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EDITORIAL

Welcome to the first edition of the year 2024. This marks the 14th anniversary of the African Journal of Chemical Education (AJCE), thanks to the contributors and the reviewers. The Impact factor of the Journal has increased a lot from the 2013 data we had. The SJIF Impact Factor Evaluation in 2013 was 4.567 whereas it increased significantly in 2020 with a value of 6.91. The ones for 2021 and 2022 maintained the value 6 but showed slight decreases, 6.022 and 6.009, respectively.

We encourage chemistry educators worldwide to submit articles on issues of Chemical Education such as teaching the various areas of Chemistry (organic, analytical, physical, inorganic), polymer, green, climate change/environmental chemistry and chemistry curricula as well as assessment in chemistry. We also encourage issues on chemistry and indigenous knowledge/practice, chemical safety, natural products, and related areas.

Have a blessed and successful 2024!

**SJIF IMPACT FACTOR EVALUATION [SJIF 2020 = 6.91; 2021 = 6.022; 2022 = 6.009]
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THE STEADY STATE IN CHEMICAL KINETICS: CHARACTERIZATION IN TERMS OF THE FIRST AND SECOND STEADY STATE RATE LAWS

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ABSTRACT

Chemical reaction rate laws facilitate the design and control of chemical processes. In turn rate laws are often arrived at after assumption of the steady state approximation, whereby the steady state is characterized by the First State Rate Law, defined for reactions involving very reactive intermediates, by assuming that the concentrations of the chemical species, involved as very reactive intermediates can be eliminated by equaling their rate of formation to their rate of disappearance, in which case the concentration of the intermediate can be assumed to be constant. In this communication theoretical evidence, as well as experimental evidence from the literature, is presented showing that the steady state can also be characterized by the Second Steady Rate Law based on pseudo-zero order kinetics. In addition, equations are derived showing that the concentration of the steady state intermediate can be expressed in terms of the initial concentration of the reactant, and that the steady state approximation is valid within the kinetic limits bounded by truly first (or second) order rate laws and the truly equilibrium rate law. The article has the following highlights: 1. The steady state in chemical kinetics is defined by the First Steady State Rate Law in terms of the constancy of the concentration of the reaction intermediate, and by the Second Steady State Rate Law in terms of the constancy of the rate of reaction. 2. Both First and Second Steady State Rate Laws can be used as bases for assuming the steady state approximation. 3. The limits of the validity of the steady state approximation are defined. [African Journal of Chemical Education—AJCE 14(1), January 2024]

INTRODUCTION

Knowledge about chemical kinetics enables us to understand, design, and control chemical reactions in the laboratory, to understand and explain the actions of enzymes in biochemical systems including the human body, to design and control chemical processes in oil refineries and other chemical industries [1-3], as well as to describe drug absorption and metabolism in the human body [4]. The most important parameter in the study of kinetics of chemical reactions is the rate law or rate equation, from which we can infer the rate constant and the stoichiometry of the reaction [1]. In the derivation of the rate law corresponding to the mechanism of a complex chemical reaction it is necessary to express the concentrations of all intermediates in terms of the concentrations of the primary reactants, because intermediates are transient.

This often requires making some assumptions [5-11]. One of the most commonly employed assumption is the steady-state approximation [5-11], first proposed by Bodenstein, and independently by Chapman and Underhill in 1913 for the photochemical gas phase reaction between chlorine and hydrogen [12-14]. The resulting stationary-state method was further developed by Christiansen, Herzfeld and Polanyi [15-19]. According to the stationary-state method, the concentrations of the chemical species, involved as very reactive intermediates (I) can

be eliminated by equaling their rate of formation to their rate of disappearance, in which case the concentration of the intermediate can be assumed to be constant [15], and hence:

$$\frac{dI}{dt} = 0 \quad (1)$$

Equation 1 holds for reactions involving very reactive intermediates, since for very reactive intermediates, the rate limiting step is the formation of the intermediate, hence the rate of disappearance of the intermediate is necessarily equal to the rate of its formation, in which case the concentration of the intermediate should remain constant. Thus, in this case, *Equation 1 rigorously defines the steady state in chemical kinetics* with respect to the constancy of the concentration of very reactive intermediates and constitutes the *first steady state rate law*. Thus, the *steady state approximation*, as proposed by Bodenstein and by Chapman and Underhill [12-14], assumes the *first steady state rate law*.

The steady state approximation is invoked when an overall chemical reaction consists of a series of consecutive elementary steps. Such reactions are encountered in several chemical kinetic systems, well-known examples of which include acid-base catalysis, enzyme catalysis, nucleophilic and electrophilic substitution reactions, quasi-unimolecular reactions, and free radical reaction [6]. The steady state approximation is also used in many cases for which the first steady state rate law is not applicable, which is often difficult to justify. Although the validity of the

steady state approximation in such cases has been the subject of debate since it was first proposed by Bodenstein and Chapman and Underhill in 1913 [12-14], and has been discussed by several authors [7-11,20-27], there is no consensus as to the conditions for a steady state in chemical kinetics, the validity of the steady state assumption, its applicable time regime, or its accuracy [10,23,27,28], It is therefore important that students of chemistry, especially at undergraduate level, understand (a) what is meant by the *steady state* in chemical kinetics, (b) the *steady state approximation* and its validity, its time regime of application and the central role it plays in chemical kinetics.

This paper addresses the difficulties currently encountered with respect to the conditions for a steady state in chemical kinetics, the validity of the steady state assumption, and its applicable time regime. It is shown that (a) the steady state can also be characterized in terms of the *second steady state rate law* based on pseudo zero-order kinetics, (b) the steady state concentration of the intermediate can be expressed in terms of the initial concentration of the reactant, and (c) the steady state approximation is applicable within the kinetic limits represented by the truly first (or second) order rate law and the truly equilibrium rate law. Empirical evidence from the literature is presented in support of the validity of the *second steady state rate law*.

THEORETICAL

Consider the reaction:



The elementary steps for this reaction are shown in Table I:

Table I. Elementary steps for a first order reaction

Step	Elementary reaction	Rate constant	Transformation
1	$A \rightarrow A^\ddagger$	k_1	Activation (A^\ddagger = activated complex)
2	$A^\ddagger \rightarrow A$	k_{-1}	De-activation
3	$A^\ddagger \rightarrow P$	k_2	Reaction (P = products)

The rate of formation of A^\ddagger is given by:

$$\frac{d[A^\ddagger]}{dt} = k_1[A] \quad (3)$$

The rate of disappearance of A^\ddagger is:

$$-\frac{d[A^\ddagger]}{dt} = [A^\ddagger](k_2 + k_{-1}) \quad (4)$$

$$\text{If } -\frac{d[A^\ddagger]}{dt} = \frac{d[A^\ddagger]}{dt}$$

$$[A^\ddagger] = \left(\frac{k_1}{k_{-1} + k_2} \right) [A] \quad (5)$$

Substituting Equation 5 into Equation 1,

$$\frac{d[A^\ddagger]}{dt} = \frac{d}{dt} \left(\frac{k_1}{k_{-1} + k_2} \right) [A] = 0 \quad (6)$$

Equation. 6 is only possible if $[A]$ is constant. This is only true for equilibrium reactions at equilibrium and can only be approximately obeyed for other reactions. The question to be answered is: Under what circumstances, other than equilibrium conditions, is Equation 6 valid?

Note, $[A] = [A]_o - \Delta[A]_t$, where $[A]_o$ = initial concentration of A, and $\Delta[A]_t$ is the change in the concentration of A at any time t. When $t = 1$, i.e., in unity time of reaction,

$$[A]_{t=1} = [A]_o - \Delta[A]_{t=1}$$

When $[A]_o \ll \Delta[A]_{t=1}$

$$[A]_{t=1} = [A]_o, \text{ a constant.} \quad (7)$$

From TABLE I,

$$\frac{dP}{dt} = k_2[A^\ddagger] \quad (8)$$

In terms of $[A]_{t=1}$ and $[A]_o$, Equation 5 becomes

$$[A^\ddagger] = \left(\frac{k_1}{k_{-1} + k_2} \right) [A]_{t=1} = \left(\frac{k_1}{k_{-1} + k_2} \right) [A]_o \quad (9)$$

Substituting for $[A^\ddagger]$ in Equation 8:

$$\frac{dP}{dt} = \left(\frac{k_1 k_2}{k_{-1} + k_2} \right) [A]_o = k_o, a \text{ constant} \quad (10)$$

where k_o is a zero-order rate constant.

A zero-order reaction implies a constant or linear rate of reaction, and under these conditions,

$$\Delta[A]_{t=1} = \text{rate of reaction.}$$

i.e., the steady state as defined by Equation 6 obtains when $\Delta[A]_{t=1} \ll [A]_o$, and is defined for the constancy of the rate of reaction or formation of reaction products. Equation 10 constitutes the *second steady state rate law* and obtains when the numerical value of the rate of reaction is insignificant compared to, or significantly smaller than, the numerical value of the initial concentration of the reactant. Thus, in essence the Second Steady State Rate law is in effect the Stationary-state hypothesis applied to the rate of reaction, i.e., the rate of reaction is “at all times much less than the numerical value of the concentrations of the reactants and products” [15]. This situation is most likely to be encountered with extremely slow reactions as measured by the rate of disappearance of the reactant.

Note Equation 10 can be written as

$$\frac{dP}{dt} = \left(\frac{k_1 k_2}{k_{-1} + k_2} \right) [A]_o = k_o = k_2 A^\ddagger \quad (10)$$

Therefore

$$A^\ddagger = \frac{k_0}{k_2} = \left(\frac{k_1}{k_{-1} + k_2} \right) [A]_o \quad (11)$$

i.e., A^\ddagger is a constant related to $[A]_o$ by Equation 11.

Equation 11 limiting cases:

Limiting Case I: $k_{-1} \gg k_2$, i.e., the Second Steady State Rate Law limit:

$$A^\ddagger = K_{(A \rightleftharpoons A^\ddagger)} [A]_o \quad (12)$$

where $K_{(A \rightleftharpoons A^\ddagger)}$ is the equilibrium constant for the $A \rightleftharpoons A^\ddagger$ reaction. Thus, beyond Limiting Case I, the reaction becomes an equilibrium reaction.

Limiting Case II: $k_2 \gg k_{-1}$, i.e., i.e., the First Steady State Rate Law limit.

$$A^\ddagger = \left(\frac{k_1}{k_2} \right) [A]_o \quad (13),$$

Or

$$k_1 [A]_o = k_2 A^\ddagger \quad (14),$$

i.e., rate of formation of the intermediate is equal to its rate of disappearance as proposed by Bodenstein [12,13] [9,10], and Chapman and Underhill [14] in 1913.

Equation 14 is a First order reaction.

In between Limiting cases I and II, A^\ddagger is given by Equations. 9 and 11.

Differentiation of Equations 11, 12 and Equation 13 lead to the First Steady State Rate Law thus:

$$\frac{dA^{\ddagger}}{dt} = 0 \quad (1)$$

The only assumptions made in arriving at Equations 10 to 11 are that

1. The rate of formation of reaction intermediates is equal to the rate of their disappearance as proposed in 1913 by Bodenstein [9,10] and Chapman and Underhill [14],
2. $\Delta[A]_{t=1} \ll [A]_o$, i.e., the numerical value of the rate of reaction is insignificant compared to, or significantly smaller than, the numerical value of the initial concentration of the reactant, consistent with the Stationary-state hypothesis for chain reactions [15].

EXPERIMENTAL APPROACH

While it is difficult to demonstrate the First Steady State Rate Law experimentally, the Second Steady State Rate Law is easily demonstrated experimentally by measuring the rate of disappearance of the reactant or the rate of formation of reaction product, which should be zero order. The resulting regression curve should exhibit high linearity confirmed by a high regression coefficient. Experimental evidence for the Second Steady State Rate Law is available in the literature as discussed below.

RESULTS AND DISCUSSION

Chemical degradation of organic substances

Linear rates of reaction were confirmed experimentally in the case of chemical degradation of organic compounds (e.g., hydrolysis) by Zaranyika et al. [29-31], when aqueous solutions of tetracycline, oxytetracycline, doxycycline and chlortetracycline were studied under dark conditions and the residual concentrations of the antibiotics monitored as a function of time.

Photochemical degradation of organic substances

The existence of linear rates of reaction have also been confirmed experimentally in the case of photochemical degradation of organic compounds by Collin et al. [32]. Collin et al. obtained linear rates of photochemical degradation when aqueous suspensions of particulate black carbon (BC) and aqueous solutions of BC derived from arctic biomass were exposed to sunlight, and the partial or complete mineralization was quantified as photochemical CO₂ emission and O₂ consumption relative to dark controls. Similarly, linear rates of photochemical degradation were also confirmed experimentally when aqueous solutions of tetracycline, oxytetracycline, doxycycline and chlortetracycline were exposed under natural sunlight conditions and the residual concentrations of the antibiotics monitored as a function of time relative to dark controls (by Zaranyika et al. [29-31]).

Microbial degradation of organic substances

The existence of linear rates of reaction were confirmed experimentally in the case of microbial degradation of pesticides by Schmidt et al. [33]. Schmidt et al. conducted microbial degradation experiments with different initial pesticide concentrations and microbial populations and showed that the degradation was zero-order with respect to pesticide concentration.

Multi-phase pseudo-zero order rate law

Current formalism for the dissipation of persistent organic pollutants in the terrestrial environment assumes that dissipation follows first order kinetics, although Edwards in 1966 had observed that the dissipation of DDT in the environment rarely conforms to first order kinetics and proposed that the dissipation is instead composed of 2 to 4 linear portions [34]. The existence of multi-phase linear rates of dissipation has now been demonstrated by Zaranyika et al. [35], who recently showed that the dissipation curves of DDT in several tropical soil environments can be resolved into biphasic or triphasic linear dissipation profiles and attributed this to the existence of different speciation forms of the insecticide in the medium. Several other incidences of the existence of multi-phase linear rates of dissipation have been reported in the literature for other organic environmental pollutants including organochlorine insecticides (endosulfan I and II) [36], organophosphate herbicides (glyphosate and dimethoate) [37,38], and tetracycline antibiotics

(oxytetracycline, doxycycline, chlortetracycline and tetracycline) [29-31]. The assumption of the steady state pseudo zero-order rate law in such cases is therefore fully justified. A generalized multi-phase pseudo zero-order rate law which governs the dissipation of persistent organic compounds in the soil and aquatic environments has since been proposed to account for such dissipation curves [30], the criteria for conformance to the multi-phase pseudo-zero order rate law being: (a) each linear phase should exhibit high linearity, and (b) the slopes of the different linear phases should differ significantly.

The steady state approximation

The steady state approximation is commonly used quoting the *first steady state rate law* [7,8,11,25,26]. The use of the steady state approximation on the basis of the *second steady state rate law*, though currently not common, is fully justified. In addition, as indicated above, in between the First and Second Steady State Rate Law limits, the steady state approximation is applicable based on Equation 11. Outside these limits, the reactions follow the truly equilibrium rate law or truly first (or second) order rate laws, although in terms of the Activated Complex or Transition State theories, truly first (or second) order rate laws are extremely rare if at all possible.

CONCLUSIONS

From the foregoing discussion, the following conclusions can be made: (a) The steady state in chemical kinetics is characterized by the *first steady state rate law*, $dI/dt = 0$, for reactions involving very reactive intermediates (I), and by the *second steady state rate law*, $dP/dt = k$, for very slow reactions as measured by the rate of formation of products (P), or by $-dA/dt = k$, the rate of disappearance of the reactant (A). (b) Both steady state rate laws can be cited as bases for assuming the steady state approximation. (c) In both cases, the concentration of the steady state intermediate can be expressed in terms of the concentration of the initial concentration of the reactant. (d) The steady state approximation is applicable within the limits represented by truly first (or second) order rate law and the truly equilibrium rate law.

DECLARATIONS

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Data availability: All data generated or analyzed during this study are included in this published article.

Competing interests: The authors have no competing interests to declare that are relevant to the content of this article.

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COMBINATORIAL CHEMISTRY IN THE UNDERGRADUATE LABORATORY

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ABSTRACT

A practical is presented to familiarize the undergraduate students with a basic concept of the combinatorial chemistry. Using two different phenols as nucleophiles and dichloromethane as electrophile in basic medium, the mixtures of three possible substitution products are obtained which are easily separable. [*African Journal of Chemical Education—AJCE 14(1), January 2024*]

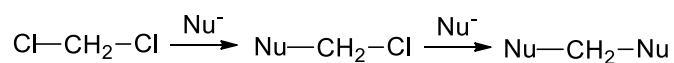
INTRODUCTION

The concept of the combinatorial chemistry was first reported by Hungarian chemist Árpád Furka approximately 40 years ago.[1] Briefly, the concept refers to obtention of the mixtures of compounds for screening rather than synthesizing and screening them one-by-one. The concept gained ample acceptance as illustrated by a number of over 8900 hits in the Web of Science as of September 2023, using a search term “combinatorial chemistry”. In addition, specialized publication venues like the ACS Combinatorial Science e.g., were launched. The mixtures of compounds obtained dubbed “libraries” are then subjected to screening to identify the active compound and to decipher its structure (“deconvolution”). Various strategies are known for this purpose and are discussed in the dedicated literature. Such approach caught attention of the pharmaceutical industry to speed-up a search for new drugs and indeed, the specialized companies offer the libraries of many thousands of compounds commercially.

RESULTS

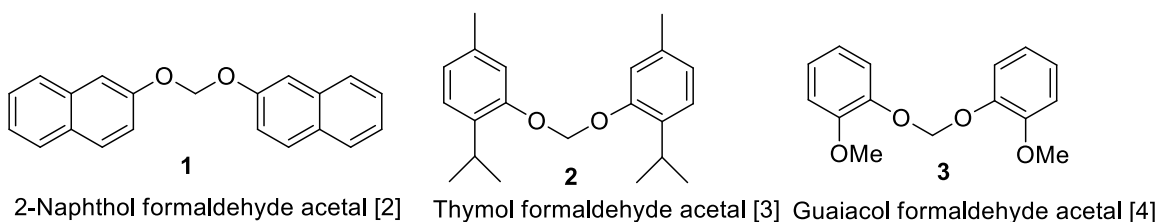
The objective of the present note is to show that a concept of the combinatorial chemistry can be easily implemented in the undergraduate laboratory as a practical, using simple and available reagents.

Dichloromethane is a common solvent, but it can be treated as a reagent due to the presence of two chlorine atoms, which can act as the leaving groups as shown in the Scheme 1. Dibromomethane, diiodomethane and bromochloromethane can be used for the same purpose, but considering a factor of price, CH_2Cl_2 is the easiest electrophile to be used.

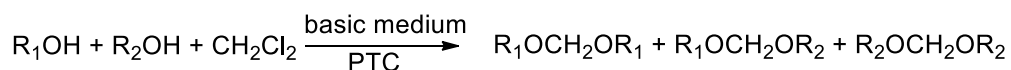


Scheme 1. Double nucleophilic substitution in CH_2Cl_2

Such substitutions gained some attention and the compounds **1-3** have been prepared in basic media by geminal substitution in CH_2Cl_2 using 2-naphthol, thymol and guaiacol, respectively, as nucleophiles.



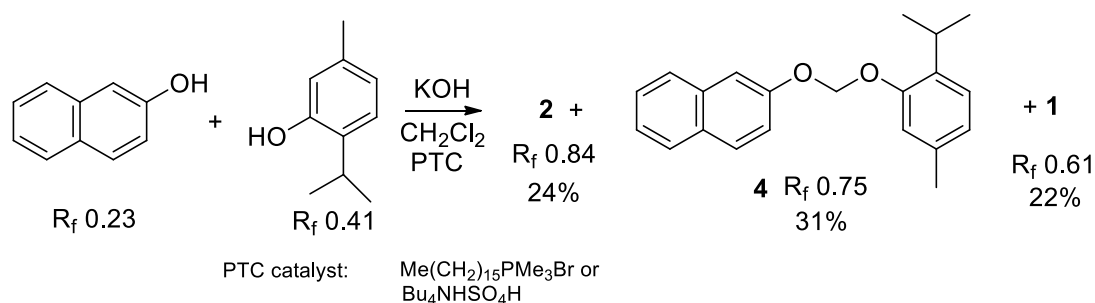
We reasoned that if two different phenols R_1OH and R_2OH were used simultaneously, a mixture of three possible products should be formed as shown in the Scheme 2.



PTC: phase-transfer catalysis

Scheme 2. Simultaneous formation of three different products: "mini-combinatorial" process

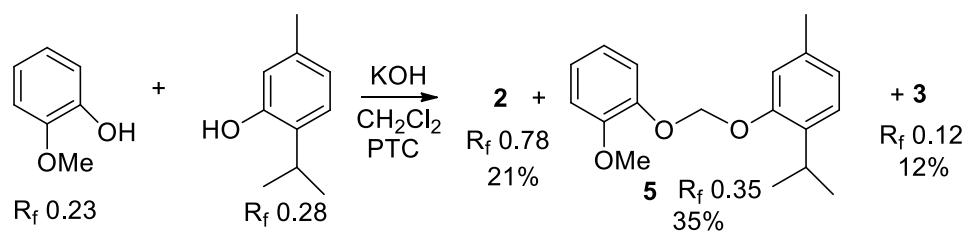
Obviously, a use of more nucleophiles would result in formation of all possible combination of the acetals. For example, the use of three phenols would result in formation of six different products. Such mixtures would be difficult to separate without the High-Pressure Liquid Chromatography setup unavailable in the undergraduate laboratories. It happens thought, that a use of combinations of two phenols only enables one to separate the products formed by simple gravitational column chromatography. Three phenols: 2-naphthol, thymol and guaiacol are the objective of the present communication since the mixtures formed accordingly to the Scheme 3 and the Scheme 4 using combinations of 2-naphthol-thymol and thymol-guaiacol, respectively, are easily separable as judged by the R_f s values of the products.



R_f s: in hexane-EtOAc 10:1 vol/vol; the yields are of the isolated products

Reaction 1

Scheme 3. Simultaneous formation of three different separable formaldehyde acetals **1**, **2** and **4**: illustration of principles of combinatorial chemistry.

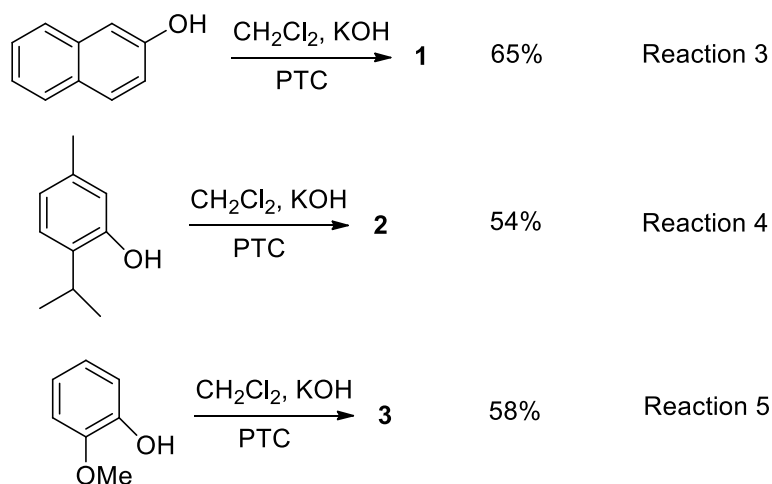


R_f s: in hexane-EtOAc 15:1 vol/vol; the yields are of isolated products

Reaction 2

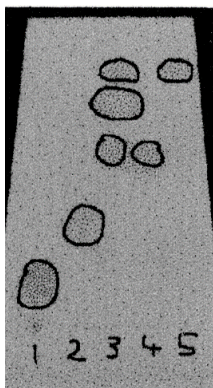
Scheme 4. Simultaneous formation of three different separable formaldehyde acetals **2**, **3** and **5**: illustration of principles of combinatorial chemistry.

The equimolar quantities of the reagents are simply incubated in dichloromethane solution with crushed KOH and the phase-transfer catalyst with or without magnetic stirring. In the latter case, the amount of KOH must be bigger, and the reaction times are longer. In one case, we left such mixture for one month without detrimental formation of the by-products. This illustrates the effectiveness of the procedure. In most cases when stirring is applied, the reactions are terminated overnight, but this is unpredictable and contingent upon the intensity of stirring and a degree of pulverization of KOH. If the unreacted substrates were still present, more PTC catalyst and more KOH should be added, and the reaction continued. The known reference compounds, the symmetrical acetals of formaldehyde, **1,2** and **3**, were prepared as shown in the Scheme 5 by the same procedures.

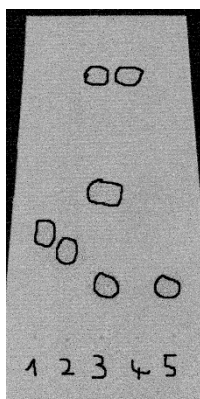


Scheme 5. Synthesis of symmetrical acetals of formaldehyde **1,2** and **3** by geminal substitution in CH_2Cl_2 , as the reference compounds.

The TLC profiles of the two processes in the Scheme 3 (Reaction 1) and in the Scheme 4 (Reaction 2) are shown in the Picture 1 and the Picture 2, respectively.



Picture 1. TLC profile (hexane-EtOAc 10:0.5 vol/vol) of the Reaction 1, line 3; 2-naphthol, line 1; thymol, line 2; Reaction 3, line 4; Reaction 4, line 5. The spots are visualized under the UV light.



Picture2. TLC profile (hexane-EtOAc 10:0.5 vol/vol) of the Reaction 2, line 3; thymol, line 1; guaiacol, line 2; Reaction 4, line 4, Reaction 5, line 5. The spots are visualized under UV light.

It is clearly seen that the two phenols reacted completely to form the mixture of three products as expected: two symmetrical acetals and one mixed acetal which shows intermediate

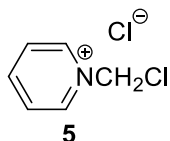
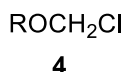
mobility on TLC. The identity of the symmetrical acetals is established by comparison of their TLC mobilities with these of the known compounds **1**, **2** and **3** obtained as shown in the Scheme 5.

At this point a basic objective of the present practical has been realized: it was shown that two different substrates form simultaneously three possible products. A time frame to conduct these experiments is as follow. To set-up of each of the alquilation one needs 1 hour. A TLC analysis of each of the reactions also requires 1 hour. This part of the procedure can be used as a basic training for the undergraduate students.

Contingent upon the conditions of a given laboratory and a level of training of the students, this practical can be continued and isolation and identification of the symmetrical and mixed acetals can be conducted. In such case 1 hour should be reserved for aqueous work-up, 6 hours for column chromatography including preparation of the silica gel column, TLC analysis of the fractions, and finally some 3 hours for crystallization and drying of the pure compounds. The students who are conversant with extraction, vacuum filtration, column chromatography and crystallization can follow this part of the procedure. The analysis of the NMR and the MS spectra is reserved for the advanced students.

CONCLUSIONS

The following points of didactic interest should be stressed. Dichloromethane is a common solvent, but it can also be treated as a reagent to realize geminal nucleophilic substitution to furnish acetals. Likewise, benzylidene dibromide, [5] benzylidene dichloride [6] and 1-dichloromethylnaphthalene [6] also furnished acetals in basic medium. In fact, chloroform with three chlorine atoms undergoes a triple substitution and obtention of triethyl orthoformate using sodium ethoxide was published. [7] Using phenols which are more nucleophilic than alcohols, one can easily obtain formaldehyde acetals in basic medium using CH_2Cl_2 even though such acetals are normally obtained in the acidic conditions from trioxane or paraformaldehyde and alcohols. A success of such double substitution is guaranteed by the impossibility of the E2 eliminations, which undoubtedly would take place with the other geminal halides, like 2,2-dihalopropanes. In addition, reactivity of the intermediate alkoxychloromethane **4** is evidently much greater than this of dichloromethane, so there is no accumulation of it by analogy to the reaction of pyridine with dichloromethane. In the latter case the reaction is slow, but a second substitution in the intermediate **5** was calculated to be ca 10000 faster than in dichloromethane. [8]



EXPERIMENTAL PART

General

All reagents were used as such without any purification. Dichloromethane was of technical grade. TLC plates coated with silica gel with a 254 nm fluorescent indicator were from Fluka. The silica gel 60 0.06 - 0.2 mm, 60 Å, for the column chromatography was from Acros. The melting points are uncorrected. The NMR spectra were recorded using Varian spectrometer at 300 MHz in CDCl_3 solutions. The exact mass spectra were recorded on an Exactive Plus HCD, Thermo Scientific.

General procedure to get simultaneously three acetals in a combinatorial mode as shown in the Scheme 3 and the Scheme 4.

Equimolar quantities of 2-naphthol and thymol, 2 eq. of each in 40-50 ml of CH_2Cl_2 , pulverized KOH (ca 1-2g) and the phase transfer catalyst (ca 0.3g; hexadecyltrimethylphosphonium bromide or tetrabutylammonium hydrogen sulfate) were magnetically stirred overnight in a round bottom flask. KOH was crushed in a mortar under protecting layer of hexane considering highly hygroscopic nature of KOH. The hexane was

pipetted out after crushing and the resulting slurry was transferred to the reaction flask with a spatula. The amount of the KOH used is only approximate. Alternatively, 7-8g of crushed KOH was used without stirring. In this case, the mixture was left for seven or more days with occasional manual swirling. The thin layer chromatography profiles are shown in the Picture 1. The KOH was removed by filtration through a sintered glass funnel and the solids were washed with CH_2Cl_2 . The combined organic phases were washed with water, dried (MgSO_4) and evaporated. The compound **1** can crystallize already at this stage and can be filtered out with the aid of a little volume of the hexane- EtOAc 5:1 vol/vol to furnish pure **1**. The solvents should be evaporated and the residual oil should be solubilized in a minimum volume of EtOAc – hexane 1:1 with warming if necessary and applied on top of the chromatography column prepared with Silica gel 60 (ca 100 g) and hexane-EtOAc mixture 40:1 vol/vol, and eluted initially with the same system until the less polar **2** and **4** come out. Then, the elution should be continued with hexane-EtOAc 30:1 vol/vol to get more **1**. The fractions which contain pure **2**, **4** and **1** eluted in this order as judged by TLC are pooled together and evaporated. The intermediate mixed fractions which might have been obtained were not purified further. The yields are shown in the Scheme 3. Instead of separating all three compounds, it is simpler to isolate only the least polar two products, which come out first. It is because the most polar compound **1**, the known naphthol formaldehyde acetal, can be isolated as

a crystalline compound before chromatography. Also, it can be easily prepared as shown in the Scheme 5 (see below).

Using the same procedure, guaiacol and thymol reacted in a combinatorial mode to form **2**, **5** and **3** eluted in this order using hexane-EtOAc 19:1 to get **2** and **5**, followed by hexane-EtOAc 15:1 to get **3**. The yields are given in the Scheme 4.

The most polar **3** can be obtained easier by reaction of guaiacol and dichloromethane as shown in the Scheme 5, Reaction 5.

General procedure to get symmetrical acetals of formaldehyde by double substitution in CH₂Cl₂ are shown in the Scheme 5

The phenol of choice 2-3 mmols is solubilized in dichloromethane (ca 40 ml) and the phase transfer catalyst is added (0.2-0.5 g) followed by KOH crushed under hexane (2-7 g) as shown above. The mixture is left overnight under magnetic stirring or left idle with only occasional manual swirling until all the substrate disappears (TLC). The aqueous work-up and evaporation of the solvent furnishes crystalline mass already at this stage. The crystalline products can be obtained by trituration with hexane, filtration and drying. In this way **1**, **2** and **3** can be easily prepared without chromatographic purification.

The analytical data of the products obtained are shown below

1 2-naphthol formaldehyde acetal: mp. 137-138° (hexane - EtOAc); lit. [9]: mp. 133-134°.

¹H: 7.77-7.25 (5 groups of signals, 14h, H aromatic), 5.94 (s, 2H, OCH₂O).

¹³C: 154.7, 134.3, 129.6, 127.6, 127.1, 126.4, 124.3, 118.9, 110.5, 91.4 (OCH₂O)

2 thymol formaldehyde acetal: mp. 49-50° (hexane – EtOAc); lit. [10]: mp. not mentioned.

¹H: 7.12-6.80 (3 groups of signals, 6H, H aromatic), 5.74 (s, 2H, O-CH₂-O), 3.29 (m of 7 lines, J=6.5Hz, 2H, CHMe₂), 2.31 (s, 6H, PhMe), 1.18 (d, J=6.5Hz, 12H, CHMe₂).

¹³C: 154.2, 136.4, 134.8, 126.0, 122.9, 115.4, 91.6 (OCH₂O) 26.6 (PhMe), 22.9 (CHMe₂), 21.2 (CHMe₂).

3 guaiacol formaldehyde acetal: mp. 90-91° (hexane – EtOAc); lit.: two articles [11, 12] do not mention about the mp.

¹H: 7.12-6.80 (three groups of signals, 8H), 5.77 (s, 2H, OCH₂O), 3.80 (s, 6H, OMe).

¹³C: 150.1, 146.2, 123.3, 120.9, 116.0, 112.2, 93.3 (OCH₂O), 55.8 (OMe).

4 2-naphthol thymol formaldehyde acetal: syrup.

¹H: 7.94-7.01 (6 groups of signals, 10H, H aromatic). 5.99 (s, 2H, OCH₂O), 3.54 (m of 7 lines, J=7 Hz, CHMe₂), 2.52 (s, 3H, PhMe), 1.39 (d, J=7 Hz, CHMe₂).

^{13}C : 154.9, 154.1, 136.5, 134.9, 134.3, 129.6, 129.4, 127.6, 127.0, 126.3, 126.1, 124.1, 123.2, 118.9, 116.2, 110.3, 91.4 (OCH_2O), 26.5 (PhMe), 22.9 (CHMe_2), 21.2 (CHMe_2).

HRMS: Cal. for $\text{C}_{21}\text{H}_{22}\text{O}_2 + \text{Na}^+ = 329.1512$; found: 329.1504.

5 guaiacol thymol formaldehyde acetal: syrup.

^1H : 7.29-6.88 (5 groups of signals, 7H, H aromatic), 5.83 (s, 2H, OCH_2O), 3.91 (s, 3H, OMe), 3.34 (m of 7 lines, $J=7.0\text{Hz}$, 1H, CHMe_2), 2.39 (s, 3H, PhMe), 1.23 (d, $J=7\text{ Hz}$, 6H, CHMe_2).

^{13}C : 154.1, 150.0, 146.2, 136.4, 134.6, 125.9, 123.2, 122.9, 120.8, 117.7, 115.1, 112.0, 92.2 (OCH_2O), 55.7 (OMe), 26.4 (PhMe), 22.8 (CHMe_2), 21.2 (CHMe_2)

HRMS: cal. for $\text{C}_{18}\text{H}_{22}\text{O}_3 + \text{Na}^+ = 309.1451$; found: 309.1455.

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TEACHERS' PERCEPTIONS AND IMPLEMENTATION OF INQUIRY-BASED LEARNING IN RURAL SCHOOLS

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ABSTRACT

An inquiry approach is a student-centered approach that seeks to enhance learners' conceptual understanding of scientific concepts and acquisition of scientific process skills. This study explored how Chemistry teachers perceive and implement the inquiry approach in rural schools. Guided by the pragmatist philosophy, the study adopted the mixed-method approach and utilized the sequential explanatory design. Data were collected from 15 chemistry teachers in the Gweru district using questionnaires, interviews, classroom observations, and document analysis. Quantitative data from the questionnaire were analyzed descriptively while qualitative data were analyzed thematically. The results of the study revealed that chemistry teachers have positive and favorable perceptions about the implementation of the inquiry approach however, its enactment in the classroom is limited extent due to a number of constraining contextual factors. In addition, chemistry teachers are still hesitant to shift from the transmissive paradigm of teaching toward a more learner-centered approach. Furthermore, the teachers were shown to have limited knowledge and skills in the practical implementation of inquiry instruction. The study recommends professional development training and support of chemistry teachers on the practical implementation of inquiry-based learning to enhance their pedagogical content knowledge and skills. [*African Journal of Chemical Education—AJCE 14(1), January 2024*]

INTRODUCTION

One of the most effective pedagogies to teach chemistry at the secondary school level is inquiry-based learning (IBL). [1] explained that the linchpin of this student-centered pedagogy is that it allows and encourages learners to be actively engaged in the scientific construction of new knowledge.

As a pedagogical approach gaining new traction in contemporary science teaching and learning, IBL requires that chemistry teachers undergo a paradigm shift in how they teach [2]. They should transition from a transmissive approach where learners are passive to an engaging pedagogy that encourages learners to be actively involved in the learning process by asking questions, designing investigations, and gathering data to formulate answers [3].

According to [4], IBL is a pedagogical approach where students actively practice several scientific processes in their quest to become knowledgeable about what science is, what science looks like, how science is done, and how it is communicated. IBL can therefore be seen as a teaching and learning approach that allows learners to actively engage in scientific practices to construct their scientific knowledge [5].

With this perspective, it means that a variety of scientific pedagogical approaches that include designed-based approaches, experimental investigations, guided discovery, hands-on,

problem-solving, project-based activities, and laboratory work; as well as conducting actual research can be used to allow learners to acquire scientific literacy [1]. As noted by [6], chemistry teachers, therefore, need to incorporate IBL in their pedagogical practices as the approach improves the interest of learners in science.

The Zimbabwean Ministry of Primary and Secondary Education (MOPSE), in its quest to address the relevancy of education for the 21st-century context, designed and developed a competence-based curriculum where learners develop an understanding of a new set of competencies that goes beyond basic knowledge and skills [7]. These sets of competencies are required by all learners so that they can be able to work collaboratively and creatively in the development of new knowledge as well as innovative products in this industrialized economy. As such, inquiry-based science learning becomes the basis for the incorporation of this new set of competencies in Zimbabwean schools. The Zimbabwe science curriculum stipulates that inquiry skills are learned through practical work where learners apply and hence understand scientific concepts. As such, learners should employ scientific skills in solving real-life problems. This study aims to determine the teachers' perceptions regarding implementing IBL for teaching and learning Chemistry at the Ordinary level in rural secondary schools in Zimbabwe.

It is critical to inquire into teachers' perceptions about IBL as a pedagogical approach within the Zimbabwean context since the epistemological perceptions of teachers and their practices are key in providing pedagogical solutions that lead to their professional development and increasing learner interest in science.

Furthermore, [8] observes that investigating teachers' thinking patterns about IBL gives potential insights into how teaching and learning can be improved for the learner's benefit. Thus, engaging in evaluating teachers' perceptions of IBL will go a long way in enacting the best pedagogical practices that promote improved learner motivation in chemistry pedagogy.

Empirical research studies have demonstrated the benefits associated with the implementation of IBL. Studies by [5] have shown that the implementation of IBL motivates and stimulates the interest of learners in science. In addition, [9] observed that the use of IBL is critical in fostering students' conceptual understanding of science.

Furthermore, [10] noted that implementation of IBL is very effective in improving the achievement and learning outcomes of students in science, students' content knowledge, higher-order thinking skills, problem-solving skills, and science process skills.

[1] summed up the benefits of IBL when they say that its implementation optimizes students' understanding of science concepts, thus leading to the acquisition of scientific literacy.

Moreover, the consistent implementation of IBL is critical in promoting students' attitudes toward science and enhancing their curiosity to learn. This will eventually reduce learners' misconceptions about science and enhance their abilities in reaching and making correct conclusions in scientific experiments [5].

Despite consensus regarding the efficacy of inquiry-based teaching, there is a low level of adoption of this pedagogy in Zimbabwean science classrooms. Instead, many Zimbabwean science teachers continue to teach science using the transmissive approach [11]. Research studies that have been conducted elsewhere also reveal a similar trend.

For instance, studies by [5] in South Africa as well as [10] in Ghana revealed that IBL is rarely adopted and used in science classrooms in these countries. [12] observed that most teachers still find it difficult to implement IBL as a result of circumstantial factors, which include inadequate resources, large class sizes, and lack of confidence and competence, that negatively affect the implementation of the approach in science teaching.

Since Chemistry teachers have the responsibility of implementing the curriculum, the views they hold about IBL are critical since they reveal insights that are important in enhancing the motivation and interest of learners in science [13]. Investigating Chemistry teachers' perceptions

about IBL will go a long way in enhancing the quality of teaching and learning and hopefully stimulate learner interest in science.

Understanding how Chemistry teachers perceive the provision and implementation of IBL in chemistry teaching at Ordinary Level could stimulate the MOPSE to develop and implement novel policies geared towards promoting better and more effective learning opportunities for learners to learn scientific inquiry [14]. The purpose of this study, therefore, was to explore how Ordinary Level rural Chemistry teachers perceive IBL and the extent to which they implement it in their classrooms.

RESEARCH QUESTIONS

The study was carried out to answer the following research questions:

1. What are Ordinary Level Chemistry teachers' perceptions towards the implementation of the inquiry-based learning approach in Chemistry teaching and learning?
2. To what extent do Zimbabwean Chemistry teachers implement inquiry-based learning practices in their classrooms?
3. What difficulties do rural chemistry teachers encounter as they implement inquiry-based learning practices in their classrooms?

MATERIALS AND METHODS

Research design

The pragmatist philosophy and the mixed methods approach were adopted and applied to guide this study. [15] explains that the mixed methods approach merges the qualitative and quantitative methods of collecting data. The merging of these two forms will enable the researcher to address the weaknesses inherent in one method by concentrating on the strengths inherent in the other method in a bid to offset biases in one method [1].

Consistent with the mixed methods approach, a sequential explanatory design was then used to collect quantitative and qualitative data [15]. This design was implemented in two phases. The first phase involved collecting quantitative data. After collecting the quantitative data, it was analyzed, and the results were used to plan for the second phase in which qualitative data was collected [15]. The qualitative data collected was then used to explain and understand the quantitative data [5].

As argued by [16], the sequential explanatory design gathers two different but complimentary strands of data consecutively. The use of qualitative data in the subsequent interpretation and clarification of the quantitative findings helps to ensure the authenticity of the

findings. The first phase of data collection involved collecting quantitative data using a survey questionnaire distributed to Chemistry teachers in the Gweru district in Zimbabwe.

The second phase of the study involved the collection of qualitative data that provided a more in-depth explanation of some of the findings that emerged from the survey questionnaire. In this regard, lesson observations, document analysis, and interviews were conducted with the teachers who participated in the survey.

Population, sample, and sampling procedures

The population of the study comprised chemistry teachers from rural secondary schools in the Gweru district, Zimbabwe. The 15 teachers who were chosen to complete the questionnaire were selected using the simple random sampling method. The researcher distributed the questionnaire to all 15 teachers in the district. Twelve teachers responded to the questionnaire.

Their teaching experience ranged between 5 to 20 years and all the teachers had an undergraduate degree in chemistry education. From the survey respondents, the researcher purposively selected 6 chemistry teachers to engage in the interviews and lesson observations. The 6 were selected on the basis that their schools were easy to access.

Data collection instruments

In this study, the main data collection instrument was a researcher-made closed questionnaire. The questionnaire was designed to obtain data on inquiry-based learning and teaching (IBL) [17]. The survey instrument was pilot tested with four chemistry teachers who did not make the sample of participants for the study. The objective of the pilot testing was meant for the teachers to identify and make comments on any items that were not clear.

The teachers did not identify any issues regarding readability allowing the questionnaire to be used in its original form. The items on the questionnaire required teachers to respond on a four-point Likert-type scale, 1 (strongly disagree), 2 (disagree), 3 (agree), and 4 (strongly agree). The items that constituted the questionnaire were structured in three main dimensions namely, teachers' perceptions about inquiry-based learning, teachers' classroom practices regarding inquiry-based learning, and teachers' difficulties in the implementation of inquiry-based learning.

Semi-structured interviews were conducted to provide data on how the teachers perceived the use the inquiry in chemistry classrooms. This enabled the researcher to collect large amounts of rich data through verbal interaction with the participants. The interview enabled the researcher to probe the participants for more detail and to seek more clarification from the participants on issues that were being discussed.

Document analysis of schemes of work and lesson plans, as well as lesson observations, were done to determine the extent to which Chemistry teachers implement inquiry-based learning practices in their classrooms. The use of multiple data collection methods as outlined by [18] facilitated the triangulation of data making the findings more reliable and valid. The data were collected after getting authority from the Ministry of Primary and Secondary Education as well as the consent of the participating teachers.

Data analysis techniques

The data that were collected using the questionnaire were analyzed descriptively by calculating the mean (average) and standard deviation for each item to determine the trends in the responses as well as establish the degree of consistency among the respondents. The qualitative data from lesson observations, document analysis, and interviews were analyzed thematically to establish themes, norms, and patterns from the respondents.

The quantitative data were integrated with the qualitative data into predetermined postulations that addressed the research questions. These were: teachers' perceptions regarding the inquiry approach, enactment of the inquiry approach in chemistry classrooms, and difficulties encountered by teachers as they enact inquiry-based learning practices in their classrooms.

RESULTS

Teachers' Perceptions of inquiry-based learning

The study obtained the perceptions of the participating teachers regarding the implementation of the inquiry approach from the responses given related to the first ten items on the questionnaire. The teachers responded to item statements on a four-point Likert scale that ranged from 1 (strongly disagree) to 4 (strongly agree). The results are shown in Table 1.

Table 1: Teachers' Perception of Inquiry-based Learning

	SA	A	D	SD	Total	mean
IBL encourages active participation and collaboration in chemistry education.	10	4	1	0	15	3.6
IBL develops learners' experimental skills.	11	2	1	1	15	3.5
Using IBL enhances creativity, innovation, and critical thinking.	12	2	0	1	15	3.7
IBL practical activities and open-ended tasks increase retention rate.	11	3	0	1	15	3.6
IBL is important because it motivates all types of students.	12	2	1	0	15	3.7
IBL enhances the design of meaningful learning experiences by learners.	10	3	1	1	15	3.5
IBL promotes conceptual understanding in chemistry.	11	1	1	2	15	3.4
IBL instills confidence in the learner.	12	1	1	1	15	3.6
IBL gives learners opportunities to apply learned chemistry content.	11	3	1	0	15	3.7
IBL makes chemistry more enjoyable.	13	1	1	0	15	3.8

The above findings demonstrate that most chemistry teachers hold positive perceptions about the implementation of inquiry-based learning in chemistry classrooms. The participating teachers agreed that inquiry implementation is an effective learning approach that encourages critical thinking, creativity, and innovation, $M = 3.7$, item 2; motivates all types of students, $M = 3.7$, item 5 and makes chemistry more enjoyable, $M = 3.8$, item 10.

The interview responses also revealed that participants have positive views and attitudes towards inquiry-based learning. This is affirmed by the following interview excerpts.

“Inquiry-based learning is useful and very effective in enhancing students’ learning since it motivates all students and makes them very active during learning.”

“It is valuable as it allows learners to reflect on what they understand in chemistry experiments, think critically about how and why things are happening in chemistry, and enable them to solve problems.

“Inquiry-based learning makes chemistry learning more interesting and enjoyable resulting in the enhancement of learners’ knowledge and understanding of chemistry concepts that are abstract.”

In the interviews, the participating teachers maintained that inquiry-based learning enables learners to apply learned chemistry content through conducting practical investigations. This is affirmed aptly by the following two interview excerpts:

“Inquiry-based learning engages learners in hands-on experiences with scientific or natural phenomena thus increasing conceptual learning.”

“Giving students opportunities to carry out practical investigations contributes to significant gains in science literacy, science process skills, and experimental skills thus leading to better acquisition of chemistry concepts.”

Teachers’ Enactment of the inquiry approach in their classrooms

To determine the extent to which chemistry teachers enact inquiry-based learning practices in their classrooms, they were requested to give responses to items that addressed the practical implementation of the inquiry approach in the classroom. The responses to the items indicated that their teaching practices were at variance with the expectations of this approach. Epistemologically, the transmissive approach is still the order of the day in their lessons. The findings are shown in Table 2 below.

Table 2: Teachers' enactment of inquiry-based learning practices in their classrooms

	SA	A	D	SD	Total	Mean
Learners work collaboratively in pairs or small groups.	1	8	5	1	15	2.6
Learners are given opportunities to explain their ideas.	3	7	4	1	15	2.8
Learners discuss and debate on the topics we are working on.	4	6	4	1	15	2.9
Learners to carry out practical activities.	1	3	4	7	15	1.9
Learners conclude from experiments they have carried out.	3	6	4	2	15	2.7
Learners do experiments by following teachers' instructions.	10	2	2	1	15	3.4
Learners design their experiments.	0	2	7	6	15	1.7
Learners test their ideas by conducting investigations.	0	4	6	5	15	1.9
Learners can work with little or no guidance.	0	4	7	4	15	2.0

These findings reveal that though chemistry teachers have favorable perceptions of the inquiry approach, they are less inclined to implement it in their classrooms. Considering item 14, “learners to carry out practical activities”, item 17 “learners design their experiments” and item 19 “learners have opportunities to work with little or no guidance”, mean scores of 1.9, 1.7, and 2.0 were obtained respectively. This indicates that the learners have limited independence, opportunities, and responsibilities to plan scientific investigations. Thus, the participating teachers still drive and control the learning process.

To gain insight into the participating teachers' epistemological orientation, the researcher conducted some lesson observations. Most of the lessons observed were content rich and the teachers used transmissive teaching methodologies that were geared towards enhancing the performance of learners in examinations. The results of the study, therefore, revealed that the majority of chemistry teachers are still to adjust and shift from transmissive pedagogies to learner-centered teaching methodologies.

It can also be noted that a few teachers are trying to enact the inquiry approach in their classrooms, hence there is a need to provide chemistry teachers with pedagogical training so that they can adopt and adapt to the expectations of this teaching pedagogy.

Difficulties teachers encounter in enacting inquiry-based learning practices in their classrooms

Regarding the difficulties they encounter, as they implement inquiry-based learning practices in their classrooms, the chemistry teachers highlighted: a lack of adequate teaching materials, equipment, and facilities ($M = 3.4$); limited IBL lesson preparation time ($M = 3.3$); large class sizes ($M = 3.1$); limited knowledge, skills, and experiences in inquiry-based learning ($M = 2.9$) as the main constraints. The results are shown in Table 3.

Table 3: Difficulties in implementing inquiry-based learning

	SA	A	D	SD	Total	Mean
IBL is not promoted in the curriculum.	1	4	5	5	15	2.1
The time to prepare IBL lessons is not adequate.	7	6	1	1	15	3.3
Teaching materials, equipment, and facilities are not adequate.	9	4	1	1	15	3.4
I have limited knowledge, skills, and experience in IBL.	6	4	3	2	15	2.9
IBL is difficult to assess.	1	4	8	2	15	2.3
I am not confident with IBL.	1	5	4	5	15	2.1
The class sizes are too large for IBL to be effective.	6	6	2	1	15	3.1

The teachers raised the concern that they had limited time to plan, prepare and conduct inquiry investigations. They indicated that more time is required to prepare inquiry-based lessons, and this is not readily available since they had heavy teaching loads. This concern raised is evident from the following interview excerpts:

“Implementation of inquiry-based learning needs a considerable amount of time.”

“We do not have adequate time to carry out all experiments as we are rushing to finish the syllabus.”

This leaves chemistry teachers with no alternative but to drill learners so that they get good grades during examinations. It can thus, be noted that while the Zimbabwean chemistry

competence-based curriculum promotes the implementation of inquiry-based learning, in reality, it gives teachers limited autonomy to teach through inquiry.

Teachers also felt that their class sizes are too large to effectively teach through inquiry. Because of this, their zeal to implement this approach is reduced as a result they resort to teacher-centered approaches for their overcrowded classrooms. The following interview excerpts help to illustrate this.

“I have many learners in my class, the class is overcrowded, and this hinders effective learning to take place”.

“It is difficult for me to implement inquiry-based learning because classes are too large, classroom management and disciplinary issues as well as plenty of time spent for preparation of materials and arrangement of the classroom”.

The effective implementation of the inquiry approach was found to be constrained by the lack of adequate teaching materials, equipment, and facilities. If schools lack material resources and facilities, teachers are forced not to implement inquiry learning effectively and consistently in their classrooms.

“Our schools are poorly resourced, we do not have sufficient resources, apparatus, and chemicals to conduct inquiry practical work”.

“My teaching using the inquiry approach is affected by lack of appropriate textbooks and infrastructures such as laboratories”.

“Lack of laboratories and finances to purchase chemicals limits the use of the inquiry approach in chemistry classrooms”.

Another concern revealed in the study was that teachers have limited knowledge, skills, and experiences in inquiry-based learning. The teachers raised the concern that they do not have sufficient knowledge and skills to prepare inquiry-oriented lessons.

“I lack skills on how to plan, prepare and implement inquiry-oriented lessons”.

“My knowledge and skills in implementing the inquiry approach in science teaching are limited, therefore I need the training to enhance my knowledge and skills.”

DISCUSSION OF FINDINGS

The results show that the participating rural teachers have favorable perceptions towards inquiry-based teaching and learning chemistry. The findings affirmed the usefulness of this approach in chemistry education. This is because its use is advantageous in that it promotes creativity, innovation, and critical thinking, motivates all types of students, makes chemistry more

enjoyable, actively engages learners, and enhances learners' knowledge and understanding of abstract chemistry concepts.

Researchers such as [19], [1]; [20]; [5]; [21] have also highlighted similar benefits of inquiry-based learning. For instance, [21] pointed out that inquiry-based learning develops creativity, innovation, communication, collaboration, critical thinking, and problem-solving skills in learners.

Consistent with the study's findings, [5] observed that inquiry-based science education is key to making science learning interesting and enjoyable, increasing learners' conceptual understanding of science and developing their experimental skills.

While chemistry teachers have favorable perceptions toward the inquiry approach, they are reluctant to adopt and enact it in their classrooms. The limited adoption of inquiry-based learning in the classroom was due to several constraining factors. Studies by [22], [5], [23] have shown a similar trend of hesitancy to adopt the inquiry approach in science classrooms.

For instance, [22] noted that even if teachers consider IBL an important and valuable approach, they still refrain from implementing it in their science classes. [24] have also observed that contextual and situational factors affect teachers' adoption of inquiry-based learning. This affirms that curriculum implementation is context specific. The findings also reveal a negative

association between teachers' beliefs inquiry-based learning and its actual implementation in the classroom.

This is consistent with the findings of [25] who observed that tension exists between the teachers' positive beliefs in favor of inquiry-based learning and the translation of these into actual practice due to internal and external concerns. Such tension hinders the successful implementation of the inquiry approach.

Several variables inhibiting the successful implementation of inquiry-based learning were identified in this study. The most frequently mentioned factors were lack of adequate teaching materials, equipment, and facilities, limited preparation time, large class sizes, as well as limited knowledge, skills, and experiences in using the inquiry approach. The findings are consistent with [23] who noted that the availability of adequate teaching materials, equipment, and facilities enhances the effective implementation of the inquiry approach.

[26] also observed that a lack of resource materials and facilities such as science laboratories, hurts the confidence of teachers to enact inquiry-based approaches in their science classrooms. On the other hand, researchers such as [27], [5] as well as [6], have pointed out that the enactment of inquiry-based learning in science teaching and learning has been hindered by the lack of laboratories in schools.

Regarding the issue of limited time for preparing inquiry-oriented lessons, [12] argued that science teachers face challenges related to inadequate time while enacting the inquiry-based learning approach. On the other hand, [28] have observed that lack of time for lesson preparation, and difficulties in classroom management complicate the process of inquiry-based learning implementation in classrooms.

The results of this study are confirmed by [29] who argues that teachers need more time to extensively prepare and implement inquiry-oriented learning activities. Because of the lack of time for conducting inquiry-oriented learning activities and the fear of not achieving educational achievements, many teachers resort to frontal teaching, traditionally the fastest way to convey information to all students. However, such information transfer does not guarantee a successful learning process.

The study revealed that large class sizes are still a factor that influences teachers' implementation of inquiry-based learning pedagogy in chemistry classrooms. The finding is consistent with [14] who observed large class sizes are tremendous constraints that challenge the ability of science teachers to implement inquiry-based learning pedagogy. [12] noted that large class sizes are a hindering factor for implementing inquiry-based learning.

In an overcrowded classroom, inquiry-based learning is hindered since the teacher is not able to assist individual students and small groups thus, the teacher resorts to the transmissive pedagogies, which are more effective and enable the coverage of curriculum content in a given time. Moreover, [22] argue that large classes can be a constraint in conducting practical experiments since inquiry-based learning requires more support for individual needs than traditional laboratory work. Such a constraint can result in predictably difficult student behaviors and result in teacher burnout.

The results of the study further show that the process of planning and implementing inquiry-based learning requires appropriate teachers' professional knowledge, skills, and experiences in inquiry-based learning. [23] argued that science teachers do not have sufficient knowledge and skills to plan and practically implement inquiry-oriented learning activities. The implication is that a positive attitude toward inquiry-based learning held by the participating teachers does not translate into actual practice in chemistry classes.

Furthermore, [29] argues that only a teacher who has the appropriate theoretical knowledge about the rudiments of the inquiry approach and has developed pedagogical-didactic-methodical competencies for its implementation in the teaching practice will realize it in a quality way and thus achieve all the benefits of such learning. Due to a lack of adequate knowledge about inquiry-

based learning, teachers often resort to traditional forms of teaching in which they participated during their formal education because they feel competent in it.

CONCLUSION

Chemistry teachers have favorable perceptions about the implementation of the inquiry approach however, they are implementing it in their classrooms to a very limited extent due to several constraining contextual factors.

Chemistry teachers still prefer the traditional teaching mode, and it is an arduous task to shift them from this transmissive approach to an engaging learner-centered one. Moreover, the chemistry teachers' knowledge and skills related to inquiry instruction are limited.

RECOMMENDATION

The study recommends professional development training and support of chemistry teachers on the practical implementation of inquiry-based learning to enhance their pedagogical content knowledge and skills.

LIMITATIONS

The study has some limitations in that the participants were drawn from rural schools in one district therefore the findings of the study cannot be generalized to urban schools and other districts in the country. Future recommendations are that a similar study be carried out including participants at urban, peri-urban, and private schools in several districts, to yield findings that will represent a variety of contexts.

In addition, the perceptions of chemistry learners about inquiry-based learning could be investigated in future research.

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ASSESSMENT OF WATER QUALITY PARAMETERS IN NYAMBAI, BRIKAMA, THE GAMBIA

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ABSTRACT

This study took place at Nyambai, Brikama, The Gambia. It was with a view to ascertaining the cause of problems with well water at the named location as complained by some inhabitants in an earlier study. Twenty well water samples were collected randomly, and nine water quality parameters were measured in each sample: nitrite, *E*-coli, conductivity, pH, hardness, manganese, cyanide, phosphate, and total dissolved solids. *E*-coli counts exceeded World Health Organization, WHO recommendation. This was attributed to violation of recommendations of distance between well water and toilet/dumpsite. All measured pH values were acidic; one sample site exceeded recommended conductivity values. All other parameters were within the National Environment Agency, The Gambia, guidelines. Nearly all wells in the study were open and had an average sanitary condition. Gambia Government needs to sensitize populace about the need to close wells and respect regulation of distance between well and dumpsite/toilet when constructing homes. Further to this, is the need to manage waste. [*African Journal of Chemical Education—AJCE 14(1), January 2024*]

INTRODUCTION

Nyambai is a part of Brikama Town in The Gambia. Its main source of water is through traditional wells, traditional/modern wells, also called hand dug wells, and government water or pipe-borne water.

The researchers in this study intended to measure water quality parameters in Nyambai with a view to ascertaining the problems by examining the measured values from collected water samples and comparing them with accepted values of water quality parameters *vis-à-vis* National Environment Agency, NEA. The Principal Investigator had earlier been involved in supervising a similar research project: Král *et al* [1]. The study done by Král *et al* mainly focused on Faraba, the permanent site of the University of The Gambia campus. Furthermore, there was the problem of inadequate materials needed to do a thorough sampling.

This study focused on water from the following sources: wells; traditional and modern. It is assumed that water from government poses no problems. This is easy to understand since well water is prone to contamination as a result of geology, for example, contamination of ground water by arsenic as detailed in several studies [2-4]. When water passes through the ground, (as in a well), it can be contaminated by what it encounters in the ground. Water from the government passes through pipes and not rocks before it reaches homes and other points of use. Further to this,

some form of treatment of water is done by National Water and Electricity Company, NAWEC. Water from wells is not treated before use; this implies that its consumption is subject to risks.

Well water may be contaminated due to closeness to a latrine, dumpsite or graveyard. According to Rural Water Supply and Sanitation Program, “*Rules and Regulations indicate that distances between sanitary facilities and dug wells should not be less than 30 meters.*” This was from a Gambia-specific project: Rural Water Supply and Sanitation Project for The Gambia [5]. Further to this, and according to National regulations on safe distance between latrines and waterpoints, the afore-stated distance is country specific, for example, in Ghana it is 50m, Burkina Faso 25m, Ethiopia 30m, Mali 15m and so on [6]. For each traditional well encountered in this research, the distance between it and a latrine/bathroom was measured. This would give an insight into one or more of the water parameters of interest, for example, *E-coli*.

Water quality is a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. The quality of drinking water is a powerful environmental determinant of health [7]. The drinking water quality management has been an important issue for over a long period of time. Water is essential for life, but it can and does transmit diseases.

The quality of water can be altered through contamination with a lot of materials. These materials may include different kinds of substances which may be unsafe for consumption. Water quality is based on certain parameters which are categorized according to whether it is physico-chemical, microbiological, or chemical parameter. Physico-chemical parameters include pH, temperature, turbidity, salinity, conductivity, total dissolved solids (TDS), color, odor and taste. Microbiological parameters are total coliform (TC) and fecal coliform (FC). The presence of *e*-coli is an indication of waste in one form or another. Chemical parameters include acidity, alkalinity, nitrate, nitrite, phosphate, potassium, ammonia, iron, chloride, and hardness.

Background

During a recent study by Král *et al* [1], some inhabitants of Nyambai complained that the water they use was not good and that it gives them problems at times; problems of stomach pains. Water quality parameters were measured in the study and twenty-one samples were collected for this purpose. One of the samples collected at Nyambai had the second highest level of nitrate and the highest level of ammonia of all the samples looked at. The nitrate level violated the NEA water quality guidelines. Afore-mentioned nitrate and ammonia levels are indicative of pollution

which may be that waste is nearby. Some parts of Nyambai are littered with a lot of dumpsites. Some of these were observed to be close to some of the wells sampled in this study.

Objectives

The study intends to

1. Find out the values of the water quality parameters pointed out earlier (with specific reference to Nyambia), and with a view to finding out the cause of the water problem in Nyambai.
2. Compare the values to that set by WHO and NEA.

METHODOLOGY/EXPERIMENTAL

The work was carried out in collaboration with the Water Resources Laboratory, Abuko. It is responsible for a lot of water related activities in The Gambia. Equipment used were manufactured by Hach, Company, America.

The following water quality parameters were investigated in this work: *E-Coli* (total and fecal), hardness, cyanide, manganese, phosphate, nitrite, pH, conductivity, total dissolved solids, (TDS), temperature, salinity, oxygen density, odor, and turbidity. In addition, sanitary survey of

each well/sample site was carried out and the distance of each well to toilet, bathroom, and dumpsite, (if seen), was measured in meters using a tape rule.

A multimeter YSI 650MDS was used to measure: pH, TDS, salinity, temperature, time, date and oxygen density. These parameters were all measured on site. Samples of well water were taken on site and transported to the Water Resources Laboratory in Abuko. All other parameters were measured in the laboratory.

A Hach spectrophotometer model DR 1900 was used to measure, phosphate, nitrite, manganese, and cyanide.

Sampling

Only water from wells were sampled. Table 1 shows each sample site, coded, and its respective latitude and longitude. This information was used to construct a map; sampling map, figure 1. For each well, an attempt was made to search for the location of the nearest dumpsite that has a refuse or some other waste. For each of such site found, its distance from the well was measured. Sanitary condition of each well was noted, as well as distance from latrine and bathroom.

Table 1 Sampling sites and their respective latitudes and longitudes

SAMPLING POINT/CODE	LATITUDE	LONGITUDE
001-ShK	13.277680	-16.656324
002-GoK	13.281896	-16.659969
003-WeK	13.28238	-16.66005°W
004-CaK	13.28205	-16.661844
005-JaK	13.281097	-16.662245
006-JgK	13.277849	-16.658717
007-ByK	13.277566	-16.655855
008-JeK	13.27718	-16.659537
009-JhK	13.27700	-16.66017
010-MaK	13.27620	-16.66075
011-KhK	13.27528	-16.66025
012-MyK	13.27454	-16.66100
013-JuK	13.275923	-16.656186
014-DaK	13.277776	-16.656327
015-SeK	13.27504	-16.655543
016-ShK	13.275153	-16.656025
017-DeK	13.273412	-16.657421
018-DoK	13.272867	-16.656297
019-MyK2	13.274904	-16.658565
020-CyK	13.274126	-16.658915

RESULTS AND DISCUSSIONS

The research took place in two stages; stage one: on-site measurement of pH, TDS, conductivity, temperature, salinity, turbidity, sanitary survey, and microbial analysis in the laboratory (*E-coli*). One objective was to ascertain cause of the water problem at Nyambai; this was found to be the presence of *E-coli* and it has been attributed, in part, to open wells, closeness to dumpsites and toilets/bathrooms. This was self-evident and expected, however, one of the sites,

sample point 018-DoK had the lowest total coliform count. This was strange because it was open and had a lot of mango trees growing all around it with roots boring into the well. The phytochemicals in the roots are probably responsible for the low count. Phytochemicals affect bacterial growth [8]. 018-DoK was the only site that had such mango trees growing around a well. This finding is very interesting.

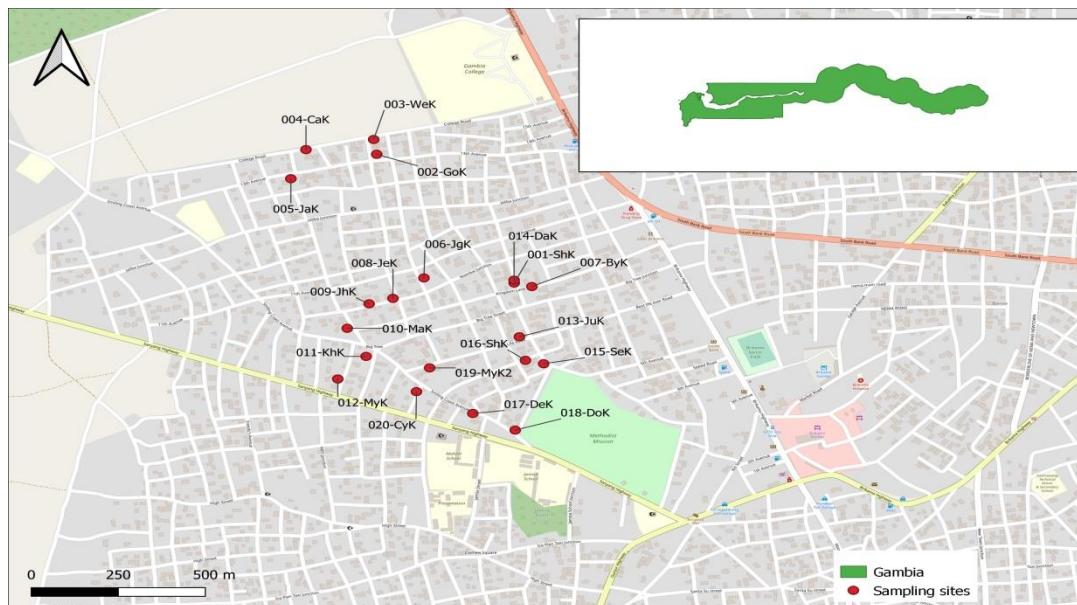


Figure 1. Sampling sites at Nyambai, Brikama

On another note, maybe the inhabitants of Nyambai should be encouraged to plant more mango trees in their compounds; this would help with the pollution by *E-coli* and climate change.

The researchers initially expected the water problem at Nyambai to be due to some other reason apart from pollution by dumpsite; geological contamination due to rock composition.

Further to the above, filter papers used in the microbial analysis were sent to a specialized laboratory for specific identification of all microbes. This would help the researchers be able to know the possible ailments associated with consumption of the water samples that had a lot of *E-coli*. Table of results of the first stage of the study is shown in table 2 below.

Table 2 Results of the First Stage

SAMPLING POINT/CODE	TYPE OF WELL	Fecal Coliform (count/sample vol.)	Total Coliform (count/100mL)	Remarks/Sanitary survey	Distance from
001-ShK	Traditional	50	more than 100	Fairly clean	Latrine – 23m Bathroom - 7.1m
002-GoK	Traditional	50	more than 100	Clean	Latrine – 20.16m
003-WeK	Traditional	50	more than 100	Close to a dump Site */Clean	Latrine – 16.5m Dumpsite – 38m
004-CaK	Traditional	50	more than 100	Close to a dump Site/ Fairly clean	Latrine – 22m Dumpsite – 17m
005-JaK	Modern	50	more than 100	Fairly clean	Latrine – 19m Bathroom – 20m
006-JgK	Traditional	50	more than 100	Dirty surroundings	Latrine – 1m Poultry farm – 17.1m
007-ByK	Traditional	50	more than 100	Clean	-
008-JeK	Modern	50	more than 100	Fairly clean	Latrine – 36.8m
009-JhK	Traditional	50	more than 100	Fairly clean	Latrine – 23m
010-MaK	Traditional	50	more than 100	Fairly clean **.	Latrine – 9m
011-KhK	Traditional	50	more than 100	Clean	Latrine – 15m

					Bathroom – 12.2m
012-MyK	Traditional	50	more than 100	Fairly clean	Latrine – 35m
013-JuK	Traditional	50	more than 100	Clean	Latrine – 22.6m Bathroom – 17m
014-DaK	Traditional	50	more than 100	Fairly clean	Latrine – 18.7m
015-SeK	Open traditional	50	more than 100	Algae seen, in and around well; bathroom and soak away very close by. / Fairly clean	Dumpsite – 26.3m Septic Tank – 6.3m
016-ShK	Traditional	50	100	Abandoned well, next to borehole supplying water. Algae in dis-used well. /clean	Septic tank – 14.5m
017-DeK	Traditional	50	more than 100	Algae grows on inside of well. Fairly clean	Latrine – 21m
018-DoK	Traditional	16	32	Fairly clean	Latrine – 28m
019-MyK2	Traditional	50	more than 100	Clean	Septic tank – 18m
020-CyK	Traditional	50	more than 100	Dirty	Latrine – 16m

*Residents complained of sand seeping into water at times.

** Whole compound throws wastewater on ground around well; wash for a living.

Table 2 has displayed the distance of each sample site from latrine/dumpsite and in few cases soak away. These measurements should help provide an appreciation of the *e-coli* results as per closeness to waste. *E-coli* colonies too many to count were simply summarized as more than 100 or 50, depending on whether it was fecal coliform or total coliform.

As part of the results of the first stage of the study, table 3 shows other parameters measured with a multimeter on-site.

Table 3 Further results of the First Stage

SAMPLING POINT/CODE	pH	Conductivity (μS/cm)	TDS (mg/L)	Salinity (%)	Oxygen Density (mg/L)	Turbidity (NTU)
001-ShK	6.58	853	555	0.42	2.9	Less than 5
002-GoK	6.60	874	568	0.43	2.31	Less than 5
003-WeK	6.45	130	84	0.06	1.18	8
004-CaK	6.13	98	63	0.04	0.32	25
005-JaK	6.15	79	52	0.04	0.25	Less than 5
006-JgK	6.91	819	542	0.04	3.40	Less than 5
007-ByK	6.95	543	353	0.26	1.63	Less than 5
008-JeK	6.84	333	217	0.16	2.32	Less than 5
009-JhK	6.79	229	143	0.10	1.75	Less than 5
010-MaK	6.85	625	406	0.30	2.30	Less than 5
011-KhK	6.65	113	74	0.05	1.43	Less than 5
012-MyK	6.68	292	190	0.14	3.21	Less than 5
013-JuK	5.86	346.6	167	0.20	2.20	Less than 5
014-DaK	6.02	149.7	61.4	0.10	1.65	Less than 5
015-SeK	5.90	634	283	0.30	1.53	Less than 5
016-ShK	6.00	1390	642	0.60	1.71	Less than 5
017-DeK	5.80	217.3	94.4	0.10	1.69	Less than 5
018-DoK	5.77	123.8	49.3	0.10	2.31	8
019-MyK2	5.90	511	252	0.20	3.81	Less than 5
020-CyK	6.00	218.8	84.7	0.10	3.38	Less than 5

In addition to table 3, odor was also looked at and all samples showed a normal result; meaning no odor was detected in any of the samples.

The second stage of the research dealt with laboratory measurement of some chemical parameters. One of the research questions was: How do the values of water quality parameters in

Nyambai compare with accepted values of water quality parameters *vis-à-vis* NEA? The following chemical parameters were investigated: total hardness, cyanide, manganese, mercury, phosphate, and nitrite. As seen in table 4, total hardness values varied from 23.2mg/L to 274.1mg/L; cyanide, manganese and mercury were all zero mg/L; nitrite values ranged from 0.000mg/L to 0.131mg/L.

Table 4 Results of the Second Stage

SAMPLING POINT/CODE	Hardness (mg/L)	Phosphate (mg/L)	Nitrite (mg/L)
001-ShK	96.5	0.62	0.001
002-GoK	181.4	3.03	0.002
003-WeK	46.3	4.66	0.002
004-CaK	34.7	0.88	0.131
005-JaK	23.2	1.09	0.004
006-JgK	274.1	2.57	0.007
007-ByK	119.7	4.57	0.000
008-JeK	42.5	0.66	0.001
009-JhK	42.5	0.55	0.001
010-MaK	69.5	1.51	0.000
011-KhK	23.3	1.46	0.008
012-MyK	46.3	1.12	0.006
013-JuK	30.9	1.08	0.001
014-DaK	23.3	2.76	0.000
015-SeK	34.7	1.66	0.001
016-ShK	46.3	0.83	0.000
017-DeK	84.9	1.58	0.002
018-DoK	23.2	6.84	0.000
019-MyK2	42.5	7.14	0.000
020-CyK	38.6	0.85	0.000

Sample 004-CaK had a value of 0.131mg/L; the NEA standard for nitrite is 0.03mg/L, for WHO it is 3mg/L; 004-CaK exceeded the NEA standard but did not for WHO standard. Phosphate

0.55mg/L to 4.66mg/L. Sample 018-DoK had the lowest e-coli count, (first study); in this work, it was one of the sites with the lowest total hardness values. Similarly, it also has one of the highest values of phosphate ion.

NEA standard for phosphate is 0.4mg/L. All the sampling sites exceeded this standard. This is noteworthy. Sample 019-MyK2 had the highest level of phosphate in this regard. Sample 009-JhK had the lowest value.

NEA standard for hardness is 200mg/L. Sample 006-JgK was the only site that exceeded this standard. It was one of two sampling sites with the dirtiest surrounding. Sample 007-ByK had a value of 119.7mg/L, approximately 200mg/L. Some of the sampling sites were used for commercial purposes, washing clothes as a means of livelihood. From the values, one can conclude that the water is economically viable. Hard water is bad for the business of washing clothes for a living.

NEA standard for manganese is 0.05mg/L. All sampling sites complied with this standard. Thus, this heavy metal is not a problem.

NEA standard for cyanide is 0.05mg/L. None of the sites violated this standard. Researchers did not know what to expect, in a general sense; they expected high levels of heavy metals for sites close to dump sites.

Regulation for guidelines stipulates a distance of 30m from a well to a toilet; only two sampled sites did not violate this guideline. 100m is the distance for a dumpsite; none of the sampled sites close to dumpsite was in agreement with this figure. This is noteworthy.

pH values of all the samples were within the guidelines of NEA and WHO. Conductivity value for sample 016-ShK was the only sample that was outside the NEA stipulated value of 1300 μ S/cm.

Table 5 shows a summary of some of the values for some water quality parameters obtained along with standards for WHO and NEA

Table 5 Summary of Values obtained for some water quality parameters and standards for WHO and NEA

Water Quality Parameter	NEA standard	WHO standard	Range of Values obtained
Nitrite	0.03 mg/L	3 mg/L	0.000 – 0.131 mg/L
<i>E</i> -coli	0 count/100mL	0 count/100mL	16 – 50 count/100mL(FC)* >>100counts/100mL (TC)**
Conductivity	1300 mg/L	50 - 500 μ S/cm	79 - 1390 μ S/cm
pH	5.5 to 8.5	6.5 – 8.5	5.77 – 6.95
Hardness	200 mg/L	1000mg/L	23.2 – 274.1mg/L
Manganese	0.05 mg/L	0.5mg/L	0.000mg/L
Cyanide	0.05 mg/L	0.1mg/L	0.000mg/L
Phosphate	0.4 mg/L	Less than 1mg/L	0.55 – 4.66mg/L
Total Dissolved Solids		300mg/L	52.0 – 642mg/L

CONCLUSION

Sample 018-DoK had the lowest count of *e*-coli and it was attributed to the presence of a lot of mango trees growing around the well. Nearly all the wells were open with and without covers. The researchers in this study advice that people should be sensitized about the importance of closing their wells, if they have covers and if not, making a cover for it. This is important because an open well means that microbes can easily enter the water from the air and pollute it. Further to this, some of the sample sites had dumpsites close by. People should be advised to stop dumping waste close to their wells as this eventually pollutes the water, especially during rainy season when runoff water percolates into the well.

Violations of the recommended distance from well to toilet is such that the inhabitants cannot go back and begin to rebuild their homes, however, Government of The Gambia can sensitize the populace about this and in addition, enforcing it as Law. The afore-mentioned violation as regards distance from a dumpsite is noteworthy; what is recommended is for a better waste collection policy and drive; this would do away with the indiscriminate dumping of waste which is the initial catalyst for a dumpsite.

Output

1. The following departments should work together to educate the public about the importance of closing their wells and also cleaning the area around it: The Department of Water Resources, Public Health officials, National Environment Agency and the Research Directorate, UTG. This study was carried out in a small community where some inhabitants use well water; other communities exist that also use well water and most likely have the same problems as regards open wells.
2. Further to 1 above, Village Heads, *Alkalos*, should be included in the exercise in order to make it more effective. This exercise should be Nation-wide.

Implications for Chemical Education in Africa

- There is a need for Africans who own and use well water for drinking to be educated about the negative implications of leaving their wells open. Opening wells makes it possible for microbes to enter and contaminate water inside.
- It would be good practice for people who own wells to plant trees around them.
- Latrines and bathrooms should be situated at respectable distances that do not violate the WHO standard of distance from latrines to source of potable water.

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ETHICAL ISSUE

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

COMPETING INTERESTS

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

AUTHORS' CONTRIBUTION

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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ESSENTIAL NANOSCIENCE IN GRADUATE EDUCATION: AN OUTLINE

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ABSTRACT

The purpose of this paper is to impart cross-disciplinary guidance and training to students in the rapidly developing nanoscience and nanotechnology area. This specially designed course projects a prismatic view to introducing the synthesis, properties, structure, bonding, and important applications of nanoparticles in different fields in meeting academic objectives. The various fundamental and applied aspects of nanoparticles are discussed that are of interest in the chemical education experience and also cover environmental concerns for their educational value. Seminar presentation, laboratory experimentation, and careful assessments of students' performance constitute very important components of this graduate-level course to enhance subject matter knowledge and other sector-specific skills. The syllabi developed signify an attempt to help students to understand the basic importance of nanoparticles in different fields and create proper awareness about the applied aspects in a wide range of applications through illustrative examples. This paper attempts to promote integrative learning to impart better education and outline the four important participatory aspects (four L's) of learning-lecture, laboratory, library, and life to bring about educational transformation in students under a single scientific theme. The course content and structure promote the students to get ready for the real challenges of actual interdisciplinary research in the current world environment as an effective approach. [*African Journal of Chemical Education—AJCE 14(1), January 2024*]

INTRODUCTION TO NANOPARTICLES

Purpose and Importance

Nanoparticles have dramatically diminished size in the range of 1 -100 nm and they exhibit size-dependent properties that are different from those of bulk materials. For example, copper nanoparticles having a physical size of less than 50 nm are very hard while conventional bulk copper displays ductility and malleability. The upwardly mobile subject of nanoscience is one of the interdisciplinary research and development domains and is expected to induce significant impacts on the quality of life (Fig 1).

The recent developments in high-precision instrumentation coupled with advances in special synthetic techniques provided insight into the unusual physicochemical properties of nanoparticles. The approaches, concepts, and methods of chemistry, physics, biology, and material science are closely interlinked, and the interdisciplinary character of nanoscience requires higher education and training in a different direction. There is exponential progress in the number of publications and patents in the past decade and led to a greater understanding of the nature of nanoparticles. The *Journal of Nanoparticle Research* is the first interdisciplinary journal devoted to nanoparticle science and technology. In recent years, *Nano Today*, *Nano Letters*, *Nature Nanotechnology*, *ACS Nano*, *Nanoscale Horizons*, *International Journal of Nanoscience*

International Journal of Nanotechnology, Internet Journal of Nanotechnology, Journal of Nanobiotechnology, Nanomedicine Research Journal, Journal of Nanoanalysis, and Virtual Journal of Nanoscale Science and Technology have joined this ever-growing list.

The 13th international conference on nanotechnology was held in August 2022 in Prague, Czech. Republic. The most interesting development is the emergence of nearly a hundred fifty important books on various intrinsic aspects of nanoscience and nanotechnology as their broad theme. The *Encyclopedia of Nanoscience and Nanotechnology*, *Handbook of Nanostructured Materials and Nanotechnology*, and *Advanced Catalysis and Nanostructured Materials* provide a good perspective and an immense amount of information in this rapidly developing area of research [1-7].

There is a steady increase in the number of technical reports and other periodicals in the discipline that help in information dissemination. *Recent Patents on Nanotechnology* is a journal started in 2007 that provides patent information useful for researchers in the area. These current developments continue to exert a powerful impact on research and will help us to extend cross-disciplinary education for the integral growth of students.

The physical and chemical properties of nanoscale materials are different from those of bulk materials. Because of the extended network of pi-bonds, carbon nanotubes conduct electricity

and have great tensile strength. As these nanoparticles find a large number of applications in different fields, an increasing number of industries are involved with the production and use of nanoparticles in the stable form [8-21]. This frontier field is currently receiving very high levels of research funding from various private industries, academic institutes, and different governmental organizations all over the world. Several websites act as valuable electronic sources of information on different aspects of nanoscience including example problems and emerging opportunities [22].

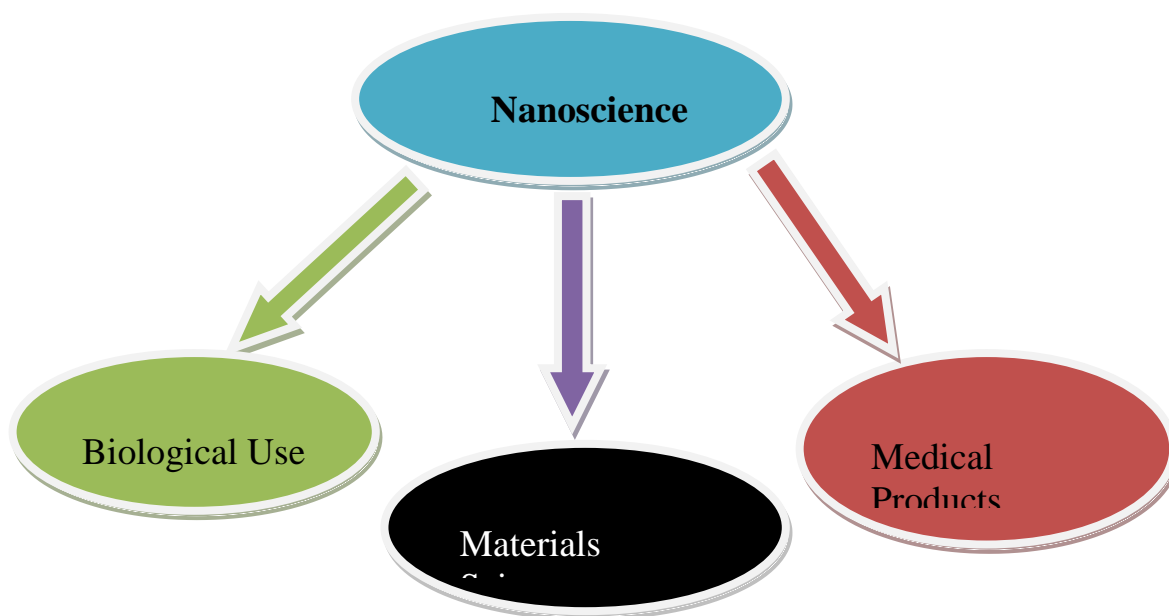


Fig 1. The interdisciplinary nature of nanoscience provides exposure to developing multi-skills

This paper is intended to inspire, introduce, motivate, and offer insight into both basic and applied aspects of nanoparticles to the students and to provide experiments to demonstrate their synthesis [23-40], characterization [41-47], and applications [48-94] as an integral part of the learning process. This course material can be useful in conducting short-term courses, and programs in training and education for the benefit of students and teachers at different progressive academic institutions or for those in advanced chemical learning centers or specialized executive education programs to reignite young minds. This paper could provide a ready reference with a broad perspective that is of interest to the readers of the scientific community working in diverse fields like education, environment, and healthcare and acts as a catalyst for further growth of the subject knowledge.

This paper may also serve as a rough guide for upgrading the general chemistry curriculum into which modern nanotechnology components could be incorporated to create awareness about the importance of nanoparticles in different areas. In addition to teacher-led training by intensive lecturing, internet-based learning as a tool in enhancing teaching-learning interactions offer flexibility and anywhere-anytime availability. There is an attitudinal sea change in the learning styles of younger generation students in the recent past and this course provides an outline to acquire the necessary skills for success in the field of an e-learning platform. Such a paper could be

used as a text in a slightly different context of the virtual course in the electronic college, one useful for the self-learning type of students for their further educational refinement and as a part of virtual education conferences to keep in tune with the contemporary developments in the field. This course is different in having a healthy mix of broad activities that pertain to theoretical lessons, intense laboratory practice, resource materials, and real-life examples is useful in specialist institutions in the education sector for those having a sound scientific background.

Content Organization

This paper is organized into twelve major sequential sections, each dealing with a healthy dose of particular aspects of nanoparticles (see Appendix 1). The topic is divided into smaller sections to enable the instructor to impart subject knowledge in sufficient detail during class hours and a clear distinction is made between different interrelated sections. The importance and scope of nanoparticles are presented at the beginning of this guided tour of the specialized field, extending further to Nature to instill students' fascination for Nature and its creations. The general classifications of nanoparticles discussed immediately after lessons from the nature section help the students to develop the skill of visualizing nanoparticle behavior by mental models. Current approaches to the production of nanoparticles are described in the subsequent section.

Further, particular physical techniques used in their characterization such as scanning electron microscope (SEM), atomic force microscope (AFM), and Fourier-transform infrared spectroscopy (FTIR) are discussed. The physical properties such as mechanical, thermal, electrical, electronic, optical, and spectroscopic properties and their chemical reactions classified under different subheadings are described in the subsequent two sections. The structure and bonding aspects, as well as their use in medicine, materials science, and catalysis, are explained as we proceed further, and other uses of nanoparticles are discussed at the end of this section. The list of ten experiments related to synthesis, property measurement, and different types of applications that could be conducted within the course is incorporated to impart experimental skills [95-100]. Also, the student's seminar component that provides them a platform to perform is included at the end.

A few relevant questions listed before the reference section provide further practice to enhance their understanding and appreciation of nanoscience and assists them to gauge their understanding of the topics covered through inquiry-based learning. The large number (150) of pertinent references listed at the end of the article act as a resource to incorporate the educational values of continuous research and development in students to prepare them for the challenges in the field. These cross-references provide useful related information or more detailed discussions on

the subject for further studies or consultation to develop sector-specific skill sets that build confidence in them through visualization techniques.

The introductory section creates awareness among the students about the importance of nanoparticles in various disciplines. Learning objectives are followed by the instructional structure section that has a checklist of how to proceed with nanoscience presentation and evaluates students' overall performance periodically. The two subsequent sections deal with syntheses by several methods and common physical techniques in structural analyses that have become necessary components. The section on structural aspects is followed by one of bonding considerations including a subsection on stabilization versus aggregation. Another section that contains all the essential information on application orientation has been incorporated and it is extremely important to highlight characteristically interesting applications as technical topics to teach including application-based conceptual knowledge. The theory class should be supplemented by practical experiments in the laboratory as a single demonstration experiment can teach as much practical knowledge as several books on the subject can reveal.

It will be in the interest of the students to improve their skills by performing experiments individually or in batches under supervision to obtain hands-on learning experience. Demonstration experiments will have an impact on the minds of students as they are exposed to the

latest experimental techniques and several sophisticated instruments. These laboratory experiments are related to the lecture material to a significant extent that helps maintain the continuity in the discussion and is designed to suit graduate-level students. While conducting the experiments, students can visualize each step, write down observations and perform calculations to prepare the laboratory reports that will help them to retain information for a long time. The experiments have been carefully selected to provide the students with a wide range of laboratory experience in the nanoparticles to fill in the gaps in the learning flow. The concluding section provides the flavor of the current trends and the prescription of scientific growth prospects.

The special features include seminar presentations and practical components to improve the process of analytical observation, increase awareness, raise their enthusiasm and interest, enhance analytical capacity, and inspire and motivate young students. These practical demonstrations or experimentation reinforces theoretical concepts taught in the classroom essential for the integral growth of the students. The list of selected references helps the reader to consult original papers, review articles, patent documents, periodicals, and internet resources including specialized web content sites or books for further exposure to all relevant aspects encompassing different domains of nanotechnology. In this context, a well-stocked library comprising a collection of relevant

textbooks, reference books, educational and research journals, scientific periodicals, and bound volumes of previous journals helps in implementing the higher education process.

In addition to the supplementary use to enrich their subject knowledge, the students can learn a lot through a daily dose of reading books in the library on wide-ranging topics. Another interesting feature is that a series of relevant questions have been incorporated to encourage the students to think about the significance of the principles or the practical aspects and to inculcate a spirit of inquiry in learners. It can be used for self-assessment that can promote a poor or low performer to a high performer and initiate subsequent interactions with inspirational instructors or teachers for further clarification. The questioning process provides an opportunity to answer questions that rekindle the learning spirit and allows the active learners to conform to an expected level of the answer. The review questions include conceptual questions based on principles and problem-solving ability questions designed to enhance students' scientific reasoning skills. In summary, this is a higher education course with a difference as it includes theory, practical, learning resources, and life exercises, all in a cohesive approach in a scientific training model intended as a guide for the students (Fig 2). This assumes special significance in a paper with each of the four principal factors that keep the students engaged in a range of learning matters under the 'all-in-one' concept. In addition to the flow of the detailed topical narratives, we have also

incorporated informative visual representations within the context of each section to create a mental picture. This acts as a special pedagogical feature that summarizes the principal points, key concepts, or important ideas to alert students to further discussions.

These simplified schemes contextualized in capsule format aid an easier and better understanding of the fundamental principles by visual impact and the distinctive style of illustrations also helps avoid monotony while reading. Selected websites and references with an emphasis on textbooks, review articles, and commentaries, act as a resource for homework. In a nutshell, such courses provide a stimulus for students to think outside the narrow boundaries built around specialized courses and trigger a broad-spectrum thinking mechanism that results in enough motivation.

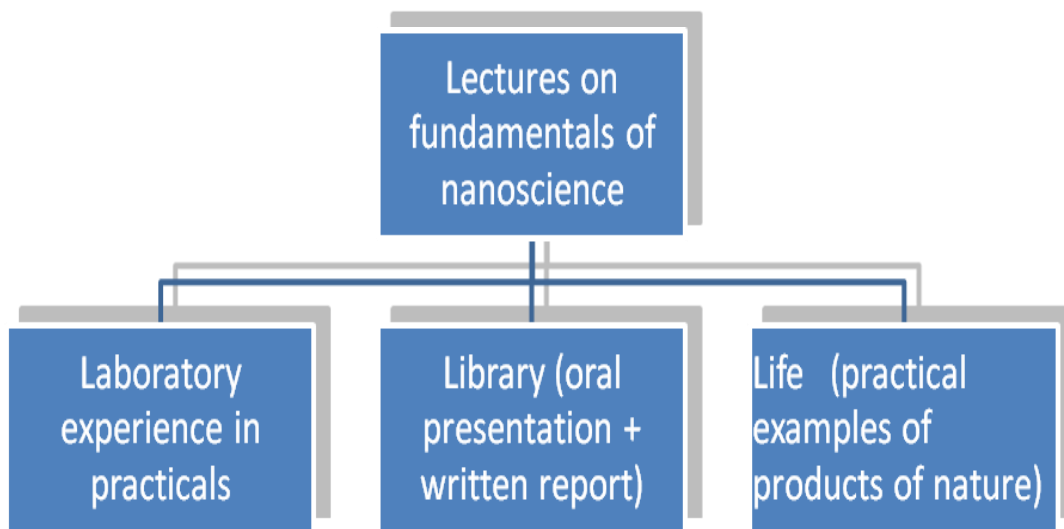


Fig 2. Highlights of the essential features of this courseware include four different inter-connected activities conducted in an integrated manner.

REVIEW QUESTIONS

1. Define and describe the following terms: Nanoscience, Nanotechnology
2. Differentiate between nanoparticles and nanomaterials.
3. Discuss the three main classification schemes of nanoparticles with suitable examples.

4. Explain the working principle of the TEM. What useful information can be extracted from the image analysis?
5. Describe the major features of the CNT and list its applications in various fields.
6. Justify the statement “Nature is an abundant storehouse of the creation of nanoproducts”
7. Explain why the optical properties of nanoscale materials often differ from those of the same materials in the bulk state with suitable illustrative examples.
8. Discuss why nanoparticles have a lower melting temperature far below that of the bulk material.
9. Write a technical essay on natural nanoparticles or nanomaterials.
10. Justify the statement “Developments in nanoengineering can bring constructive applications in many areas as well as destructive atmospheric pollution.”
11. Discuss problematic environmental consequences of large-scale production of nanoparticles.
12. What are two broad approaches to synthesizing nanoparticles? Name and discuss four methods of preparation. Discuss the advantages and disadvantages of wet methods.
13. What have been the trends in nanoscience research in recent years?
14. Explain the principle of AFM and its impact on our understanding of nanoparticles.

15. Briefly discuss the statement “Substances in their nanoparticle form interact differently from their physical form”.
16. Describe bonding concepts and perspectives in a nanoscience sense.
17. Give a critical explanation of the structural aspects of nanoparticles.
18. Comment on “Theoretical investigation of the structure of nanoparticles”
19. Describe the difference between particle stabilization and particle aggregation. List the factors that may disturb the stability.
20. Write a brief essay discussing the importance of electron microscopy techniques in the characterization of nanoparticles.
21. What properties allow nanoparticles to act as better catalysts?
22. Summarize some of the major synthetic techniques leading to the formation of nanoparticles.
23. Describe two examples in which the physical properties of nanoparticles differ from those of macromaterial counterparts.
24. Suggest design and planning principles of nanosystems that appreciate their usefulness. What methods are commonly used for the preparation of nanoparticles?
25. Explain particle stabilization versus aggregation with a couple of parameters with special reference to the bonding.

26. Summarize the principal uses of nanoparticles in the industry.
27. Discuss the sources and impacts of solid nanoparticles. Describe the implications of attempts to produce nanoparticles on an industrial scale.
28. Elucidate ideas and ideals of nanoparticle production from a broad-based global perspective.
29. Write a two-page introductory essay answering each of the questions (i) What is the relationship between the nanosystem and nanoparticles.
(ii) How do temperature and solvent affect the state of aggregation?
(iii) What are the advantages of composite nanomaterials?
30. Give a detailed account of how the control steps help in the entire process of reduction of anthropogenic nanoparticulates.
31. What selective factors lead to unique behavior, in nanomaterials?
32. Name the physical stabilization parameters of concern to nanoparticle design considerations.
33. Discuss the advantages and disadvantages of recent advancements in nanoscience.
34. What are zero-, one-, two-, and three-dimensional nanomaterials?
35. Write the principles of the working of SEM and TEM.
36. Explain top-down and bottom-up approaches to producing nanomaterials.
37. Describe how oxide nanoparticles can be obtained by the sol-gel technique.

38. What is a nonodrug delivery system? What are the special structures/features of the system?
39. What are some of the most interesting nanoparticles found in nature?
40. Discuss the societal and environmental impacts of nanotechnology.

The students actively participated in the true spirit of the learning process as indicated by the chain of positive responses received in the classroom. Their academically focused sustained involvement in practical and seminar activities was observed, which suggests higher levels of alertness and considerable interest. Their performance was evaluated continuously for learning efficiency through regular in-semester tests for the portions covered till that time and an end-semester examination incorporating the entire syllabus.

Another exercise that is undertaken is that the students have to submit a written seminar report for evaluation as part of the examination process and oral presentation was assessed for overall quality, domain-specific information content, presentation skills, and ability to answer questions. A sample of course handouts and laboratory manuals are provided as supporting materials to promote active learning culture among the student community. As part of the industry-interface initiative, invited lectures on a particular topic by individual experts in nanotechnology from industries are arranged to update the knowledge and help students to expand their subject range and industrial inclination. Another academically stimulating activity that provides feedback

is to ask one or two students to summarize the portion covered in the previous class and ask typical cross-questions about the topic to get oral short answers. This continuous exercise led to a stimulating discussion about related scientific aspects from a broad perspective and provided the students an opportunity to improve their scientific skills through an open-ended interaction that was reflected in greater student participation and higher performance.

This question-and-answer activity has attracted some interest and excitement, acting as an exercise in education, an increasingly important part of students' transformational process. The focus on key learnings actively integrated into institutional initiatives helped both the value addition by imparting good education and unlocked the student's scientific potential to some extent by motivation. This vibrant course format with quality content allows broad access to the learning process by being opensource in nature and the students exhibited remarkable enthusiasm and continued interest during the actual course delivery process. More emphasis was placed to identify and suggest the students follow a clear path to performance improvement during the in-semester tests and subsequently, they were graded to explain their relative performance at the end of the end-semester examination.

The entire class was able to meet certain standards through proper interactions during the course through a direct approach and the students spent a substantial amount of time and expended

a quantum of energy in learning the subject that induced them in a new direction altogether. The unique format and intrinsic strength to capture the essence of the special field coupled with better scientific growth opportunities have triggered an enhanced interest among students. The various educational activities in the classroom and laboratory inspired the whole class in some way involving self-learning type students to those with a self-paced learning style.

CLOSING REMARKS

We have designed the course so that the participating students will become aware of different valuable nanoscience aspects enabling them to gain subject knowledge and relevant skills in the specialized subject through complementary activities (Fig. 3). The objective is to provide insight and understanding of a range of nanoscience topics through value-added information integration in an interactive format and the incorporation of principles of different domains gives the course an interdisciplinary flavor. The main focus for learning academic knowledge and practical work in this discipline is to motivate the majority of learners' interest and develop proper intellectual infrastructure that enhances their mastery of the personal process of living. This paper emphasizes experimental methods and analytical techniques with the objectives of synthesis, analysis, application, and evaluation in an educational exercise protocol in a stimulating learning environment. Encouraging the students with questioning and experimentation will help them to

acquire the ability to provide rational explanations, identify the sources of uncertainties, and respond to problems in the field of molecular nanotechnology. It is taught as an interdisciplinary course with a balance between academic learning through classroom discussions, self-learning nanoscience education materials, and laboratory training that reflects on different aspects of the subject. This short-duration course is particularly useful at universities that offer a range of specialized educational services and innovative educational programs at different institutions or scientific research centers with exceptional academic qualities.

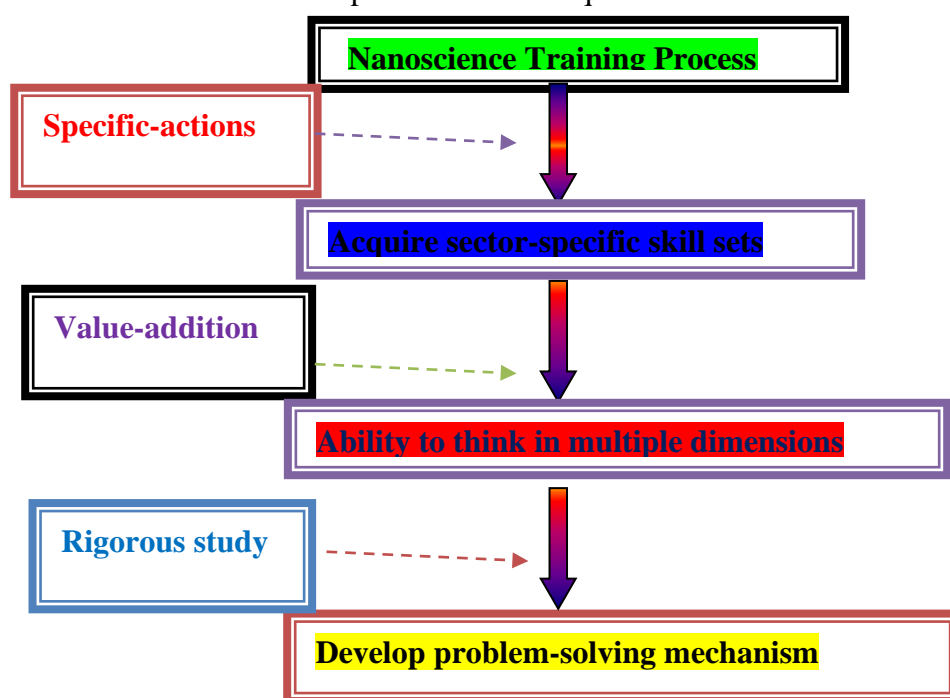


Fig 3. Schematic diagram showing academic education and intellectual growth interconnections.

Thus, nanoscale research and education lead to a better understanding of nature, aiding sustainable development, producing innovative products, high throughput processes, and diagnostics that are of scientific and commercial interest. Emerging areas include topics to understand specific perturbations at the molecular level, exploring the key properties to find out new applications, creating some interesting problems to solve, and developing a deep understanding of nanoscience-related issues. The control and prevention of environmental pollution are more relevant with the increasing momentum of the green movement and the recent introduction of the *International Journal of Green Nanotechnology; Material Science and Engineering*.

The use of green catalysts and nanoparticle production processes to form environmentally safe compounds and the investigation of environmental contamination and human exposure of nanoparticles/nanomaterials by dermal, inhalation, and ingestion routes will make a significant advance in this direction. The unforeseen environmental consequences of the promotion of large-scale nanoparticle production by environmental monitoring pose serious challenges to the researchers in the field due to an incomplete picture of the problem and a lack of a more detailed understanding of the biological or geological processes of nature. An active learning approach in a flexible format can provide an environment for creative thinking and encourage imaginative

mental processes that lead to an experience with a difference. The framing of syllabus content would benefit the students from a healthy dose of fundamental conceptual knowledge with an application orientation and there is room for considerable further development.

Key multidimensional challenges for future research in the next decade include the following: i) build and develop miniature sensor systems (nanosensors) to detect molecular phenomena ii) manufacture advanced materials with desired shapes and properties (nanomanufacturing) iii) the elucidation of biochemical pathways involved in several biotransformations iv) construction of molecular machines to destroy pathogens and robotic sensor devices for superior security systems v) synthesize scavengers inside blood vessels to inhibit scale formation on inner walls vi) development of novel electrode material for the fuel cell meant for hydrocarbon usage. vii) computer-aided molecular design and modeling studies to make atomically precise functional structures viii) development of nanoemulsion vaccines to promote a strong immune response against AIDS virus (HIV) ix) creation of low-cost process with an overall efficiency of energy production to solve the energy problem x) develop a biocompatible device that can be implanted in patient's body to monitor insulin levels xi) special- formula surface cleaners to make our homes free from disease-causing microorganisms, bacteria, and viruses xii) special nano-additives that enhances mileage and reduce exhaust emissions in vehicles. There will be new domains added to the expanded nanotechnology map with innovative steps in futuristic health care and across industries that range from pharmaceuticals to machine manufacturing, biotechnology to nanoelectronics, and food processing to nanochemicals [101-150].

The discovery of active pharma ingredients or precursors with biomedical features during the drug development process and the study of the safety and efficacy of such new drugs have a huge potential for the development of a culture of creative thinking. Another key area is the fabrication and development of multifunctional nano-chips for sector-specific applications. The main research themes could include nanomachines, multifunctional membranes, nanochips, nanoelectronics, and instruments at the nanoscale. Exploration of research questions on nanoaspects of the entire spectrum of networking atoms of different elements in the periodic table provides clues about the behavior of resulting nanomaterials. The sales, service, spares, and safety aspects of nanosystems will come into sharp focus with the growing popularity of nanomaterials and nanosystems soon. It will also allow some key initiatives in marketing aspects including intense investment and innovative institutional solutions actively integrated into these initiatives. An intensive investigation of the release of nanoparticles in the atmosphere and their impact on the cardiovascular and respiratory health of humans is a step in the right direction in the distant future. As an attempt to incorporate updating skills, one could add materials that are both informative and insightful from time to time through the survey of current research results. In a nutshell, nanoscience offers good prospects for innovative products in a completely different direction for nano-applications and the advancement of knowledge in our understanding of nature at its nanoscale fabrication of essential components.

Appendix 1: Detailed Structure of the Course

1. Course Objectives

- To introduce the basic concepts and the essential features required to understand nanoscience and appreciate its important role
- To recognize the main classes of nanoparticles based on different parameters and be able to give examples of each
- To know the synthetic techniques normally used in the laboratory to obtain nanoparticles
- To underline the role of the different types of analytical techniques used in the characterization of nanoparticles
- To understand the properties of various types of nanoparticles
- To become familiar with the research and development reported in the specialized literature and to encourage students to take an active part in seminars
- To outline the prospects of nanoscience and to emphasize the applied aspects to appreciate the important implications

2. Course Outcomes

After the completion of the course, the students will be able;

- To explain the basic concepts and the essential features of nanoscience
- To classify the nanoparticles into various categories based on different parameters
- To describe the common synthetic techniques of nanoparticles
- To discuss the data collection process and interpretation of instrumental data to extract useful information
- To be able to make accurate qualitative statements about the properties of various types of nanoparticles
- To speak about the recent advances and trends in specialized research in the area
- To present the prospects of nanoscience and research implications

3. Instructional Structure

1. Introductory Remarks

- 1.1. Scope and Importance
- 1.2. Lessons from Nature
- 1.3. Nanoparticle Classification
- 1.4. Current Concepts
- 1.5. Unique Dimensions/Exceptional Cases

2. Synthetic Strategies

2.1. Top-down Approach and Bottom-Up Approaches (Mechanical milling, Etching, Laser ablation, Sputtering, Electro-explosion, Supercritical fluid synthesis, Sol-gel process, Laser pyrolysis, Molecular condensation, Chemical reduction, Green synthesis)

2.2. Physical Methods (Laser ablation, Mechanical milling, Sputter deposition, Ion-implantation, Ultra-sonication, Irradiation)

2.3. Chemical Methods (Chemical Reduction, Gas Phase/Chemical Vapor Deposition, Sol-gel, Hydrothermal, Micro-emulsion, Co-precipitation/Colloidal, Sonochemical, Microwave-assisted, and Laser/Spray pyrolysis)

2.4. Biological Methods (Green synthesis using plants/microbes/biomolecules/enzymes)

2.5. Other Preparative Routes (Green Methods vs Conventional Methods)

3. Characterization Techniques

3.1. UV-Visible Spectroscopy (UV-Vis)

3.2. Fourier Transform Infrared Spectroscopy (FTIR)

3.3. Scanning Electron Microscope (SEM)

3.4. Transmission Electron Microscope (TEM)

3.5. Scanning Tunneling Microscope (STM)

3.6. X-ray photoelectron Spectroscopy (XPS)

3.7. Powder X-ray Diffractometry (XRD)

3.8. X-ray Fluorescence Spectroscopy (XRF)

3.9. Atomic Force Microscopy (AFM)

4.0. Dynamic Light Scattering (DLS)

4.1. Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

4.2. Matrix-assisted Laser Desorption/Ionization Mass Spectrometry (MALDI-MS)

4.3. Scanning Mobility Particle Sizer (SMPS)

4.4. Zeta Potential Measurement

4. Properties of Nanoparticles

4.1. Physical Properties

4.1.1. *Mechanical & Thermal Properties*- Hardness, Tensile Strength, Thermal Conductivity, Thermodynamic Properties (particle stability, decomposition, stoichiometry)

4.1.2. *Magnetic & Electrical Properties* – Magnetic Susceptibility, Magnetoresistance, Electrical Conductivity, EPR/NMR

4.1.3. *Optical & Spectroscopic Properties* – Dielectric Constant, Refractive Index, Photoconductivity, Photoluminescence, IR/Raman/UV spectra

4.1.4. *Transport properties* in low dimensional systems

4.2. Chemical Reactions

4.2.1. Reactions of Metal Atoms

4.2.2. Adsorption of Gases

4.2.3. Functionalization Reactions,

4.2.4. Reactions with other Compounds,

4.2.5. Stability (Temp, pH, Oxidation)

4.2.6. Factors that Affect the Rate of Chemical Reactions

4.2.7. Surface Chemistry Properties

4.2.8. Catalytic Reactions using Nanoparticles

5. Structural Aspects & Bonding Considerations

5.1. Size and Shape,

5.2. Electron Configuration

5.3. Flexibility (Dipole Moment/Polarizability)

5.4. Geometrical Configuration

5.5. Stabilization vs. Aggregation

5.6. Intricate Structural Patterns

5.7. Types of Bonding

5.8. Simulated Models

5.9. Quantum Dots, Wires, and Wells

6. Application Areas

6.1. Providing Products & Processes

6.2. Novel Nanomaterials (Inorganic/Organic/ Carbon/Polymeric/Dendrimers)

6.3. Innovative Pharma-products, Pathogen Removal, Drug Delivery, Prevention of Bacteria Spread

6.4. Applications in healthcare (Diagnosis, Nanodrugs, Orthopedic Implants)

6.5. Use in Environment (Protection, Maintenance, Remediation, Enhancement)

6.6. Nanoparticles as Catalysts in Chemical Reactions

6.7. Water and Air Purification, Cleaning Oil Spills from Oceans

7. The Way Forward

7.1. New Solutions to Old Problems

- 7.2. Nanomaterials in Anti-Microbial Solutions and Microbial Fuel Cells
- 7.3. Nanotechnology in Medicine (Drug Delivery, Targeted Therapy, Diagnosis, Molecular Imaging)
- 7.4. Applications in Engineering, Energy, and Electronics (nanocomposites, sensors, solar cells, catalysts, photodetectors)
- 7.5. Nanoscience in Food (Processing and Packaging) and Textile Industry
- 7.6. Nanosystems in Agriculture (Crop growth/protection, Soil Enhancement, Stress Tolerance)
- 7.7. Emerging Materials and Technological Solutions
- 7.8. Nanorobotics in Biomedical Applications
- 7.9. Applications of Green Nanotechnology

8. Experimental Examples

- 8.1. Synthesis of Carbon Nanotubes
- 8.2. Preparation of Titanium Oxide Nanoparticles
- 8.3. Physical Characterization of Various Nanoparticles
- 8.4. Application of Nanoparticles in Catalysis
- 8.5. Use of Nanoparticles in Composite Materials
- 8.6. Medical Applications Demonstration

10. Student Seminar Presentation/Analysis of Breakthrough Research Papers

- ❖ Purpose of the study
- ❖ What researchers accomplished
- ❖ Background information on methods
- ❖ Researcher's approach
- ❖ Experimental observations
- ❖ Commentary on research implications
- ❖ References

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Appendix 2: Essential Nanoscience Outline: Brief Content

1. Course Objectives
2. Course Outcomes
3. Instructional Structure
4. Introduction to Nanoparticles
5. Nanoparticle Classification
6. Synthetic Strategies
7. Characterization Techniques
8. Properties Observed
9. Structural Aspects
10. Bonding Considerations
11. Applications Orientation
12. Experimental Activity
13. Seminar Presentation
14. Closing Remarks
15. Review questions
16. References
17. Supplementary Material

Appendix 3: Supplementary Materials

Experimental procedures, Laboratory instructions, Safety precautions

1. Synthesis of gold/silver nanoparticles
2. Synthesis of CdS nanoparticles stabilized by polyphosphate
3. Characterization of the silver nanoparticles
4. Preparation of gold nanoparticles using tea

5. Application of CNT membranes for water purification
6. Application of nanoparticles in medicine
7. Generation of particulate pollutants in a confined environment
8. Synthesis of zinc sulfide nanoparticles
9. Synthesis of carbon nanoparticles from candle soot
10. Sample analysis using SEM/TEM/AFM

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