SLLP} to get the hybridization state (sp² & sp³) of the hetero atom in the heterocyclic compounds.

Adequate examples on prediction of the hybridization state from the corresponding T_{SLP} value (total number of σ bonds around the central atom + lone pair of electron on central atom) of the central atom have been explored in Table 1. Molecular Geometry (normal and sub normal) and bond angle with respect to the corresponding hybridization state and lone pair of electrons of simple molecules or ions have been displayed in Table 2. Hybridization state of hetero atom in heterocyclic compounds containing one, two or more same or different number of hetero atoms with the help of localized lone pair of electron (LLP) have been evaluated in Table 3.

Table 1 T_{SLP} and corresponding hybridization state

<table>
<thead>
<tr>
<th>T_{SLP} (Total number of σ bonds + LP)</th>
<th>Nature of Hybridization State</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>sp</td>
<td>BeCl₂, HgCl₂, C₂H₂, CO₂, CO, CdCl₂, ZnCl₂ etc.</td>
</tr>
<tr>
<td>3</td>
<td>sp²</td>
<td>BCl₃, AlCl₃, C₂H₄, C₆H₆, SO₂, SO₃, HNO₃, H₂CO₃, SnCl₂, PbCl₂ etc.</td>
</tr>
<tr>
<td>4</td>
<td>sp³</td>
<td>NH₄⁺, BF₄⁻, H₂SO₄, HClO₄, PCl₃, NCl₃, AsCl₃, HClO₃, ICl₂⁺, OF₂, HClO₂, ScI₂, HClO, ICl, XeO₃ etc.</td>
</tr>
<tr>
<td>5</td>
<td>sp³d</td>
<td>PCl₅, SbCl₅, SF₄, ClF₃, BrF₃, XeF₂, ICl₂⁻ etc.</td>
</tr>
<tr>
<td>6</td>
<td>sp³d²</td>
<td>SF₆, AlF₆³⁻, SiF₆²⁻, PF₆⁻, IF₅, BrF₅, XeOF₄, XeF₄, BrF₄⁻, ICl₄⁻ etc.</td>
</tr>
<tr>
<td>7</td>
<td>sp³d³</td>
<td>IF₇, XeF₆ etc.</td>
</tr>
</tbody>
</table>
Table 2 Hybridization, Molecular Geometry and Bond Angles without/with lone pair of electrons

<table>
<thead>
<tr>
<th>Hybridization</th>
<th>LP</th>
<th>Molecular Geometry (Regular / Normal)</th>
<th>Approximate Bond Angles (Degree)</th>
<th>Examples</th>
<th>LP</th>
<th>Molecular Geometry (Sub-normal)</th>
<th>Approximate Bond Angles (Degree)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>sp</td>
<td>0</td>
<td>Linear</td>
<td>180</td>
<td>CO₂, CS₂, BeCl₂, HgCl₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>sp²</td>
<td>0</td>
<td>Trigonal Planar or Triangular Planar</td>
<td>120</td>
<td>BH₃, AlCl₃, C₂H₄, BF₃, NO₃⁻, CO₃²⁻</td>
<td>01</td>
<td>Angular or V-shape</td>
<td>&lt;120</td>
<td>SO₂, NO₂⁻</td>
</tr>
<tr>
<td>sp³</td>
<td>0</td>
<td>Tetrahedral</td>
<td>109.5</td>
<td>BH₄⁺, BF₄⁻, SnCl₄, H₂SO₄, HClO₄, SiCl₄</td>
<td>01</td>
<td>Pyramidal</td>
<td>&lt;109.5</td>
<td>NH₃, PH₃, AsH₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>02</td>
<td>Bent shape or V-shape</td>
<td>&lt;109.5</td>
<td>H₂O, H₂S, H₂Se</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>03</td>
<td>Linear</td>
<td>180</td>
<td>ICl, BrF, ClF</td>
</tr>
<tr>
<td>sp³d</td>
<td>0</td>
<td>Trigonal Bipyramid (equatorial)</td>
<td>120</td>
<td>PF₅, PCl₅</td>
<td>01</td>
<td>See-Saw</td>
<td>&lt;120(equatorial) &lt;90 (axial)</td>
<td>SF₄</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(axial)</td>
<td>90</td>
<td></td>
<td>02</td>
<td>T-shape</td>
<td>&lt;90</td>
<td>ICl₃, F₃Cl</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>03</td>
<td>Linear</td>
<td>180</td>
<td>XeF₂, I₅⁻</td>
</tr>
<tr>
<td>sp³d²</td>
<td>0</td>
<td>Octahedral</td>
<td>90</td>
<td>SF₆, WF₆, SeF₆, SnCl₆²⁻</td>
<td>01</td>
<td>Square pyramidal</td>
<td>&lt;90</td>
<td>IF₅, BrF₅</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>02</td>
<td>Square planar</td>
<td>90</td>
<td>XeF₄</td>
</tr>
<tr>
<td>sp³d³</td>
<td>0</td>
<td>Pentagonal Bipyramid</td>
<td>72 &amp; 90</td>
<td>IF₇</td>
<td>01</td>
<td>Pentagonal Pyramidal or Distorted Octahedral</td>
<td>72 &amp; 90</td>
<td>XeF₆</td>
</tr>
</tbody>
</table>
Table-3 Hybridization state of Hetero atom in Heterocyclic Compounds with the help of LLP

<table>
<thead>
<tr>
<th>Heterocyclic Compounds (Planar/non planar)</th>
<th>Number of σ bonds around hetero atom (from single and double bonds) ((T_s))</th>
<th>Number of localized Lone Pair of e’s (LLP)</th>
<th>Total Number of σ bonds around hetero atom ((T_{LLP}))</th>
<th>Power on the Hybridization state of the hetero atom ((P_{Hyb}) = (T_{LLP}) – 1) (Corresponding Hybridization state)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrrole (Planar)</td>
<td>03</td>
<td>0 (lone pair of electron undergo delocalization, DLP with the ring system)</td>
<td>03</td>
<td>02 ((\text{sp}^2 \text{N}))</td>
</tr>
<tr>
<td>Furan (Planar)</td>
<td>02</td>
<td>01 (out of two lone pair of electrons, one undergo delocalization, DLP and other remain as LLP)</td>
<td>03</td>
<td>02 ((\text{sp}^2 \text{O}))</td>
</tr>
<tr>
<td>Thiophene (Planar)</td>
<td>02</td>
<td>01 (out of two lone pair of electrons of S one undergo delocalization, DLP and other remain as LLP)</td>
<td>03</td>
<td>02 ((\text{sp}^2 \text{S}))</td>
</tr>
<tr>
<td>Pyridine (Planar)</td>
<td>02</td>
<td>01</td>
<td>03</td>
<td>02 ((\text{sp}^2 \text{N}))</td>
</tr>
<tr>
<td>Indole (Planar)</td>
<td>03</td>
<td>0</td>
<td>03</td>
<td>02 ((\text{sp}^2 \text{N}))</td>
</tr>
<tr>
<td></td>
<td>Quinoline</td>
<td>02</td>
<td>01</td>
<td>03</td>
</tr>
<tr>
<td>-------</td>
<td>------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td></td>
<td>Isoquinoline</td>
<td>02</td>
<td>01</td>
<td>03</td>
</tr>
<tr>
<td>Imidazole</td>
<td>03 (N1)</td>
<td>0 (N1)</td>
<td>03</td>
<td>02 (sp³ N1)</td>
</tr>
<tr>
<td></td>
<td>02 (N3)</td>
<td>01 (N3)</td>
<td>03</td>
<td>02 (sp³ N3)</td>
</tr>
<tr>
<td></td>
<td>Pyrimidine</td>
<td>02 (N1)</td>
<td>01 (N1)</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>02 (N3)</td>
<td>01 (N3)</td>
<td>03</td>
<td>02 (sp³ N3)</td>
</tr>
<tr>
<td></td>
<td>Purine</td>
<td>02 (N1)</td>
<td>01 (N1)</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>02 (N3)</td>
<td>01 (N3)</td>
<td>03</td>
<td>02 (sp³ N3)</td>
</tr>
<tr>
<td></td>
<td>02 (N7)</td>
<td>01 (N7)</td>
<td>03</td>
<td>02 (sp³ N7)</td>
</tr>
<tr>
<td></td>
<td>03 (N9)</td>
<td>0 (N9)</td>
<td>03</td>
<td>02 (sp³ N9)</td>
</tr>
<tr>
<td>Compound</td>
<td>N1</td>
<td>N2</td>
<td>N3</td>
<td>N4</td>
</tr>
<tr>
<td>-------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Thiazole (Planar)</td>
<td>02 (N)</td>
<td>01 (N)</td>
<td>03</td>
<td>02 (sp(^2) N)</td>
</tr>
<tr>
<td>(out of two lone pair of electrons on S, one undergo delocalization, DLP, and other remain as LLP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzothiazole (Planar)</td>
<td>02 (N)</td>
<td>01 (N)</td>
<td>03</td>
<td>02 (sp(^2) S)</td>
</tr>
<tr>
<td>(out of two lone pair of electrons on S, one undergo delocalization, DLP, and other remain as LLP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrazine (p-diazine) (Planar)</td>
<td>02 (N1)</td>
<td>01 (N1)</td>
<td>03</td>
<td>02 (sp(^3) N1)</td>
</tr>
<tr>
<td>(N1, N3 and N5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanidine (Planar)</td>
<td>02 (N1, N3 and N5)</td>
<td>01 (N1, N3 and N5)</td>
<td>03</td>
<td>02 (sp(^2) N1, N3, N5)</td>
</tr>
<tr>
<td>Phenothiazine (Planar)</td>
<td>03 (N)</td>
<td>01 (S)</td>
<td>03</td>
<td>02 (sp(^2) S)</td>
</tr>
<tr>
<td>(out of two LP of S, one undergo delocalization (DLP),</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Prediction of bond order for diatomic species having (1-20)\(e^s\):**

The graphical representation (Fig. 11), shows that bond-order gradually increases to 1 in the range (0-2) electrons then falls to zero in the range (2-4) electrons then it further rises to 1 for

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Bond Order 1</th>
<th>Bond Order 2</th>
<th>Bond Order 3</th>
<th>Bond Order 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenazine (Planar)</td>
<td>02 (both N)</td>
<td>01 (both N)</td>
<td>03</td>
<td>02 (sp(^2) both N)</td>
</tr>
<tr>
<td>1,2,3,4-tetrazine</td>
<td>02 (N1,N2,N3,N4)</td>
<td>01 (N1,N2,N3,N4)</td>
<td>03</td>
<td>02 (sp(^2) All N)</td>
</tr>
<tr>
<td>Azocine (Planar)</td>
<td>02</td>
<td>01</td>
<td>03</td>
<td>02 (sp(^3) N)</td>
</tr>
<tr>
<td>Azetine (Planar)</td>
<td>02</td>
<td>01</td>
<td>03</td>
<td>02 (sp(^3) N)</td>
</tr>
<tr>
<td>Aziridine (non-planar)</td>
<td>03</td>
<td>01</td>
<td>04</td>
<td>03 (sp(^3) N)</td>
</tr>
<tr>
<td>Oxetan (non-planar)</td>
<td>02</td>
<td>02</td>
<td>04</td>
<td>03 (sp(^3) O)</td>
</tr>
</tbody>
</table>
(4-6) electrons and once again falls to zero for (6-8) electrons then again rises to 3 in the range (8-14) electrons and then finally falls to zero for (14-20) electrons. For total no of electrons 2, 6 and 14, one can use multiple formulae, because they fall in the overlapping region in which they intersect with each other.

**Prediction of bond order for oxide based acid radicals:**

It can be illustrated by the following examples

Eg.

- \( \text{ClO}_4^- \) : (Valency of one Peripheral atom Oxygen = 2, Charge on acid radical = -1, Total Number of Peripheral atoms = 04), Therefore B.O. = 2 + (-1/4) = 1.75
- \( \text{ClO}_3^- \) : (Valency of one Peripheral atom Oxygen = 2, Charge on acid radical = -1, Total Number of Peripheral atoms = 03), Therefore B.O. = 2 + (-1/3) = 1.66
- \( \text{ClO}_2^- \) : (Valency of one Peripheral atom Oxygen = 2, Charge on acid radical = -1, Total Number of Peripheral atoms = 02), Therefore B.O. = 2 + (-1/2) = 1.5
• AsO$_4^{3-}$: (Valency of one Peripheral atom Oxygen = 2, Charge on acid radical = -3, Total Number of Peripheral atoms = 04), Therefore B.O. = 2 + (-3/4) = 1.25

• AsO$_3^{3-}$: (Valency of one Peripheral atom Oxygen = 2, Charge on acid radical = -3, Total Number of Peripheral atoms = 03), Therefore B.O. = 2 + (-3/3) = 1.0

• SO$_4^{2-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -2, Number of Peripheral atoms = 04), Therefore B.O. = 2 + (-2/4) = 1.5

• SO$_3^{2-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -2, Number of Peripheral atoms = 03), Therefore B.O. = 2 + (-2/3) = 1.33

• PO$_4^{3-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -3, Number of Peripheral atoms = 04), Therefore B.O. = 2 + (-3/4) = 1.25

• BO$_3^{3-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -3, Number of Peripheral atoms = 03), Therefore B.O. = 2 + (-3/3) = 1

• CO$_3^{2-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -2, Number of Peripheral atoms = 03), Therefore B.O. = 2 + (-2/3) = 1.33

• SiO$_4^{4-}$: (Valency of Peripheral atom Oxygen = 2, Charge on acid radical = -4, Number of Peripheral atoms = 04), Therefore B.O. = 2 + (-4/4) = 1

*Relation of different parameters (Bond length, Bond Strength, Bond energy, Thermal stability and Reactivity) with Bond order:*

B.O. $\propto$ 1 / Bond length or Bond distance;

B.O. $\propto$ Bond strength;

B.O. $\propto$ Bond Energy;

B.O. $\propto$ Bond dissociation Energy;

B.O. $\propto$ Thermal Stability; B.O. $\propto$ 1 / Reactivity
Correlation among / between Literature values of bond-distances (Å) and bond dissociation energy (KJ mol⁻¹) of some oxide based acid radicals with their predicted bond order values:

Literature values of the Cl-O average bond lengths in ClO₄⁻, ClO₃⁻ and ClO₂⁻ are 1.50, 1.57 and 1.64 (Å) for their predicted bond orders values 1.75, 1.6 and 1.5 respectively; As-O average bond lengths in AsO₄³⁻ and AsO₃³⁻ are 1.75 and 1.77 (Å) for their predicted bond order values 1.25 and 1.0 respectively which suggests that with increasing Bond-Order bond length decreases.

Literature values of bond dissociation energies of O₂⁺, O₂ and O₂⁻ are respectively 642.9, 493.6 and 395.0 KJ mol⁻¹ for their predicted bond orders values 2.5, 2.0 and 1.5 respectively; bond dissociation energies of NO⁺, NO and NO⁻ are respectively 1046.9, 826.9 and 487.8 KJ mol⁻¹ for their predicted bond order values 3.0, 2.5 and 2.0 respectively, which suggests that with increasing Bond-Order bond dissociation energy increases.

Magnetic Behavior of Diatomic Species:

Magnetic behavior of diatomic species can be predicted by classify the diatomic species having total number of electrons (1-20) into three different sets and thus calculating the number of unpaired electron/electrons (n) by using three different formulae for three different sets.

Bond order of homo and hetero nuclear diatomic molecules or ions having total number of electrons fall in the range (1-20) can be evaluated from their total number of electrons only without drawing their electronic configuration and their magnetic moments (μs) in Bohr Magneton (B.M.) can be evaluated by calculating the number of unpaired electrons have been illustrated in Table 4 and Table 5 respectively.
Table 4 Bond order of diatomic species having (1-20) electrons

<table>
<thead>
<tr>
<th>Species (Molecules or ions)</th>
<th>Total Number of e’s (n)</th>
<th>Bond-Order (B.O.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bond-Order Values for the species having (1-2)e’s ; Bond order = n/2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂⁺, H₂, He₂⁺⁺</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Bond-Order Values for the species having (2-6)e’s ; Bond order = (14- n) / 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be₂⁺, Li₂⁺, Be₂⁺⁺, Li₂⁺⁺</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>He₂⁺⁺, Li₂⁺⁺</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Li₂⁺⁺, He₂⁺⁺</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Li₂⁺⁺, Be₂⁺⁺, He₂⁺⁺</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td><strong>Bond-Order Values for the species having (6-14)e’s ; Bond order = (18- n) / 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be₂⁺⁺, Li₂⁺⁺, Be₂⁺⁺⁺, Li₂⁺⁺⁺</td>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>Be₂⁺⁺⁺, Li₂⁺⁺⁺</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Be₂⁺⁺⁺, B₂⁺⁺⁺</td>
<td>9</td>
<td>0.5</td>
</tr>
<tr>
<td>B₂⁺⁺⁺, Be₂⁺⁺⁺, Ha</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>B₂⁺⁺⁺, C⁺⁺⁺</td>
<td>11</td>
<td>1.5</td>
</tr>
<tr>
<td>C₂⁺⁺⁺, B₂⁺⁺⁺, N₂⁺⁺⁺, CN⁺⁺⁺</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>C₂⁺⁺⁺, N₂⁺⁺⁺</td>
<td>13</td>
<td>2.5</td>
</tr>
<tr>
<td>N₂⁺⁺⁺, CO⁺⁺⁺, C₂⁺⁺⁺, CN⁺⁺⁺, O₂⁺⁺⁺</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td><strong>Bond-Order Values for the species having (14-20)e’s ; Bond order = (20-n) / 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂⁺⁺⁺, NO⁺⁺⁺, O₂⁺⁺⁺</td>
<td>15</td>
<td>2.5</td>
</tr>
<tr>
<td>NO⁺⁺⁺, O₂⁺⁺⁺</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>O₂⁺⁺⁺</td>
<td>17</td>
<td>1.5</td>
</tr>
<tr>
<td>F₂⁺⁺⁺, HCl</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>F⁺⁺⁺</td>
<td>19</td>
<td>0.5</td>
</tr>
<tr>
<td>Ne⁺⁺⁺</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5 Magnetic moments ($\mu_s$) in B.M. of diatomic species

<table>
<thead>
<tr>
<th>Species (Molecules or ions)</th>
<th>Total Number of e’s (n)</th>
<th>Number of unpaired electrons (n)</th>
<th>Magnetic moment ($\mu_s$) in Bohr Magneton (B.M.)</th>
<th>Remark on magnetic behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂⁺⁺⁺</td>
<td>1</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>H₂⁺⁺⁺⁺, He₂⁺⁺⁺⁺</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>H₂⁺⁺⁺⁺, He₂⁺⁺⁺⁺</td>
<td>3</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>He₂⁺⁺⁺⁺</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>Li₂⁺⁺⁺⁺, He₂⁺⁺⁺⁺</td>
<td>5</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>Li₂⁺⁺⁺⁺, Be₂⁺⁺⁺⁺, Be⁺⁺⁺⁺⁺⁺</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>Be₂⁺⁺⁺⁺, Li₂⁺⁺⁺⁺</td>
<td>7</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>Be₂⁺⁺⁺⁺, Li₂⁺⁺⁺⁺</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>Be₂⁺⁺⁺⁺, B₂⁺⁺⁺⁺</td>
<td>9</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>B₂⁺⁺⁺⁺, Be₂⁺⁺⁺⁺, Ha</td>
<td>10</td>
<td>2</td>
<td>2.82</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>B₂⁺⁺⁺⁺, C⁺⁺⁺⁺⁺⁺</td>
<td>11</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>C₂⁺⁺⁺⁺, B₂⁺⁺⁺⁺, N₂⁺⁺⁺⁺, CN⁺⁺⁺⁺</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>C₂⁺⁺⁺⁺, N₂⁺⁺⁺⁺</td>
<td>13</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>N₂⁺⁺⁺⁺, CO⁺⁺⁺⁺, C₂⁺⁺⁺⁺, CN⁺⁺⁺⁺, O₂⁺⁺⁺⁺</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>N₂⁺⁺⁺⁺, NO⁺⁺⁺⁺, O₂⁺⁺⁺⁺</td>
<td>15</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>NO⁺⁺⁺⁺, O₂⁺⁺⁺⁺</td>
<td>16</td>
<td>2</td>
<td>2.82</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>O₂⁺⁺⁺⁺</td>
<td>17</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>F₂⁺⁺⁺⁺, HCl</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
<tr>
<td>F⁺⁺⁺⁺</td>
<td>19</td>
<td>1</td>
<td>1.73</td>
<td>Para magnetic</td>
</tr>
<tr>
<td>Ne⁺⁺⁺⁺</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>Diamagnetic</td>
</tr>
</tbody>
</table>
Spin multiplicity and its corresponding spin state:

First of all we should classify the species (atoms, molecules, ions or complexes) for which spin multiplicity value and its corresponding spin state should be evaluated into three types based on the nature of alignment of unpaired electrons (upward, downward, or mixed alignment) present in them.

For upward alignment

Eg.

\[ \begin{array}{c}
\uparrow \\
\uparrow \\
\uparrow \\
\end{array} \]  \[ \begin{array}{c}
\uparrow \\
\uparrow \\
\uparrow \\
\uparrow \\
\uparrow \\
\end{array} \]  \[ \begin{array}{c}
\uparrow \\
\uparrow \\
\uparrow \\
\end{array} \]

Spin multiplicity = \((n + 1) = (1+1) = 2\) (spin state = doublet); \((2+1) = 3\) (spin state = triplet) and \((3 + 1) = 4\) (spin state = quartet) respectively.

\[ \begin{array}{c}
\uparrow \downarrow \\
\uparrow \\
\uparrow \\
\end{array} \]  \[ \begin{array}{c}
\uparrow \downarrow \\
\uparrow \\
\uparrow \\
\end{array} \]

Spin multiplicity = \((n +1) = (2 + 1) = 3\) (in this case ignore paired electrons) (spin state = triplet) and \((1 + 1) = 2\) (spin state = doublet)

\[ \begin{array}{c}
\uparrow \downarrow \\
\uparrow \\
\end{array} \]

Spin multiplicity = \((n +1) = (0 + 1) = 1\) (spin state = singlet)

For downward alignment

\[ \begin{array}{c}
\downarrow \\
\downarrow \\
\downarrow \\
\end{array} \]  \[ \begin{array}{c}
\downarrow \\
\downarrow \\
\downarrow \\
\end{array} \]  \[ \begin{array}{c}
\downarrow \\
\downarrow \\
\downarrow \\
\end{array} \]

Spin multiplicity = \((-n +1) = (-1 + 1) = 0\); \((-2 + 1) = -1\) and \((-3 + 1) = -2\) respectively.

\[ \begin{array}{c}
\uparrow \downarrow \\
\uparrow \downarrow \\
\uparrow \\
\end{array} \]  \[ \begin{array}{c}
\uparrow \downarrow \\
\uparrow \downarrow \\
\uparrow \\
\end{array} \]

Spin multiplicity = \((-n +1) = (-2 + 1) = -1\) (ignore paired electrons) and \((-1 + 1) = 0\) respectively.

For mixed (upward & downward) alignment

\[ \begin{array}{c}
\uparrow \\
\downarrow \\
\end{array} \]

Here total no of unpaired electrons = 2 in which one having upward direction (+1) and other having downward mode (-1).

Hence Spin multiplicity = \([(+n) + (-n) +1] = [(+1) + (-1) + 1] = 1\) (spin state = singlet)
Here the total no of unpaired electrons = 3 in which two unpaired electrons lie in upward (+2) and one unpaired electrons lie in downward (-1).
Hence Spin multiplicity = \[ (+n) + (-n) + 1 \] = \[ (+2) + (-1) + 1 \] = 2 (spin state = doublet)

Here the total no of unpaired electrons = 5 in which three unpaired electrons lie upward (+3) and two unpaired electrons lie downward (-2).
Hence Spin multiplicity = \[ (+n) + (-n) + 1 \] = \[ (+3) + (-2) + 1 \] = 2 (spin state = doublet)
For 1, 2, 3, 4, 5, 6 or >6 spin multiplicity values (n+1), where n = number of unpaired electrons, the corresponding spin state will be singlet, doublet, triplet, quartet, quintet and multiplet respectively.

Aromatic and Anti-Aromatic nature of Organic Compounds along with their Omission behavior:
If the compound must be cyclic, planar, conjugated with even and odd number of A value, [where, A = \[ \pi b + \varepsilon p + 1 \]\text{(constant)}, here \[ \pi b \] = number of \[ \pi \] bonds with in the ring system and \[ \varepsilon p \] = delocalized lone pair of electrons (DLP) and each negative charge if present may be treated as one pair of electrons] will be aromatic and anti-aromatic nature respectively.

Stability / reactivity / acidity of different organic compounds with the help of Aromaticity:
If we easily predict the nature of organic compound i.e. aromatic, anti-aromatic or non-aromatic then we can resolve different kind of problems regarding stability, reactivity, acidity etc. by using the following supposition.

- Order of stability is aromatic > non aromatic > anti aromatic
- Order of reactivity is Anti-aromatic > non aromatic > aromatic
- Order of Acidity directly proportional to the stability of the Conjugate base
Eg: cyclopentadienyl anion (aromatic) > cyclopentadiene (non-aromatic) > cyclopentadienyl cation (anti aromatic). Hence, cyclopentadiene (its conjugate base i.e. Cyclopentadienyl anion is aromatic in nature) is much more acidic than cycloheptatriene (its conjugate base i.e. Cycloheptatrienyl anion is anti-aromatic in nature).

**Omission behavior of aromatic and non-aromatic organic compounds:**

There are some compounds which do not follow the above rules of A value. Huckel’s also cannot explain the aromatic or non-aromatic behavior of these compounds. These compounds have been represented below.

Cyclodecapentaene (Fig. 12), is non aromatic due to the interaction of the hydrogen of 1 and 6, it is non planar, although here, $A = \pi b + DLP + 1(\text{constant}) = 5 + 0 + 1 = 6$ (even number).

Pyrene (Fig. 12), is a polycyclic aromatic hydrocarbon consisting of four fused benzene rings, resulting in a flat aromatic system. It has 8 $\pi$ bonds and zero (0) DLP. Here, $A = 8 + 0 + 1 = 9$ (odd number). But still it is aromatic instead of anti-aromatic because double bonded C$_{15}$-C$_{16}$ does not take part in resonance.

**Fig. 12 Geometry of Cyclodecapentaene and Pyrene**
Aromatic and Anti-Aromatic behavior of Heterocyclic Compounds along with their omission nature:

The heterocyclic compound having cyclic, planar, conjugated (i.e. all the carbon atoms having same state of hybridization, sp²) with even number of ‘A’ value will be treated as aromatic in nature and with odd number of ‘A’ value will be treated as anti-aromatic in nature.

In case of a multi hetero atom based heterocyclic compound, containing both DLP and LLP hetero atoms, Aromatic and Anti Aromatic behavior should be predicted with respect to DLP based hetero atom only.

Eg. Benzothiazole (Fig. 13), is a multi hetero atom based heterocyclic compound, containing both DLP and LLP hetero atoms. Here, for N, DLP = 0, LLP = 1 and for S, DLP = 1, LLP = 1, so, in this case ‘A’ value should be calculated with respect to S only not N. Here, A = 4 + 1 + 1 = 6 (even no) = Aromatic.

But when heterocyclic compounds contain both LLP based hetero atoms then Aromaticity should be predicted with respect to that hetero atom which contains lowest possible position number as per IUPAC nomenclature or any one of the hetero atom.

Eg. Imidazole (Fig. 13) is a multi hetero atom based hetero cyclic compound in which, N1 is DLP based hetero atom and N3 is LLP based hetero atom. In this case Aromaticity should be predicted with respect to the DLP based hetero atom N1. For N1, A = πb+DLP+1(constant) = 2+1+1 = 4 (even No) - Aromatic

Eg. Pyrimidine (Fig. 13) is a multi hetero atom based hetero cyclic compound in which, both N1 & N3 are in same environment based hetero atoms (LLP based hetero atoms). In this case Aromaticity should be predicted with respect to N1 (lowest possible position number as per IUPAC nomenclature). For N1, A = πb+DLP+1(constant) = 3+0+1 = 4 (even no) – Aromatic.
Omission behavior of some heterocyclic compounds with respect to their Aromatic / Anti Aromatic and Non Aromatic nature

Heterocyclic compounds containing different DLP based hetero atoms (one contains vacant d orbitals):

In Phenothiazine (Fig. 14), there is two DLP based hetero atoms N and S. In between N and S, since S having vacant d orbitals, so, in this case ‘A’ value will be predicted with respect to DLP based S hetero atom which contains vacant d orbitals only. Here, $A = \pi_b + DLP + 1(\text{constant}) = 6 + 1 + 1 = 8$ (even no) = Aromatic.

Heterocyclic compounds containing same DLP based heteroatom having no d orbitals:

Omission behavior of some heterocyclic compounds will be observed (Fig. 14), when there, is at least two hetero atoms (same or different) but both the hetero atoms do not have any d orbitals (such as O, N etc.) and they are in DLP based environment in the ring system.

These molecules have been studied with advanced molecular orbital techniques known as ‘ab initio calculations’. ‘Ab initio quantum chemistry methods’ are computational chemistry methods based on quantum chemistry [28].
In the case of 1,2-dioxin, 1,4-dioxin and dibenzo-1,4-dioxin there is DLP based O atoms in all the molecules but still they will be non-aromatic due to prevention of significant free electron delocalization (makes non conjugated). The π electrons from the carbon bonds and the lone pair electrons on the oxygen atoms do not overlap to a significant degree due to absence of vacant d orbitals in both O atoms in each case (pπ-dπ overlap is not possible here in conjugation). It makes these molecules non conjugated and thus allows the molecules to become non aromatic instead of aromatic (A value = even No).

In the heterocyclic compounds, where, there is two DLP based N atoms instead of two DLP based O atoms or there is one DLP N atom along with one DLP O atom, the same phenomena of non-aromatic behavior will be observed. Because, both N and O atoms do not have any vacant d orbitals, and hence pπ-dπ overlap is not possible here in conjugation.

**Heterocyclic compounds containing same DLP based hetero atoms having vacant d orbitals:**

*1,4-dithiin and 1,2-dithiin heterocyclic compounds* (Fig. 14) are anti-aromatic, here both S atoms, having vacant d orbitals, contain one DLP and one LLP and here both DLP of both S atoms participate in the delocalization. Hence, for the prediction of ‘A’ value, consider both DLP (DLP = 2). Here, A = πb + DLP + 1 (Constant) = 2 + 2 + 1 = 5 (odd No) = Anti Aromatic.

![Fig.14 Structure of phenothiazine, 1,2-dioxin, 1,4-dioxin, dibenzo-1,4-dioxin and 1,2-dithiin and 1,4-dithiin](image)

In the heterocyclic compounds, where, there is two DLP based N atoms instead of two DLP based O atoms or there is one DLP N atom along with one DLP O atom, the same phenomena of non-aromatic behavior will be observed. Because, both N and O atoms do not have any vacant d orbitals, and hence pπ-dπ overlap is not possible here in conjugation.
Aromatic, anti-aromatic and non-aromatic behavior of organic compounds including heterocyclic compounds have been illustrated with adequate number of examples in Table 6 and 7 respectively.

Table 6 Aromatic, anti-aromatic and non-aromatic behavior of organic compounds

<table>
<thead>
<tr>
<th>Organic Compound (Cyclic, Planar/Cyclic, non-planar)</th>
<th>( \pi b ) value [( \pi b ) = number of ( \pi ) bonds with in the ring system]</th>
<th>( e^p ) value [( e^p ) = number of delocalized electron pair outside or adjacent to the ring system]</th>
<th>( A ) value [( A = \pi b + e^p + 1 ) (constant)] (even no/odd no)</th>
<th>Nature of compound (aromatic/anti-aromatic/non-aromatic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene or [6] annulene (Cyclic, Planar)</td>
<td>3 ( \pi ) bonds</td>
<td>0</td>
<td>( 3 + 0 + 1 = 4 ) (even no)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Naphthalene (Cyclic, Planar)</td>
<td>5 ( \pi ) bonds</td>
<td>0</td>
<td>( 5 + 0 + 1 = 6 ) (even no)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Anthracene (Cyclic, Planar)</td>
<td>7 ( \pi ) bonds</td>
<td>0</td>
<td>( 7 + 0 + 1 = 8 ) (even no)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Cyclopropene (Cyclic, non planar due to one ( sp^3 ) hybridized carbon atom)</td>
<td>1 ( \pi ) bond</td>
<td>0</td>
<td>( 1 + 0 + 1 = 2 ) (even no)</td>
<td>Non-aromatic</td>
</tr>
<tr>
<td>Cyclopropenyl cation (Cyclic, Planar)</td>
<td>1 ( \pi ) bond</td>
<td>0</td>
<td>( 1 + 0 + 1 = 2 ) (even no)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Cyclopropenyl anion (Cyclic, Planar)</td>
<td>1 ( \pi ) bond</td>
<td>( 1 ) (For one negative charge on carbon which undergoes delocalization)</td>
<td>( 1 + 1 + 1 = 3 ) (odd no)</td>
<td>Anti-aromatic</td>
</tr>
<tr>
<td>Cyclobutadiene or [4] annulene (Cyclic, Planar)</td>
<td>2 ( \pi ) bonds</td>
<td>0</td>
<td>( 2 + 0 + 1 = 3 ) (odd no)</td>
<td>Anti-aromatic</td>
</tr>
<tr>
<td>Cyclopentadiene (Cyclic, non planar due to one ( sp^3 ) hybridised carbon atom)</td>
<td>2 ( \pi ) bonds</td>
<td>0</td>
<td>( 2 + 0 + 1 = 3 ) (odd no)</td>
<td>Non-aromatic</td>
</tr>
<tr>
<td>Cyclopentadienyl cation (Cyclic, Planar)</td>
<td>2 ( \pi ) bonds</td>
<td>0</td>
<td>( 2 + 0 + 1 = 3 ) (odd no)</td>
<td>Anti-aromatic</td>
</tr>
<tr>
<td>Cyclopentadienyl anion (Cyclic, Planar)</td>
<td>2 ( \pi ) bonds</td>
<td>( 0 ) (For one negative charge on carbon which undergo delocalization)</td>
<td>( 2 + 1 + 1 = 4 ) (even no)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Cyclooctatetraene or [8] annulene (Cyclic, Planar)</td>
<td>4 ( \pi ) bonds</td>
<td>0</td>
<td>( 4 + 0 + 1 = 5 ) (odd no)</td>
<td>Anti-aromatic</td>
</tr>
<tr>
<td>Cyclooctatrienyl cation (Cyclic, non-planar due to one ( sp^3 ) hybridized carbon atom adjacent to positive charge)</td>
<td>3 ( \pi ) bonds</td>
<td>0</td>
<td>( 3 + 0 + 1 = 4 ) (even no)</td>
<td>Non aromatic</td>
</tr>
</tbody>
</table>
Table 7 Aromatic-Anti Aromatic and Non Aromatic behavior of heterocyclic compounds with DLP

<table>
<thead>
<tr>
<th>Hetero Cyclic Compound (Cyclic, Planar, Conjugated)</th>
<th>$\pi_b$ value [(\pi_b) =number of $\pi$ bonds () with in the ring system]</th>
<th>DLP</th>
<th>A value [A = \pi_b + DLP + 1) (constant)] (even No /odd No)</th>
<th>Remark on Nature of compound (Aromatic/Anti Aromatic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrole</td>
<td>2</td>
<td>1</td>
<td>$2 + 1 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Furan</td>
<td>2</td>
<td>1</td>
<td>$2 + 1 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Thiophene</td>
<td>2</td>
<td>1</td>
<td>$2 + 1 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Pyridine</td>
<td>3</td>
<td>0</td>
<td>$3 + 0 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Indole</td>
<td>4</td>
<td>1</td>
<td>$4 + 1 + 1 = 6$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Quinoline</td>
<td>5</td>
<td>0</td>
<td>$5 + 0 + 1 = 6$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Isoquinoline</td>
<td>05</td>
<td>0</td>
<td>$5 + 0 + 1 = 6$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Compound</td>
<td>Number</td>
<td>Charge (N)</td>
<td>Aromaticity</td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>--------</td>
<td>------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Imidazole</td>
<td>02</td>
<td>01 (N1)</td>
<td>2 + 1 + 1 = 4 (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Pyrimidine (m-diazine)</td>
<td>03</td>
<td>0 (N1)</td>
<td>3 + 0 + 1 = 4 (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Purine</td>
<td>04</td>
<td>01 (N9)</td>
<td>4 + 1 + 1 = 6 (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Thiazole</td>
<td>02</td>
<td>01 (S)</td>
<td>2 + 1 + 1 = 4 (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Benzothiazole</td>
<td>04</td>
<td>01 (S)</td>
<td>4 + 1 + 1 = 6 (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Hetero Cyclic Compound (Cyclic, non-planar)</td>
<td>$\pi_b$ value ($\pi_b =$number of $\pi$ bonds with in the ring system)</td>
<td>DLP</td>
<td>A value ($A = \pi_b + DLP + 1$(constant)) (even No/odd No)</td>
<td>Remark on Nature of compound</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-----</td>
<td>-----------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Pyrazine (p-diazine)</td>
<td>$03$</td>
<td>$0$</td>
<td>$3 + 0 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Cyanidine</td>
<td>$03$</td>
<td>$0$</td>
<td>$3 + 0 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Phenazine</td>
<td>$07$</td>
<td>$0$</td>
<td>$7 + 0 + 1 = 8$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>1,2,3,4-tetrazine</td>
<td>$03$</td>
<td>$0$</td>
<td>$3 + 0 + 1 = 4$ (even No)</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Azocine</td>
<td>$04$</td>
<td>$0$</td>
<td>$4 + 0 + 1 = 5$ (odd No)</td>
<td>Anti aromatic</td>
</tr>
<tr>
<td>Azetine</td>
<td>$02$</td>
<td>$0$</td>
<td>$2 + 0 + 1 = 3$ (odd No)</td>
<td>Anti aromatic</td>
</tr>
</tbody>
</table>
Calculation of chemical bonds in Straight Chain and Cycloalkene System:

Chemical bonds (π-bonds, σ-bonds, single and double bonds) in the open chain and cyclic olefinic hydrocarbons having complex molecular formulae like $C_{176}H_{250}$, $C_{2000}H_{2000}$ can be calculated without drawing their structures by using different formulae, involving the number of carbon and hydrogen atoms only.

Calculation of chemical bonds (π bonds, σ bonds, single and double bonds) in open chain and cyclic olefinic hydrocarbons without drawing their structures have been illustrated in Table 8 and Table 9 respectively.

Table 8 Calculation of bonds in open chain olefinic hydrocarbons

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C$_2$H$_4$</td>
<td>H$_2$C=CH$_2$</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>C$_3$H$_6$</td>
<td>H$_2$C=CH-CH$_3$</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>C$_3$H$_4$</td>
<td>H$_2$C=C=CH$_2$</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>C$_4$H$_8$</td>
<td>i)H$_2$C=CH-CH$_2$-CH$_3$</td>
<td>1</td>
<td>11</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ii)H$_3$C-CH=CH-CH$_3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C$_4$H$_6$</td>
<td>i)H$_2$C=C=CH-CH$_3$</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ii)H$_2$C=CH-CH=CH$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C$_4$H$_4$</td>
<td>H$_2$C=C=C=CH$_2$</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>C$<em>{176}$H$</em>{250}$</td>
<td>-</td>
<td>52</td>
<td>425</td>
<td>373</td>
<td>52</td>
</tr>
<tr>
<td>C$<em>{2000}$H$</em>{2000}$</td>
<td>-</td>
<td>1001</td>
<td>3999</td>
<td>2998</td>
<td>1001</td>
</tr>
<tr>
<td>C$_{99}$H$_4$</td>
<td>-</td>
<td>98</td>
<td>102</td>
<td>4</td>
<td>98</td>
</tr>
</tbody>
</table>
Table 9 Calculation of bonds in Cyclo Alkene system

<table>
<thead>
<tr>
<th>Example (CₓHᵧ)</th>
<th>Cycloalkene</th>
<th>π bond / bonds (P_c) = [(2X-Y)/2]</th>
<th>σ bonds (S_c) = [X+Y]</th>
<th>Single bonds (A_c) = [(3Y/2)]</th>
<th>Double bond/bonds ([2X-Y)/2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃H₄</td>
<td>Cyclopropene</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>C₄H₄</td>
<td>Cyclobutadiene</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>C₅H₆</td>
<td>Cyclopentadiene</td>
<td>2</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>C₆H₈</td>
<td>Cyclohexadiene</td>
<td>2</td>
<td>14</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>C₇H₈</td>
<td>Cycloheptatriene</td>
<td>3</td>
<td>15</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>C₈H₈</td>
<td>Cyclooctatetraene</td>
<td>4</td>
<td>16</td>
<td>12</td>
<td>4</td>
</tr>
</tbody>
</table>

Calculation of chemical bonds in Straight Chain and Cycloalkyne System:

Chemical bonds (π-bonds, σ-bonds, single and triple bonds) in the open chain alkynes and cycloalkynes can be calculated in the same way by using different formulae, involving the number of carbon and hydrogen atoms without drawing their structure as follows.

E.g.: In cycloheptyne (C₇H₁₀), X = 7, Y = 10, therefore, number of π bonds (P_c) = (2x7-10)/2 = 2; number of σ bonds (S_c) = (7+10) = 17; numbers of single bonds (A_c) = [(2x7+5x10)/2]/2 = 32/2 = 16 and number of triple bonds (T_c) = [(2X-Y)/2])/2 = [(2 x 7 – 10)/2]}/2 = 2/2 = 1.

Calculation of chemical bonds (π bonds, σ bonds, single and triple bonds) in open chain alkynes without drawing their structures have been illustrated in Table 10.
Table 10 Calculation of bonds in open chain alkyne system

<table>
<thead>
<tr>
<th>Example for Open Chain Alkyne</th>
<th>( \pi ) bonds ([((2X-Y)/2) + 1])</th>
<th>( \sigma ) bonds ([X+Y-1])</th>
<th>Single bonds ([((2X+5Y)/2) - 3)/2]</th>
<th>Triple bond/bonds ([((2X-Y)/2) + 1)/2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{C}<em>{10}\text{H}</em>{18})</td>
<td>2</td>
<td>27</td>
<td>26</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{11}\text{H}</em>{20})</td>
<td>2</td>
<td>30</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{12}\text{H}</em>{22})</td>
<td>2</td>
<td>33</td>
<td>32</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{13}\text{H}</em>{24})</td>
<td>2</td>
<td>36</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{14}\text{H}</em>{26})</td>
<td>2</td>
<td>39</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{15}\text{H}</em>{28})</td>
<td>2</td>
<td>42</td>
<td>41</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{16}\text{H}</em>{30})</td>
<td>2</td>
<td>45</td>
<td>44</td>
<td>1</td>
</tr>
<tr>
<td>( \text{C}<em>{6}\text{H}</em>{6})</td>
<td>4</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>( \text{C}<em>{12}\text{H}</em>{14})</td>
<td>6</td>
<td>25</td>
<td>22</td>
<td>3</td>
</tr>
</tbody>
</table>

**CONCLUSION**

It may be expected that these time economic innovative mnemonics would go a long way to help students of chemistry at Undergraduate, Senior Undergraduate and Post-Graduate level who would choose the subject as their career. Experiment in vitro on 100 students showed that by using these formulae students can save up to 30-40 mins time in the examination hall. On the basis of this, I can strongly recommend to use these time economic innovative mnemonics in the field of chemical education.

**ACKNOWLEDGEMENTS**

I would be grateful to the SERB, DST, New Delhi, Govt. of India, for their financial assistance (Sanction no – SERB / F / 5537 / 2013-14 dated 27/11/2013 and D.O. No. SB / EMEQ - 014 / 2013). I want to delegate my innovative review article in the field of chemical education to my beloved father Late Anil Ranjan Das, who was also a chemistry teacher and also founder of my chemistry world (www.arijitchemistryworld.com) and my beloved mother Mrs.Sulekha Das, who has a great inspiration behind my innovational research work.
REFERENCES


EARLY CHEMISTRY MISCONCEPTIONS: STATUS AND IMPLICATIONS FOR SCIENCE EDUCATION IN ETHIOPIA

Abayneh Lemma Gurmu
PhD student, Department of Science Education
College of Education and Behavioral Studies, Addis Ababa University, Ethiopia
E-mail: misabbay@gmail.com

ABSTRACT

Misconceptions towards basic chemistry concepts have been identified at all level of chemistry education in recent studies. Such set of early misconceptions about very basic chemistry concepts were even found to be reflected by pre service and experienced in-service teachers. This implies that numerous set of chemical misconceptions kept cycling in the entire educational system. As a result, the entire science educational system is being blamed of producing learners with numerous misconceptions and low conceptual understanding. In fact, the alarmingly declining students’ performance in regional and national examination in Ethiopia (NOE, 2010), for example, could be an indicator of this situation. Moreover, such quality threatening issues are not getting fair stakeholders’ emphasis especially in Ethiopia. It was aimed, therefore, to discuss the status of early misconceptions and its implications. [African Journal of Chemical Education—AJCE 8(2), July 2018]
GENERAL BACKGROUND

Meaning of Misconception

Learners could have number of preconceptions about a given scientific phenomenon [1, 2]. Some of these preconceptions are in conflict with the scientific view [3-5]. Preconceptions which are in conflict with the scientific view are called misconceptions. Such preconceptions are also called students’ conceptions [2, 5], children’s science [6, 7], alternative conceptions or alternative ideas [1, 8-11], and as mistakes [4, 12], errors [4, 12, 13], misunderstandings [4, 13], misleading beliefs [14], misinterpretation of facts [7], and as private concepts [15], naive theories and naive conceptions or naive knowledge [5, 9], and as commonsense beliefs [14, 16].

However, it is important to understand that not all preconceptions are misconceptions. It is also necessary to underline that a misconception is not a mistake and it does not stem from lack of knowledge [1, 4, 17]. Rather, misconception is the understanding of a concept in a wrong or missing way. If a student has a misconception, his/her conception is not true or missing whereas it is true for himself/herself. Although it is wrong, it works for the student [1, 5, 17].

History of Diagnostic Researches

Exploring students’ misconception in science started as a research at late 1970s, and became more prominence at early 1980s [1]. During this period, as briefly stated by Taber [2], research groups based at the Universities of Waikato (New Zealand), Leeds (UK) and Surrey (UK) undertook extensive programs of research into children’s ideas in science, and a range of seminal studies were published. These studies effectively initiated a research programs into the nature of children’s ideas, how they developed and how teachers should respond [2]. The program was underpinned by a perspective on learning that is commonly referred to as constructivism. The interest in this area of research led to a number of books on children’s ideas in science [2, 4]. It
was also this publication that brings the issue of diagnostic researches and respective remedies in
to other European and Asians countries like Germany [10], Israel [18], Turkey [5] and Oman [19].

In Ethiopia, it was the introduction of a new ‘Master of Science Education (M.Ed)’ post
graduate program that exposed most post graduate students to the idea of students’ alternative
conceptions. In fact, few distinguished diagnostic studies have been carried out before. For
instance, Temechegn [2] carried out remarkable diagnostic studies and came up with some
conceptual change strategies. But, after the introduction of the new M.Ed program, significant
number of studies are being carried out by both former researchers [10, 11] and postgraduate
students [17] of which some of them were published. Still, the problem in our context is that most
of the studies were found to focus only on higher level chemistry concepts, almost leaving the
basic and fundamental concepts untouched [20].

Identification of Misconception

It is important to know what prior knowledge students bring to learning environment in
order to help them to construct new knowledge [1, 5, 9]. In the past and still at present in our
country, students’ prior knowledge was not considered seriously [17, 20, 21]. When misconception
diagnostic studies started to appear in the literature, science educators have focused on developing
valid and reliable methods to identify them. Therefore, variety of methods to identify students’
misconceptions are being proposed and examined for their effectiveness. These include interviews
[4, 7, 22, 23], word associations [22], open-ended questions [24], multiple-choice test [6, 25],
multiple-choice test with explanation [5, 6, 25], two-tier multiple choice test [6] and three-tier
multiple choice test [5].

Here, it should be noted that, each of the above diagnostic instruments has its own strength
and drawback. For instance, interview and open-ended test enable us to get in-depth information
on students’ pre and existing conceptions [24, 26]. But, they are disadvantageous for being time consuming to interview large number of students to get greater generalizability. Moreover, these methods also require additional training of researchers [5].

On the other hand, multiple choice test is very helpful in that it can easily be prepared, administered and scored [6]. However, such tests do not go deep enough inside into the students’ ideas on the topic and students very often give correct answers for wrong reasons. Also, multiple-choice tests were found to direct the students’ attention on information in isolation by testing one element at a time. Therefore, the larger context and structure of relationships between and among the elements get lost [5, 25]. Such tests were also found to overestimate intensity of diagnosed misconceptions as they couldn’t enable us identify misunderstanding (lack of understanding) from misconceptions [5, 17]. In this regard, Abayneh [17] found that one-tier test overestimates students’ misconception by 12% while the two-tier test overestimates students’ misconception by 8%. This implies that diagnostic tests like multiple choice items and two-tier tests are less efficient in exactly figuring out the extent of students’ misconceptions. As a result, such tests are not potential enough to discriminate misconception from lack of knowledge.

This overestimation problem can be maintained by adding a second and/or a third tier in to each item of the test by which the test becomes a two-tier or three-tier multiple choice test. In this regard, three-tier multiple choice tests are very much effective in exactly identifying missed understanding from missed conception. Because, such tests enable us know confidence of participants in their answer. Hence, only if the respondents is enough confident in his/her choice, the suspected alternative conceptions is taken as misconceptions [5, 7].

Generally, it should be noted that each diagnostic instrument has its own advantages and drawbacks. So, there is no best (single) diagnostic instrument. As a result, the use of mixed
diagnostic instruments was found to be more effective in most comparative diagnostic studies [5, 6, 17]. In most cases, three-tier multiple tests incorporated with interview were found to be effective [5].

**EARLY CHEMISTRY MISCONCEPTIONS**

As already mentioned above, early diagnostic studies which target students’ conceptions about basic chemistry concepts have got less emphasis. It is only in recent studies that basic chemistry concepts have been getting more emphasis. In these days, however, it looks like that the target of most diagnostic studies is shifting from advanced concepts entertained at higher education in to fundamental and basic concepts entertained in primary education [4, 10, 20, 21]. Because, it was being found that these early misconceptions about basic and fundamental chemistry concepts have been diagnosed in primary, secondary and tertiary education (19, 20, 21]. In this section, status of early misconceptions, commonly observed misconceptions and basic concepts which are more susceptible to misconceptions are briefly discussed as follows.

**Overall Status of Early Misconception**

Most of the conducted diagnostic inquiries were found to target more complex and advanced chemical concepts which are entertained at tertiary education. As a result, wide range of chemical misconceptions towards more advanced and complex concepts were found. In looking for remedial solutions, through further studies, some researchers suspected that those college, university students, and even teachers could have misconceptions not only about the advanced chemical concepts but also, about those very basic chemical concepts from the very beginning which they have learnt in primary education before many years [27, 28, 29]. Consequently, many early diagnostic studies have been conducted and numerous 11 – 16 years students’
misconceptions were accordingly found [1, 4, 30, 31]. In this regard, a general concepts inventory review was also came up with a detailed list of existing students’ misconceptions and suggested implication, and made available for further interventions [1, 4].

In Ethiopia too, similar diagnostic studies revealed that junior students have variety of misconceptions about the very basic chemical concepts [9, 11]. Besides, from baseline survey of USAID/IQPEP Ethiopia and national learning assessment report, it was hypothesized that presence of such intense students’ early misconceptions might be one possible source of the alarmingly declining students’ science performance in regional and national examinations [32, 33]. Some diagnostic studies carried out abroad also found to support such hypothesis. As a result, diagnostic comparative studies focuses only on basic chemistry concepts were being carried out on primary and secondary students, pre-service teachers (college and university students), in-service primary and secondary teachers [3, 19, 21, 22, 34, 35].

Muireann et al. [35], for example, found that Irish pre-service teachers have as equivalent proportion of chemical misconception as before they join the university. In their comparative and consecutive studies, they administered the same diagnostic tests each year starting from first year to the same students. Finally, they found that the same set of misconceptions diagnosed at first year still exist on the graduate teachers’ mind even after years of trainings.

Besides, Abayneh [21] carried out a comparative diagnostic study by which eighth grade students and their chemistry teachers were allowed to take a multi-tier chemistry misconception test and attend a semi structured interview. At the end, the correlation of intensity and areas of both students’ and teachers’ misconceptions about basic chemical concepts was found to be significant, average of 0.86. On the other hand, a diagnostic study (on eighth grade students and pre-service chemistry teachers’ misconception about chemical and physical changes) carried out
by the same author revealed that those college graduates have almost similar set and magnitude of misconceptions about such basic and simple chemical concepts [21].

Generally, findings of all the comparative studies shows that those early misconceptions about basic chemical concepts are dominantly found at any level and remaining in the entire educational system [3, 19, 20, 21].

**Basic Chemical Concepts Mostly Susceptible to Misconceptions**

Recent diagnostic studies carried out on early misconceptions revealed that some basic chemical concepts are more susceptible to alternative conception than others [19, 21]. As per the findings of these diagnostic studies, particulate nature of matter [9, 17, 36], physical state of matter [10, 19], chemical and physical changes [20, 28], phase changes [20, 21, 37] and stoichiometry [11, 19] are among the most susceptible basic chemistry concepts.

**Commonly Observed Chemistry Early Misconceptions**

Sets of wide range of misconceptions and naïve ideas towards these basic concepts were diagnosed and documented by respective researchers. From these, misconceptions commonly observed are summarized in the table below with source of documented studies.

Table 1: Commonly Observed Chemistry Early Misconceptions

<table>
<thead>
<tr>
<th>Diagnosed Misconceptions</th>
<th>Studies Diagnosed In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (in puddles) will disappear to nothing when exposed to sun ray.</td>
<td>Barke, 2009; Barker, 2000</td>
</tr>
<tr>
<td>Water decomposes to H and O during evaporation (or the water will split up into millions of tiny micro bits and floated up).</td>
<td>Kind (2004), Barker(2000); Abayneh (2013a; 2013b)</td>
</tr>
<tr>
<td>Water contain hydrogen and oxygen molecule in it.</td>
<td>Barke (2009), Abayneh (2013a; 2013b)</td>
</tr>
<tr>
<td>When a stick is broken, the bonds at the broken area will also be broken.</td>
<td>Suleiman <em>et al.</em> (2012)</td>
</tr>
<tr>
<td><strong>Volume of gases increases up on heating because of the swelling of their molecules, or vice versa (decrease because of shrinking).</strong></td>
<td>Barke (2009), Abayneh (2013a; 2013bb)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Sugar disappears up on dissolving.</strong></td>
<td>Happs (1980) in Kind (2004), Abayneh (2013a; 2013bb)</td>
</tr>
<tr>
<td><strong>Sugar turns to water up on dissolving.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>Sugar decomposes to its elements up on dissolving in water.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>Nail melts when exposed to moisture and air.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>Nail dissolves when exposed to moisture and air.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>CdCl₂ is toxic like Cd metal.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>The chemical composition of flame of a burning candle is just flame.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>The chemical compositions of flame of a burning candle are dust particles.</strong></td>
<td>Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>The chemical composition of flame of a burning candle is gases like Oxygen, hydrogen, carbon dioxide and so on.</strong></td>
<td>Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>The iodine crystal will melt up on heating.</strong></td>
<td>Kind (2004), Barker (2000), Abayneh (2013a; 2013b)</td>
</tr>
<tr>
<td><strong>The iodine molecule (I₂) decomposes to its constituent atoms up on sublimation.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
<tr>
<td><strong>Benzene disappears when left open.</strong></td>
<td>Kind (2004), Abayneh (2013a; 2013b), Barker (2000)</td>
</tr>
</tbody>
</table>

### Particulate Nature or Properties of Matter

| **Atom is like some kind of billiard object fully filled throughout by some other particles.** | Abayneh (2013b), Kind (2004) |
| **Atom of an element can be seen through microscope.** | Abayneh (2013b), Kind (2004) |
| **Atom of an element have physical state and color, density, melting point and so on like any other form of matter.** | Muireann *et al*. (2013), Barker (2000), Abayneh (2013b) |
| **Atoms of elements exist in liquid state.** | Abayneh (2013b), Kind (2004) |
| **Space between an atom and a molecule is filled with dust particles, germs and bacteria.** | Kind (2004), Barker (2000), Abayneh (2013b) |
| **Matter is not conserved as gases weighs less than solid.** | Muireann *et al*. (2013) |
| **Matter has no permanent aspect. When matter disappears from sight (example, when sugar dissolves in water) it ceases to exist.** | Kind (2004) |
| **Matter has a materialistic core to which various random properties having independent existence are attached. Matter can disappear, whereas its properties (such as sweetness) can continue to exist completely independently of it.** | Kind (2004) |
Weight is not an intrinsic property of matter. The existence of weightless matter can be accepted. Kind (2004)

Simple physical transformations (such as dissolution are not grasped as reversible.) Kind (2004)

**State of Matter**

A single H₂O molecule has different shape and structure in solid, liquid and gaseous state. Abayneh (2013b)

River water and ice water are different in their chemical composition. Abayneh (2013b)

Molecules (particles) of water can experience motion only in liquid state. Abayneh (2013b)

Some solids decompose, change slowly into some other (useless) substance; or mature, change slowly into some other (useful) substance. Kind (2004)


**Stoichiometry**

2H₂ and H₄ are the same in every aspect. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

2NH₃ and N₂H₆ are the same too! Abayneh (2013b)

All the reacting species combine together whatever their proportion is. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

The mass of all products of burning wood is less than that of the wood. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

Most of the mass of a large tree comes from soil. Sileshi & Barke, 2007)

The weight of a metal remains the same after combustion (ignoring the role of oxygen). Suleiman et al. (2012), Hihnston & Scott (1991)

When gases are produced from combustion reaction of a liquid and solid, the total mass decrease, even if a system is closed. Suleiman et al. (2012)

The mass of magnesium strip is greater than that of magnesium oxide which is formed after burning of the magnesium strip. Suleiman et al. (2012)

Magnesium strip loses parts of its mass as energy up on combustion. Suleiman et al. (2012)

The mass of water remains constant before and after a sugar is dissolved in it, whatever the mass of the sugar is (as if the sugar was just disappeared or lost). Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

The mass of the rust is greater than that of the nail because of addition of soil. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

The mass of the rust is less than that of the nail because the nail is just eaten up. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)

The mass of the rust is equal to that of the nail. Abayneh (2013b), Sileshi & Barke, 2007, Sileshi (2011)
IMPLICATION FOR SCIENCE EDUCATION

Implication for Primary Education

Dominance of these misconceptions about the very basic chemistry concepts in the entire educational system implies that there is some kind of gap, especially in primary education as most of these concepts are introduced and presented in higher primary education. The gap could mainly be in terms of ways of subject delivery, nature and organization of the subject contents and teachers’ competencies as all these were found to be most influential source of misconceptions [1, 4, 9]. In this regard, such dominance implies that our primary educational system enhances only memorization of terminology and definitional description. It is not giving a chance for children to observe, examine and feel the chemical phenomena beyond each learnt concept, and share, compare and evaluate their own existing understanding with others [4, 32, 38].

It rather implies that, our primary education assessment system could not identify students with desired and alternative conceptions. This, in turn, implies that our assessment activities are not incorporating diagnostic tests.

Generally, existence of such wide range and intense alternative conceptions implies that diagnosis-based educational assessment and misconceptions curing instructional system are not totally being incorporated and practiced in the existing curriculum. As a result, our primary education system could not give chance, responsibility and competency to teachers to employ continuous diagnosis-based assessment and misconceptions curing instructional activities. It should be noted, therefore, that this ignorance is obviously endangering the quality of our primary education.
Overall Implication

Even though, most of alternative conceptions are found in primary education, it was still being found that high school, college, university students and even in-service teachers have the same set of alternative conceptions about very basic chemistry concepts [3, 20, 21, 34, 35, 39]. This means that, having all these set of alternative conceptions, primary students are being able to join high schools and higher learning institutions. Moreover, they are even being able to pass higher education entrance, school leaving and teaching competency national examinations without any problem [20, 40].

As a result, it could clearly and unfortunately be understandable that our entire educational evaluation and assessment system fails to at least identifying learners with desired, alternative and no conceptions. Having felt this failure, one can realize that diagnostic type items remains ignored in our entire educational system ranging from a specific classroom level formative assessment up to a national teaching competency summative evaluation. This failure in turn implies that dominance recycling of early misconceptions is further endangering quality of our overall education.

CONCLUSION AND RECOMMENDATIONS

In this review, it was attempted to figure out how serious early misconceptions are dominantly recycling in our educational system. It also found logical that the entire educational assessment and evaluation system fails to identify learners with desired, alternative and no conceptions. This means that both our formative and summative assessment tools employed at all level are not incorporating diagnostic type instruments. Here comes the problem! This does mean
that, our educational system is not entertaining the issues of concept inventory and respective curing: no much awareness and hence, no consideration at all.

Therefore, standing on this base, it is not feasible to even think about the remedial interventions. Because, awareness and fair emphasis need to be worked on first. Hence, those well exposed science educators and researchers need to struggle towards exposing the risk of dominancy of alternative conceptions and creating respective awareness. On the other hand, the most influential stakeholders (like policy makers, curriculum experts, educational assessment and competency specialist and authorities) needs to take a breath, listen to our findings and think about it.

In doing so, the issues of diagnostic type instruments are going to be entertained in respective assessment and evaluation process. It is only in this way that we will be fortunate to make continuous diagnostic assessment and misconception curing instructional strategies part of our entire educational system. In this way, we will be courageous enough to look for, employ experiments and choose the most updated diagnostic and other curing strategies like some educationally distinguished countries.

REFERENCES
35. Muireann S., Peter E. & Sarah H. (2013). The Chemical Misconceptions of Pre-service Science Teachers at the University of Limerick: Do they change?
The African Journal of Chemical Education (AJCE) is a biannual online journal of the Federation of African Societies of Chemistry (FASC). The primary focus of the content of AJCE is chemistry education in Africa. It, however, addresses chemistry education issues from any part of the world that have relevance for Africa. The type of contents may include, but not limited to, the following:

**RESEARCH PAPERS** reporting the results of original research. It is a peer-reviewed submission that deals with chemistry education at any level (primary, secondary, undergraduate, and postgraduate) and can address a specific content area, describe a new pedagogy or teaching method, or provide results from an innovation or from a formal research project.

**SHORT NOTES** containing the results of a limited investigation or a shorter submission, generally containing updates or extensions of a topic that has already been published.

**REVIEWS** presenting a thorough documentation of subjects of current interest in chemical education.

**LABORATORY EXPERIMENTS AND DEMONSTRATIONS** describing a novel experiment/demonstration, including instructions for students and the instructor and information about safety and hazards.

**SCIENTIFIC THEORIES** describing the scientific, historical and philosophical foundations of theories and their implications to chemical education.

**ACTIVITIES** describing a hands-on activity that can be done in the classroom or laboratory and/or as a take home project.

**INDIGENOUS KNOWLEDGE AND CHEMISTRY IN AFRICA** as a special feature that addresses the relationship between indigenous knowledge and chemistry in Africa. It could be in the form of an article, a note, an activity, commentary, etc.

**LETTER TO THE EDITOR**: A reader response to an editorial, research report or article that had been published previously. The short piece should contribute to or elicit discussion on the subject without overstepping professional courtesy.

All manuscripts must be written in English and be preferably organized under the following headings: a) **TITLE**, Author(s), Address(es), and **ABSTRACT** in the first page, b) **INTRODUCTION** reviewing literature related to the theme of the manuscript, stating the problem and purpose of the study, c) **METHODOLOGY/EXPERIMENTAL** including the design and procedures of the study, instruments used and issues related to the reliability and/or validity of the instruments, when applicable, d) **RESULTS AND DISCUSSION**, e) **REFERENCES** in which reference numbers appear in the text sequentially in brackets, each reference be given a separate reference number, *et al* and other notations like *Ibid* are avoided, and finally f) **ACKNOWLEDGEMENTS**.

When submitting a manuscript, please indicate where your manuscript best fits from the above list of categories of content type. All enquiries and manuscripts should be addressed to the Editor-in-Chief: email eic@faschem.org, PO Box 2305, Addis Ababa, Ethiopia.