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CONTENTS

IONIC SOLUBILITY EQUILIBRIA CALCULATIONS - A NEW APPROACH

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ABSTRACT

In the classical approach, students have to verify assumptions using, amongst others, a "pure solution" or "the common-ion effect" concerning the situation they are studying to solve ionic solubility equilibria calculations. Furthermore, the simultaneous equilibria are shown in a non-trivial way. We propose a new way to understand these equilibria by implementing a method in which all conditions appear naturally in the mathematical equations. We present the Excess Parameter with solubility product equations to determine cation and anion's analytical and equilibrium concentrations. We consider the Bronsted ions acid-base behavior applying the equilibrium fractions (a). It is possible to use conditional *Ksp* (it involves *Ksp* and α) to ease calculations. Another option to solve calculations is to use the classical approximation or the iteration numerical calculations. This approach logically exposes concepts that we believe it is a good and promising method to teach and discuss Aqueous Solution Chemistry and Analytical Chemistry. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Virtually all teachers use the study of ionic solubility equilibria in Analytical Chemistry in which a "pure solution" is the prime studied situation. That is, when adding a sparingly soluble ionic solid to water, the common-ion effect responsible for decreasing the solubility of a compound modifies the "pure solution" situation. This approach has been in use since the ionic solubility-product proposal by Nernst [1], and we will call this method the classical approach.

The introduction in 1884 of Arrhenius's electrolytic dissociation theory has since then provided a significant modification to how the scientific community understands the Aqueous Solution. Previously, the usual idea did not consider the dissociation (or ionization) processes. Nowadays, some consequences of this previous idea are writing chemical equations in an aqueous solution using the compound formula added to the solution or the solubility of a sparingly salt calculated as if it existed in the solution. This concept was known as the XIX Century Concept [2].

Truthfully the XIX Century Concept is heavily used, and the classical approach, among other aspects, is characterized by (i) the use of global equations to describe the solution and to underestimate other species and processes in the solution, (ii) the numerical calculations are more important than chemical concepts; (iii) the approximations are not easily understood; (iv) different steps of dilution were not distinguished, making the resolution more difficult. Butler [3] has proposed a systematic method in which the representation of all intermediate species presented in equilibrium replaced the use of global equations. Although the solution description does not include the use of a global equation, the numerical calculations are similar to any other classical methodology in the systematic method. Nowadays, a more modern concept named the XX Century Concept shows the actual behavior of existing species in solution, including the solvation process.

In the classical approach to ionic compounds' specific solubility equilibria, only the Law of Mass Action and equilibrium concentration are applied. However, the difference between equilibrium and analytical concentration is not generally explicit, and therefore it causes some confusion. Indeed, this classical approach does not consider the actual equilibrium concentration of several ions because it depends on the pH value and all the species related to either the cation, anion or even both cation and anion involved in the system. Moreover, both topics are unreported by the classical approach. It means the pH value is implicit and adequately selected for equilibrium and analytical concentrations equality to be acceptable by approximation. The systematic method [4] explores solutions involving simultaneous equilibria, in which exercises require approximations to solve the calculations. Nonetheless, it does not consider the pH effect. For simple calculations, it is usual to consider some approximations to solve an exercise, and the calculation for a more complex example is solved using software. Moreover, to solve an exercise, the systematic method resolution considers a succession of nontrivial steps and assumptions about the chemical system. Therefore, the resolution becomes a calculation problem, depreciating the chemistry.

As an alternative to teaching and solving problems involving solubility equilibria, this article proposes a new method that integrally applies the XX Century Concept for Chemical Solution. This method, the XXI Method, similar to the systematic method, considers distinct chemical equations to represent all the system equilibria. Therefore, the system could be easier interpreted. Moreover, we could calculate the equilibrium concentrations because the pH system would always be known, and the equilibrium fraction could be obtained [5].

The procedure will use the balance of matter (of phase, actually) and the Law of Mass Action equation to propose a new parameter named The Excess Parameter. The solution to the problem by the student will be formed in two parts: obtaining of the Excess Parameter expression and applying it in the solubility equilibria.

THE EXCESS PARAMETER CONCEPT

Here are some considerations to introduce The Excess Parameter Concept. Thinking in teachers in this moment, and not in the student, to help with methodology comprehension, consider a system formed by a mixture of a cation (M^{q+}) solution and an anion (B^{p-}) solution with a solid formation. Figure 1 shows a schematic diagram with all steps designated. The final solution pH (Step 3) was adjusted (by adding a strong acid or base, for example). In the approach for students, real compounds are better than hypothetic cation and anion, once no general equation were obtained, but the excess parameter is calculated in each system.

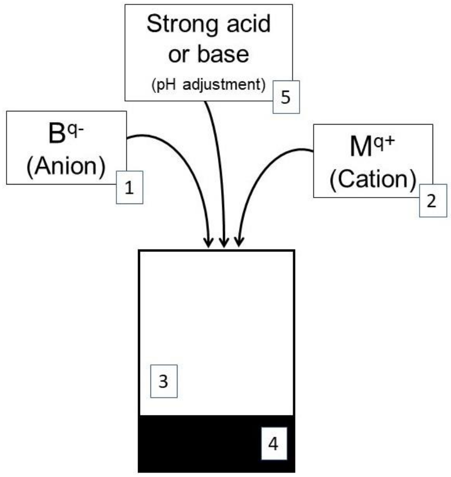


Figure 1 - Mixture of cation (M^{q+}) solution and anion (B^{q-}) solution schematic diagram.

The equation below represents the solubility equilibrium that occurred after the mixture. Electric charges were omitted to simplify it.

$$M_mB_{b(s)} \leftrightharpoons mM_{(aq)} + bB_{(aq)} \qquad pKs$$

Considering the Brønsted acid-base behavior for both species, the metal ion and the anion, both as monoprotic systems, we have:

$$HB_{(aq)} \leftrightharpoons B_{(aq)} + H^+_{(aq)} \qquad pKa$$

$$M_{(aq)} + H_2O_{(l)} \leftrightharpoons MOH_{(aq)} + H^+_{(aq)} \qquad pKa$$

The water molecule shown in the Bronsted metal ion acid-base equilibrium is the ligand in an aquocomplex. We ought to remember that N. Bjerrum[6] has proposed the solvated metal ion classification as Bronsted acid. Also, it is interesting to emphasize that $H^{+}_{(aq)}$ means all proton hydrates (Eigen, Zündel ions, etc.), and we usually omit water molecules whenever possible [5].

The phase balance of each ion either in solution or in solid phase can be obtained (Equations 1 and 2). The index is the number of each step in Figure 1.

$$n_2(M) = n_3(M) + n_4(M) \quad (1)$$

$$n_1(B) = n_3(B) + n_4(B) \quad (2)$$

The stoichiometry in **solid** (Equation 3) is a piece of additional information, and it is always known.

$$\frac{n_4(M)}{n_4(B)} = \frac{m}{b} \quad (3)$$

Only in special circumstances, when we directly add the solid to the system, this stoichiometry (Equation 3) exists in the solution. It is worth mentioning that the classical methodology uses this special case as an initial situation ("pure solution").

We do not always know the concentration or the numerical information substance amount in Step 4 (Figure 1), but we know the solid stoichiometry. However, the cation and the anion solutions concentration information and volume in Steps 1 and 2 (or directly its amount of substance) is usually known. For instance, it is possible to rewrite Equations 1 and 2 using Equation 3, as presented in Equations 4, 5, and 6.

$$b.n_4(M) = m.n_4(B) \tag{4}$$

$$n_4(M) = n_2(M) - n_3(M) \tag{5}$$

$$n_4(B) = n_1(B) - n_3(B) \tag{6}$$

Furthermore, we can obtain a relation between the two ions in Equation 7.

$$b.n_2(M) - b.n_3(M) = m.n_1(B) - m.n_3(B) \tag{7}$$

A rearrangement allows for maintaining separate information about the solution obtained after the mixture (Step 3) and the original one of cation and anion (Steps 1 and 2) (Equation 8).

$$b.n_2(M) - m.n_1(B) = b.n_3(M) - m.n_3(B) \tag{8}$$

Until this step, we have considered only the substance's ions amount. If we divide both sides by Step 3's volume, the right side of the equation would be related to cation and anion concentrations. It is interesting to observe that concentrations are, by definition, analytical ones, since the amount of metal ions is related to all chemical species in the solution containing the metal (for example, hydroxocomplexes). A similar explanation is valid for the anion analytical concentration (Equation 9).

$$\frac{b.n_2(M) - m.n_1(B)}{V_3} = b.c_3(M) - m.c_3(B) \tag{9}$$

The first part of Equation 9 is defined as The Excess Parameter (Equation 10):

$$Excess = \frac{b.n_2(M) - m.n_1(B)}{V_3} \quad (10)$$

Furthermore, Equation 10 is related either to the metal ion amount or the anion in Excess, compared to the solid stoichiometry.

Moreover, we can represent the Excess as a solubility equation, as Equation 11 demonstrates:

$$Excess = b.c_3(M) - m.c_3(B) \quad (11)$$

The Excess Parameter simple numerical analysis allows us to obtain valuable information on the system.

When the Excess Parameter is positive, there is a higher metal ion concentration than an anion concentration. When the Excess Parameter is negative, there is a lower metal ion concentration than an anion one. Both situations are called *common-ion effects* in the classical approach. However, in that approach, they should be previously identified before any calculation. In our proposed one, the situation is shown naturally.

When the Excess Parameter is zero, the concentration of each ion in the solution is the same. It is similar to the default situation in the classical approach (*pure solution*). However, following the methodology presented in this article, the excess of cation or anion appears more natural, and we can interpret the situation after knowing that parameter value. Besides, in the classical method, each concentration situation is calculated differently.

Meanwhile, there are two incognitos to solve mathematically (Equation 10). To solve the cation and anion concentrations in the Excess we can use the solubility product equation (Equation 12).

$$Ksp = 10^{-pKs} = [M]_3{}^{m}[B]_3{}^{b} \quad (12)$$

There is an important point here. We highlight that the concentrations in Equation 12 are equilibrium concentrations (by definition), not analytical ones. At this stage, it is important to remember that the Law of Mass Action is defined in terms of activity. Although we can use the activity and activity coefficient to correct the concentration value, we will not consider those factors in this paper.

In this example, we consider ions' acid-base behavior. Thus, we have associated the equilibrium concentration with the analytical one by equilibrium [4] fractions in Equation 13. The acid-base equilibrium fraction is exclusively a function of the pH solution and the Bronsted acid-base system pKa [5].

$$\alpha_i = \frac{[i]}{c(i)} \quad (13)$$

Therefore, the conditional *Ksp* could be defined (Equations 14 and 15) as:

$$Ksp = [\alpha_o(M)c_3(M)]^m[\alpha_i(B)c_3(B)]^b \quad (14)$$

$$Ksp^{cond} = \frac{Ksp}{\alpha_o(M)^m\alpha_i(B)^b} = c_3(M)^m c_3(B)^b \quad (15)$$

The traditional conditional constant enables separation between the problem's constant variables and the unknown ones. Once we have established the solution's pH, the equilibrium fraction values (α) remain constant, and so does the *Ksp*. It means conditional-Ksp will depend on pH only.

The logarithm form (or 'p' operator) is a very easy way to treat the system. Therefore, the Ksp^{cond} can be written as presented in Equation 16.

$$pKs^{cond} = -log\, Ksp^{cond} = pKs + log\alpha_0(M)^m\alpha_i(B)^b \quad (16)$$

Both Equation 11 and Equation 16 represent systems of equations with two variables. With convenient replacement, we can obtain Equation 17, for example:

$$Excess = b.C_3(M) - \left(\frac{10^{-pKs^{cond}}}{(c_3(M))^m}\right)^{1/b} \quad (17)$$

There are several ways to solve this equation, such as (i) numerical analytical method, (ii) method of classical approximations, and (iii) iterative method.

Each one has its challenges. However, to a chemist, the goal is to obtain a chemical result, not numerical skills. The first one demands hard work with mathematical skills in which the result will be about the compound stoichiometry formed only. We do not believe there is any advantage in exploring this method. The classical approximation method should delve into the system's numerical analysis. In a sum, this method evolves.

$$A + b \sim A \qquad if\ A \ggg b$$

In this case, first we needed to prove if $c_3(M) > c_3(B)$, then $c_3(M) >>>> c_3(B)$ (or the other two possible situations). After this proof, the solution is simpler than the method (i). The question remains if this approximation is valid because depending on the situation it is not always applied. Therefore, it should be used carefully.

The third method, the iterative one, needs a previous explanation of iterative methods. It is easy to implement programs such as Excel spreadsheets, R, Python, Sci-lab, MathLab languages, and others on computers. Consequently, even if the students do not understand these algorithms, they would be able to obtain the correct chemical result just by using them.

Therefore, we have proposed an add-on for Excel [7] with several interesting chemical functions. One of them allows cation and anion concentration calculations using as a parameter: the Excess parameter, pKs (or pKs^{cond}), and cation and anion stoichiometric coefficients.

We present four examples in the Supplementary Information. They have used all conditions defined in XXI Method, such as a schematic diagram, and all equations involved in the solution are shown (each equation for each process). Subsequently, we have considered and selected the equilibrium. Therefore, students can understand future challenges they will have to face. Since we can always consider the Bronsted acid-base, we will not initially consider gas-liquid or complexation equilibrium.

DISCUSSION

Although this methodology has several advantages over the classical one, we would like to emphasize two crucial points. The first one is that the argument presented here is very dense since we have shown a general case. For this reason, it ought to be evaluated by professionals, not students. For students, there is an evolution of concepts and skills, but we stress that the expression of concept parameter should be obtained by student in each real situation. The second point is that the classical method is often used due to the absence of others. Therefore, it is only after knowing and applying our new method that researchers/teachers can observe issues or inconsistencies in the classical one.

The classical method starts with a particular case of ionic compounds' solubility when the solution stoichiometry is equal to the solid. Thus, qualitatively, there is a solution's composition[8]. We believe it is a XIX Century Concept's direct consequence since researchers study ionic compounds' solubility by adding solid to water. In contrast, the classical method shows the “common-ion effect’ as a different situation, thus, with another numerical resolution. According to the information offered in each problem or exercise, identifying the "common-ion effect" situation or the "pure solution" situation is not trivial. Furthermore, the simultaneous equilibrium effect needs another approach that differs from those two presented here.

The classical methodology considers only the Law of Mass Action instead of also uses the Balance of Matter to solve those exercises (with simple equilibria). It keeps the simple equilibria concept implied in the initial decision. Moreover, it considers both the Law of Mass Action and the Balance of Matter whenever the system presented a simultaneous equilibria situation. Therefore, for a simultaneous equilibria situation, the classical methodology needs another approach to solve the exercise. Furthermore, there are no distinctions between dilution processes responsible for Step 3 conditions. This further confirms that these ideas were implicit in the arguments and in the numerical calculation.

In this new approach, we separate the dilution process from the equilibrium situation, and the numerical resolution becomes a consequence. There is a schematic design shown in Figure 2. Therefore, even complex problems become easier to assimilate and solve.

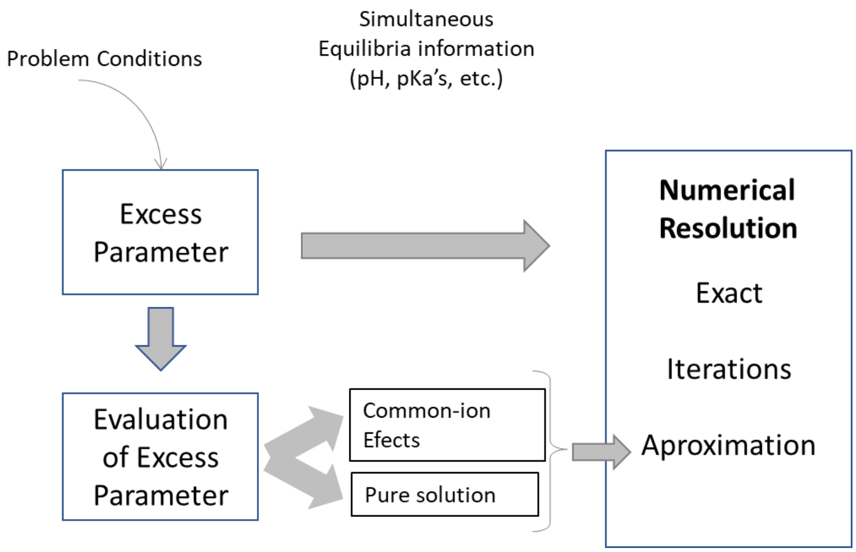


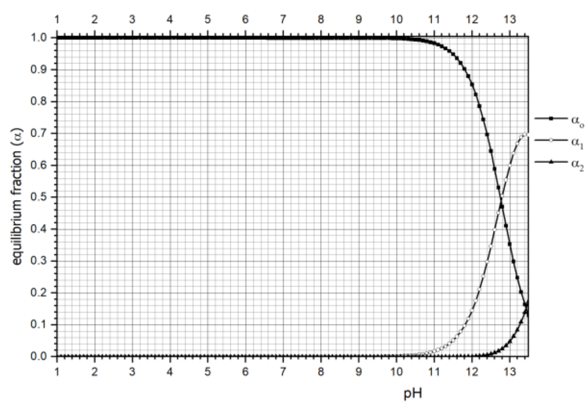
Figure 2 - Solve solubility equilibria calculations through Excess parameter definition schematic design.

This approach allows the behavior comprehension of two ionic solids in contact with the solution or even in cases of non-ionic compounds.

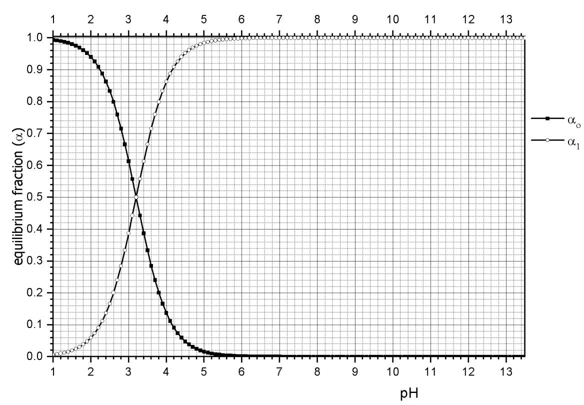
Effect of pH – Species Distribution Diagram

In practical problems, the solution's pH is usually known or corrected to a known value. The Species Distribution Diagram (SDD) identifies the range this parameter (pH) is essential in ionic solubility equilibria. It means the equilibrium fraction range (α) tends to be 1 for the cation and anion. In this situation, low soluble salts are not affected by the solution's pH.

Figure 3 shows the SDDs of some cations and anions. Each ion pair in the study defines the pH range. For cations, it is $\alpha_o \rightarrow 1$. For anions, the highest equilibrium fraction tends to be 1. For instance, calcium fluoride is not influenced by pH values in the pH range from 4.1 up to 11.8 (considering $\alpha \rightarrow 1$ when $\alpha > 0.9$). In contrast, there is no overlapping pH range for copper (II) phosphate, meaning the pH influences this solubility equilibrium in all pH values.



(A)



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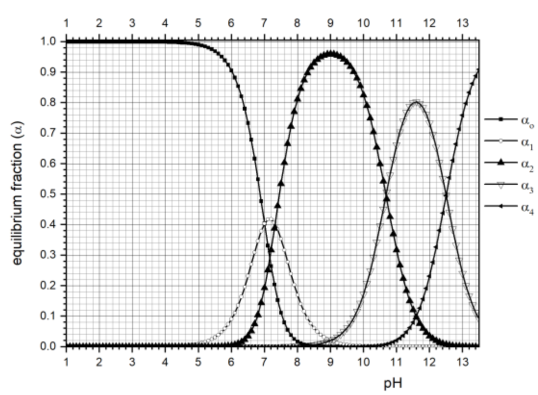
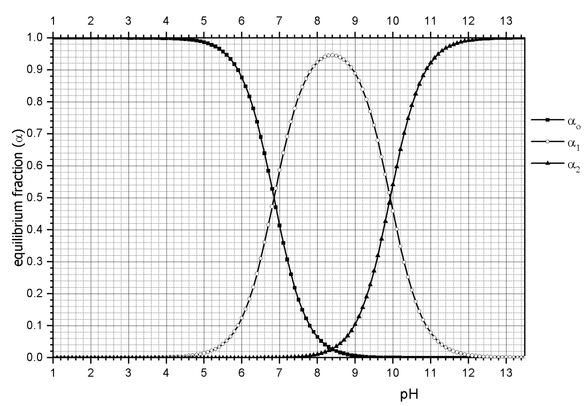




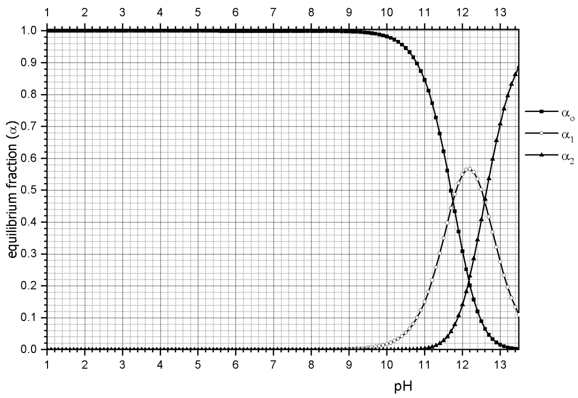
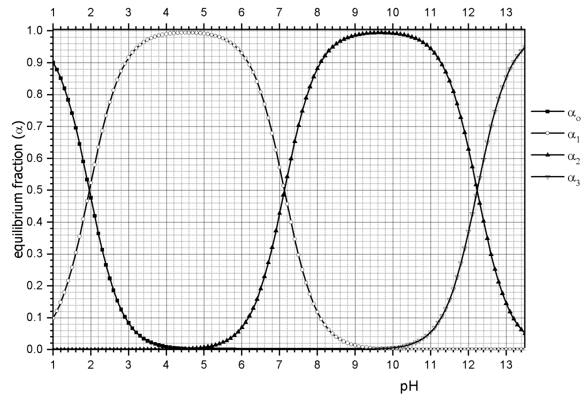
(C)	(D)
 (E)	 (F)

Figure 3 - Species Distribution Diagram (SDD) to different Bronsted acid-base systems. (A) calcium; (B) fluoride; (C) copper (II); (D) carbonate; (E) silver; (F) phosphate.

Proposed approach examples

There are four examples to demonstrate our proposed approach's potential. Each example's resolution is in the Supplementary Information. Furthermore, we present different numerical methodologies to solve each problem.

Number 1: It is a common-ion effect example. An amount of solid has been formed in a solution by adding a quantity of cation and anion. The chosen pH value is within a range that does not influence the solubility equilibrium.

Number 2: This is an example of a "pure solution" influenced by the solubility equilibrium's pH. It is a sparingly soluble salt in contact with a pH-defined solution. It is interesting to mention that the carbonate and the phosphate sparingly soluble salt will depend on the solution's pH in almost all pH range.

Number 3: It is similar to the first example; however, the pH value influences the cation and the anion equilibrium concentrations in the solution. Textbooks do not show this sort of problem because the Bronsted acid-base of metal is not usually shown. Only earth alkaline metals and silver are influenced by a pH value above 10 because the first pKa is higher than 11. Table 1 shows common metal ions' pKa values.

Number 4: It is the formation of two solids in contact with the solution. Less soluble salt pKs importance naturally emerges from equations.

Table 1 – Bronsted Acid-Base Equilibrium Constant for selected metal ions.[9]

Íon	**pKa_1**	**pKa_2**	**pKa_3**	**pKa_4**	**$-\log s_0$**
Al^{3+}	4.99	5.55	5.66	6.6	7.7
Ba^{2+}	13.36	24.36			13.32
Cd^{2+}	10.08	10.27	12.95	14.05	6.7
Ca^{2+}	12.67	14			3.86
Pb^{2+}	7.47	9.52	10.95	11.64	4.09
Co^{2+}	9.55	10.22	12.24		6.67
Cu^{+}	0.4	7.84	10.38		8.54
Cu^{2+}	7.64	8.6	10.36	13.1	7.56
Cr^{3+}	3.6	6.05	6.6	11.31	4.05
Sn^{2+}	3.53	4.15	9.88		5.88
Fe^{2+}	6.7	9.5	11.07		3.3
Fe^{3+}	2.19	3.31	6.62		8.92
Mg^{2+}	11.44	16.86			9.5
Mn^{2+}	10.59	11.6	12.6	13.81	6.99
Hg^{2+}	3.4	2.56			3.4
Ni^{2+}	9.86	11.29	15.28		8.41
Ag^{+}	11.75	12.59			5.46
Zn^{2+}	8.94	8.95	10.09	12.37	5.41

The principal aspect of the methodology proposed is to expose and allow the student to comprehend each step of the reasoning involved in simultaneous equilibria calculation. It is important to emphasize that the classical methodology does not present these steps but a hermetic calculation procedure in which students must previously know several conditions. Some artifices are implicit, and consequently, the students cannot comprehend chemical and numeral interpretations. In addition, it presents several distinguished topics simultaneously, and once more, hermetically, those topics must be introduced or imposed on the student. The XXI Method allows for the explicit of these situations and to expand chemical concepts to other experimental conditions, being able to be "discovered" by the students from initial assumptions (the triad solution).

An example is to consider the ion stoichiometry in the solution presented in the first example (Pure Solution). The classical approach imposes this condition, but the XXXI Method presents it as a special case in which stoichiometry is always veritable in the solid phase. Another example is the absence of a clear distinction between analytical and equilibrium concentrations. In the classical methodology this distinction is imposed, again, in pH effect evaluation, as presented in Example Number 2 (2[Ca2+] = c(F-) [8,10]). Once more, in the XXI Method, the distinction between analytical and equilibrium concentration appears naturally. Analytical concentration and solubility product (which is defined in terms of equilibrium concentration, or activity, if it is of interest) define The Excess Parameter equation. Relating both, we naturally evaluate simultaneous equilibria. Another unclear situation in the classical methodology is not considering the dilution process (or the balance of matter in different solutions or steps). Also, it not clearly presents all dilution and stoichiometry strategies and therefore is more difficult for the student to solve elaborated exercises. Once more, as the XXI Method explicitly presents all the strategies applying the balance of matter and phase, it permits solving the problem by clearly presenting the stoichiometry, the quantity involved, and the unknown concentrations, and finally, the selected numerical method determines the unknown values.

CONCLUSION

With our proposal, it is possible to gradually expose a solution's behavior from the Balance of Matter and the Law of Mass Action. We consider this to be our contribution’s great advantage. Any previous implicit evaluation is not necessary.

Our methodology allows a straightforward solubility equilibria resolution and interpretation. It is possible to visualize the exercise with the schematic diagram and the detailed equations. Furthermore, the step-by-step resolution process allows clarity and a natural form to solve these equilibria.

To sum up, it is difficult to select a universal best approach to teaching a topic. Teaching solid solubility equilibria using our methodology requires an evaluation and an analysis of the studied system's stoichiometry. This evaluation ought to be associated with the results' natural interpretation based on simple calculations with no need for assumptions. We argue it is a very interesting approach since it uses a fundamental exercise for the student's development and provides an alternative to the classical methodology.

SUPPLEMENTARY INFORMATION

Situations involving solubility equilibrium using the Excess Parameter and solutions by classical approximation, exact calculation, and iteration method are shown in Supplementary Information. [Contact the author.]

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CHEMISTRY STUDENTS' KNOWLEDGE AND PRACTICES OF CHEMICAL WASTE MANAGEMENT IN CHEMISTRY LABORATORIES

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ABSTRACT

The study investigated chemistry students' knowledge and practices of chemical waste management in chemistry laboratories in a higher educational institution in Ghana. Descriptive survey design was employed, and the stratified sample comprised of 93 chemistry major students who were selected from levels 100, 200 and 300 in University of Education, Winneba. Questionnaires and unstructured interview were used to collect data which were then analyzed by descriptive statistics (mean and standard deviation) and inferential statistics (t-test and correlation). The results revealed students' good knowledge of, yet poor practices of chemical waste management in the various chemistry laboratories. The t-test conducted revealed a statistically significant difference ($p=0.000<0.05$) in students' knowledge and practices of chemical waste management in the school's chemistry laboratories. Also, a Pearson correlation ($r=0.415$) corroborated the finding that students weakly put their good knowledge in chemical waste management into practice. It is recommended for tertiary educational institutions to build a culture of sustainability and environmental protection in accordance with Sustainable Development Goals (SDG 6 and SDG 11) [3] among science students to by encouraging them to put their knowledge about waste management into practice and protect the environment. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Educational institutions are engaged in training students in the field of science and this cannot be properly done without laboratory investigations and research from both students and lecturers. The main subject areas that science students read include Chemistry, Physics and Biology. Scientific institutions and educational research activities commonly produce a wide variety of hazardous wastes in relatively small volumes including new materials of unknown toxicity and hazards [1]. These could represent a significant risk to human health and the environment unless it is identified, contained and disposed in accordance with applicable laws, regulations and best waste management practices.

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials [2]. It usually relates to unwanted materials produced by human activities, and is generally undertaken to reduce their effect on health, the environment or aesthetics as well as resource recovery. Chemical wastes can be solid, liquid, gaseous or radioactive substances which requires different methods and fields of expertise in their management. It is expected that institutions which train young scientist and researchers in science should put in place waste management strategies so that chemical wastes generated do not negatively impact on the environmental compartments such as water, air and soil. According to [3], factors that significantly contribute to waste generation in schools include students' gender ratio, students' awareness level, administrative and staff background.

Waste management practice is a difficult and multidisciplinary activity that requires knowledgeable and innovative practices of implementation, supervision, monitoring and compliance of policies. This implies that institutions, especially tertiary institutions of education must stand for and apply ethical and social responsibility guidelines so as to transmit and build a culture of sustainability and environmental protection in accordance with Sustainable Development Goals (SDG 6 and SDG 11) [3]among its science students; especially chemistry students who deal more with chemical substances.

The environmental impact caused by teaching and research with regard to chemical waste is of increasing concern and attempts to solve the issue must be made consciously and conscientiously. Education and research-related institutions, in most laboratory and non-laboratory activities, contribute to the generation of small quantities of waste, many of which are highly toxic. Some of these activities and wastes are listed by government agencies who are concerned about environmental pollution as detrimental to the planet. A few of these are disposal of acids, metals, solvents, chemicals and selected synthesized toxic products, whose toxicity is often unknown [4]. According to [5], generation and poor management of chemical wastes and their activities in school laboratories, could subtly lead to environmental pollution. The potential risks and hazards caused by such subtle pollution as well as inappropriate management and disposal of liquid wastes could bear directly on users of the contaminated space. In other words, the lack of effective measures to dispose toxic wastes could cause environmental pollution and pose harm to laboratory staff. [6] also stated that school laboratories consume less chemicals than factories, however, the wide variety of chemicals used in schools increase the complexity of the management, storage and disposal of laboratory chemicals.

In Ghana, most second cycle and third cycle schools run science programs and have laboratories purposely for practical activities. During school laboratory activities, a lot of chemicals with varied toxicity are used and released into the environment. Although, many studies [7]; [8]; [9]) have reported on solid waste management practices in Ghanaian schools, none of them reported on how other laboratory chemical wastes, beside solid waste, are managed. In addition, the population of these educational institutions (Senior High Schools and universities) are increasing just as those who study chemistry and perform laboratory work with chemicals are also increasing. This means that the generation of chemical wastes would invariably increase and so its management practices must be taken into consideration.

[8] opined that the population of educational institutions, especially Senior High Schools in Ghana, is increasing rapidly due to introduction of free Senior High School education by the Government of Ghana. The subsequent increase in the number of students reading science courses which include chemistry at the tertiary level could deepen the already existing problem with management of generated waste laboratory chemicals and their improper or indiscriminate disposal. Furthermore, some school laboratories have become business-oriented and analyses a lot of research samples from industrial to domestic waste for individuals and corporate organizations. [10] asserted

that safety system for laboratory liquid waste disposal has become an important issue in the environmental protection, safety, and hygiene of all universities. It is, therefore, important to assess the waste management practices and management plans in university laboratories and find out about their waste management and sustainability plans. Although there are many universities in Ghana, this study assesses chemistry students' knowledge and practices of chemical management in chemistry laboratories in a teacher training university and possible sustainability plans for their environment and the nation at large.

Objectives of the study

The objectives of the study were to:

i. assess the knowledge of students in a teaching chemical laboratory on management of chemical waste
ii. examine the practice of chemical waste management by students in a teaching chemical laboratory towards sustainability

Hypothesis

Ho_1: There is no significant difference in the knowledge and practice of chemical waste management among chemistry students in chemical laboratory.

METHODOLOGY

Research design

In this study the descriptive survey design was employed. [12], explained that survey research designs are procedures in quantitative research in which investigators administer a survey to a sample or to the entire population of people to describe the attitude, opinions, behaviors, or characteristics of population. According to [11] descriptive research is devoted to the gathering of information about prevailing conditions or situations for the purpose of description and interpretation. The method of research which concerns itself with the present phenomena in terms of conditions, practices beliefs, processes, relationships, or trends invariably is termed as descriptive survey study [12].

The survey design that employed a cross-sectional approach was used in this study because it allowed for comparison of variables at the same time but not desire its cause-and-effect relationships. It also allowed for observation of the sample at both the group and individual levels. It further allowed for quantitative studies. It, however, could not be used to analyse behaviour over time.

Population and sample

The population of the study involved all the science students in University of Education, Winneba (UEW). The target population was all the chemistry students reading chemistry while the accessible population were only chemistry major students. Random sampling techniques was used to select 93 chemistry major students comprising of 30 level 100, 31 level 200 and 32 level 300 students.

Research Instruments

Questionnaires were administered to provide quantitative data to ensure objectivity, generalisation and reliability [13]. It was used to assess knowledge about the nature of chemicals, storage, waste generation and waste management towards sustainability. The questionnaire which consisted of a set of Likert scaled questions were to obtain candid facts about existing laboratory practices, chemical waste generation, waste management plans and general awareness of effect of chemical waste on ecosystems. In addition, the students' knowledge and practices of chemical waste management were scored for analysis.

An unstructured interview was used to solicit for information which were not captured by the questionnaire.

Validity

In order to ensure that the questionnaire items were valid, it was given to a senior lecturer at the Department of Chemistry Education who assessed to ensure that the items were relevant to the objectives of the study.

Reliability

Reliability of the questionnaire was assessed by using Cronbach's alpha test to determine the internal consistency of the instrument. Poorly constructed items were deleted and some redefined to avoid ambiguity in understanding and responding to questions. The Cronbach coefficient alpha for items were acceptable (above 0.68) and that implied items were consistent with each other and could together represent construct under study. The reliability coefficients for items on knowledge was 0.70 while that of practice was 0.76. [14] reported that Cronbach alpha coefficient of 0.7 and above is an indication of acceptable reliability. Also, a general accepted rule is that α of 0.6-0.7 indicates an acceptable level of reliability, and 0.8 or greater a very good level [15].

Ethical consideration

Permission was sought from the University and Dean of Science Education for clearance to carry out the research. Student participants were then briefed on the nature of the study so that they could make informed decisions on their participation or otherwise. After the briefing, consent forms were given to them to sign. Each category of students was engaged with at different times to avoid intimidation and allow freedom of interaction with the researchers at a briefing session.

Data analysis

The administered questionnaires were all collected and analysed using Statistical Package for Social Science (SPSS) version 25 [16]. Descriptive statistics such as mean and standard deviation were used to analyse and bring meaning to data collected. Also, inferential statistics such as t-test and Pearson correlation were used to establish relationship between students' knowledge and practice of chemical waste management.

RESULTS

Presented in Table 1 is a summary of the demographic information of the student respondents.

Table 1: Demography of student respondents

s/n	Variable	Frequency	Percentage (%)
1	**Age**		
	15-20	8	8.6
	21-25	43	46.2
	26-30	28	30.1
	31-35	14	15.1
2	**Sex**		
	Male	71	76.3
	Female	22	23.7
3	**Level**		
	100	30	32.3
	200	31	33.3
	300	32	34.4

Table 1 shows that 8 (8.6%), 43(46.2%), 28(30.1%) and 14(15.1%) of the respondents were aged between 15-20, 21-25, 26-30 and 31-35 respectively. Among the student respondents 71(76.3%) were male while 22(23.7%) were female. The number of respondents in level 100 were 30 (32.3%), level 200 were 31(33.3%) and level 300 were 32(34.4%).

Students' responses to the items on knowledge of chemical waste management in the laboratory were summarized into means and standard deviations. These have been presented in Table 2.

Table 2: Knowledge of Science Students on Chemical Waste Management in the Laboratory

s/n	Statement	Mean	SD
4	Containers used for the accumulation of hazardous waste should be in good condition and free of leaks	2.94	0.27
5	A waste accumulation container should be opened only when it is necessary to add waste, and should otherwise be capped.	2.89	0.40
6	Hazardous waste must not be placed in unwashed containers that previously held incompatible materials.	2.69	0.59
7	Waste containers must be compatible with chemical wastes placed in them (for example, acid should not be stored in metal cans).	2.87	0.42
8	Waste containers must be properly labeled	2.95	0.27
9	Proper waste categorization can help avoid unnecessary, inappropriate, and costly waste handling, treatment, storage and disposal.	2.89	0.31
10	It is possible to convert a laboratory procedure to a micro-scale method that uses significantly less sample and reagents.	2.55	0.62
11	Procurement of hazardous material should be initiated only if a non-hazardous substitute is not available	2.42	0.72
12	Good laboratory record keeping and labeling of all chemicals and chemical wastes containers help to prevent accidents, like explosions.	2.91	0.41
13	Any chemical material that is potentially recyclable should not be contaminated with other chemicals for disposal.	2.90	0.33
	Mean of means	2.81	0.43

From Table 2, the students scored a mean of 2.94 (SD=0.27)) to agree that chemical containers used for accumulation of hazardous waste should be in good condition and free from leaks. They agreed (mean=2.89; SD=0.40) that hazardous waste containers must be opened only when it is necessary to add waste and should be capped. Students scored means of 2.69(SD=0.59) and 2.87(0.42) to agree that chemical waste must be compatible with their containers and other chemicals waste substances respectively. The students agreed (mean=2.89; SD=0.31) to proper waste categorization and agreed (mean=2.55; SD=0.62) that in the teaching laboratory a macro-scale activity can be converted to a micro-scale method so as to use less reagents and sample. The respondent did not know or were not sure (mean=2.42; SD=0.72) that in procurement of chemicals, hazardous materials are initiated only when a non-hazardous substitute is not available. They agreed (mean=2.90; SD=0.33) that good laboratory record keeping and labeling of all chemicals and chemical wastes containers help to prevent accidents, like explosions and were knowledgeable (mean=2.9; SD=0.33) on the fact that any chemical material that is potentially recyclable should not be contaminated with other chemicals for disposal. The mean of means (mean=2.81; SD=0.43) shows that students have good knowledge on chemical waste management in the laboratory.

DISCUSSION

The knowledge of science students who generate chemical wastes was assessed and the results indicated that they have good knowledge on chemical waste management. From Table 2, the mean of means for students' responses to items which assessed their knowledge was 2.81 (SD=0.43). The mean score indicated that chemistry students agreed to have good knowledge on chemical waste management practices in their laboratories. The small standard deviation is an indication of chemistry students' consistency to demonstrate high knowledge in chemical waste management since most of them scored 2.8 or a value closer to this to agree on having good knowledge. This was confirmed by the mean score (mean=8.33; SD= 1.84) that they obtained relating to their knowledge in chemical waste management. They agreed that chemical containers used for accumulation of hazardous waste should be in good condition and free from leaks, chemical waste must be compatible with their containers, chemical waste containers must be properly labeled to facilitate waste segregation in the laboratory and micro scale laboratory work are encouraged in teaching laboratories to minimize chemical waste that get into the environment. They added that chemical waste that can be recycled should not be contaminated to enhance reuse of materials in chemical laboratories and agreed that good laboratory record keeping and labeling of all chemicals and chemical wastes containers help to prevent accidents, like explosions. The importance of having good knowledge on chemical waste management is to promote sustainable development.

Human actions are at the heart of environmental issues and sustainable development ultimately depends on knowledge and behavior changes [17]. Students' good knowledge on chemical waste management protect them from explosions and other harm due to improper waste management in the laboratories. Also, this knowledge helps to protect fishes and other aquatic organisms who are mostly affected when chemical waste gets into water bodies. Similarly, [18] opined that good knowledge on waste management practices contribute to economically viable and ecologically sustainable human future. This study contradicts the findings of [17]who reported that teachers in training lack knowledge regarding waste management. As in industries, the universities have started to worry about the wastes generated in their teaching and research activities, since they are composed by a great variety of substances, potentially toxic and harmful, which should go through adequate treatment before being disposed, aiming to avoid environmental problems and contamination of living beings [19]. The respondents, however, did not know that procurement of hazardous material should be initiated only if a non-hazardous substitute is not available. This means that when they are working in the laboratory any chemical appropriate for the task can be used regardless of its toxicity.

Students' responses to items that sought to assess their chemical waste practices in the laboratory were analyzed using descriptive statistics (computed into means and standard deviations) and presented in Table 3.

Table 3: Science Students' Chemical Waste Management Practices in the Laboratory

s/n	Statement	Mean	SD
14	Certain used organic solvents are distilled and reused in the laboratory.	2.27	0.81
15	Hazardous analytical reagents are replaced with non-hazardous reagents	2.32	0.82
16	Glassware and some disposable equipment are often decontaminated and re-used	2.58	0.79
17	Chemical waste containers are picked up and the waste disposed of regularly at the laboratory premises	2.57	0.78
18	Chemical wastes that have the potential to react with each other are not placed in the same container	2.80	0.52
19	Chemical wastes generated in the laboratory are disposed of into the sink.	2.68	0.63
20	Chemical wastes (especially expired chemicals) are disposed with the help of Environmental Protection Agencies (EPA)	2.65	0.58
21	Chemical waste disposal is in compliance with EPA regulations	2.67	0.54
22	Chemical stocks are rotated (first in, first out) in the laboratory to help avoid expiration.	2.61	0.55
23	Wastes generated in the laboratory are segregated according to the hazard class and packed into cardboard boxes.	1.48	0.57
24	Certain hazardous chemical wastes are rendered non-hazardous by specific neutralization or deactivation laboratory procedures.	1.40	0.62
	Mean of means	**2.37**	**0.66**

From Table 3, the students were not sure (mean=2.27; SD=0.81) whether certain used organic solvents are distilled and reused in the laboratory. They were not sure (mean=2.32; SD=0.82) hazardous analytical reagents are replaced with non-hazardous reagents. The students however agreed (mean=2.58; SD= 0.79) that glassware and some disposable equipment are often decontaminated and re-used in their laboratories. Again, they agreed (mean=2.57; SD=0.78) that chemical waste containers are picked up and disposed of regularly at the laboratory premises and also agreed (mean=2.80; SD=0.52) that chemical wastes that have the potential to react with each other are not placed in the same container.

Furthermore, the students scored above a mean of 2.5 to agree that they dispose of chemical waste into sinks but mentioned that chemical waste and expired chemicals are disposed in compliance with the Ghana Environmental Protection Agencies (EPA) regulations. Also, they agreed (mean =2.61; SD=0.55) to practice chemical stock rotation (first-in, first-out) in the laboratory to help avoid expiration. In addition, students disagreed that wastes generated in the laboratory are segregated according to the hazard class and packed into cardboard boxes. Also, they disagreed that laboratory procedures such as neutralization or deactivation laboratory procedures are used to render hazardous chemical wastes non-hazardous. The mean of means for practicing chemical waste management was 2.37 (SD=0.67). This suggests that most of the students were not sure or did not know about most of the chemical waste management practices in their laboratories.

The principles involved in chemical waste management system covers waste avoidance, Waste reduction, Waste reuse and Waste disposal. These principles cut across safe waste management practices to ensure the safety of people and the environment. In this study, the students were not sure about the practice of waste reuse in their laboratory. They were not certain that hazardous chemicals are usually replaced with non-hazardous ones. In effect, chemical waste treatment and reusing of some chemical wastes were not practiced in the school chemistry laboratories. According to [20]students' awareness on the correct conditioning, segregation, and identification of the waste generated in laboratories is an important aspect of chemical waste management plan. In order to ensure green chemistry, science educators should raise awareness of the academic community about the importance of the correct disposal of chemical waste.

The results revealed that some liquid chemical wastes were disposed into sinks. This indicates that chemical contaminant such as heavy metals and acids are frequently introduced into drains and nearby environment. The untreated hazardous wastes disposed into the environment cause potential hazard to human health or the environment (soil, air, and water) when it is poorly managed. This practice does not enhance sustainable chemistry.

Chemical stock rotation (first-in, first-out) in the laboratory is very vital to reduce the amount of chemical waste that expires and are discarded. This practice is in line with waste prevention strategy employed in waste management. Waste prevention and waste reuse are important practices that ensures green chemistry. Preventing the use of excess materials, reusing materials, recycling, and buying recycled-content products reduce a school's impact on the environment by saving energy, mitigating climate change by reducing greenhouse gas emissions, reducing the need for raw materials to make new products, and decreasing the amount of material put into landfills. It is importance for schools to broaden the adoption of green principles in academics by training the next generation of chemists to prioritize green and sustainable practices in their undergraduate and post graduate laboratories [21].

The students indicated that waste segregation was not practiced based on hazard class of chemicals. In a follow-up interview, the students mentioned that waste segregation practiced was only to separate waste into either solid or liquid waste. This type of waste segregation can result in laboratory accidents in situations where two or more solid or liquid chemical wastes can react violently. Similarly, [22] asserted that incorrect classification and overlooked compatibility of chemicals can lead to follow-up hazards and threaten the safety of the campus. In addition, it does not enhance recycling of laboratory waste which are plastics and papers. In order to ensure sustainable waste management practices in schools, segregation of waste should be considered as scientific and social responsibility of all the teachers, staff and students working in any laboratory using chemicals. Also, all the teachers, entire laboratory staff and students should be trained to carry out waste segregation in designated waste containers with appropriate labelling. The lack of effective measures of disposal of hazard wastes may cause environmental pollution and pose harm to laboratory staff and users [10].

In addition, neutralization or deactivation laboratory procedures were not practiced in the school's chemistry laboratories. This suggests that chemical waste do not receive any treatment before they are discarded. The lack of standard operational management, and relevant disposal channels of chemical waste can cause secondary pollution to the environment [23]and mitigate the achievement of the United Nations sustainability goals (SDGs 6 and 11) by the set attainment date [3]

Ho_1: There is no significant difference in the knowledge and practice of chemical waste management among patrons in teaching chemical laboratory.

A t-test was used to compare the means of students' scores on their knowledge of chemical waste management to their practices of chemical waste management in order to respond to the null hypothesis. The results are presented in Table 4.

Table 4: t-test comparison of students' knowledge and practice of waste management

Item	N	Mean	SD	t- value	p-value	r- value
Score on knowledge	93	8.45	1.72	47.14	0.00	0.415
Score on practice	93	6.56	2.83	22.36		

The mean score of students' knowledge in chemical waste management was 8.45 (SD =1.72) while that of their practice was 6.56 (SD = 2.83). The small standard deviation obtained for knowledge indicates that most of the students obtained scores close to this mean value and hence were consistent with having good knowledge on chemical waste management than how they practice it. A t-test conducted revealed a significant difference ($p=0.000<0.05$) in students' knowledge and practices of chemical waste management in school laboratories. It suggests that a student may have good knowledge in chemical waste management but how it is put into practice is poor. The null hypothesis is therefore rejected. Pearson correlation revealed that students weakly ($r=0.415$) put their good knowledge in chemical waste management into practice. The inability of students to properly practice waste management makes the environment susceptible to pollution and hence, is a concern for both environmental and public health. In order to achieve quality water supply, protect life under water, ensure food security, and promote the attainment of sustainable development goals, efforts should be made to inculcate into students the proper ways of managing chemical waste both at home and in school.

CONCLUSION

The practice of chemical waste management by students in their chemistry laboratories does not reflect on the good knowledge they have in chemical waste management. It is important for educational institutions, in this regard UEW to provide all needed materials and support to students at all levels of education to enhance proper practices of chemical waste management to protect our environment. It is, therefore, recommended that educational institutions particularly at the tertiary level must build a culture of sustainability and environmental protection in accordance with Sustainable Development Goals (SDG 6 and SDG 11) [3] among its science students; especially chemistry students who deal more with chemical substance to facilitate achievement of the SDG goals.

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STUDENT INTERACTION PATTERNS AS PRECURSORS OF ACQUIRING CHEMISTRY PROCESS SKILLS DURING QUANTITATIVE PRACTICAL LAB ACTIVITIES

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ABSTRACT

Quantitative analysis is one of the most important secondary school chemistry topics where students can acquire chemistry process skills (CPS) through a series of laboratory activities. Research agrees that student interaction patterns (SIP), like interactions with other students, the teacher, and interfaces, improve online learning effectiveness, but their effectiveness in the acquisition of CPS in face-to-face chemistry labs is not clear. This study examined which interaction patterns students use most to gain CPS in a quantitative analysis chemistry lab. SIP and CPS during lab activities were observed in 197 chemistry students in randomly selected intact classrooms. The observation of students on these variables was evaluated using a 21-item laboratory interaction evaluation scale with a cronbach alpha of 0.84 and Chemistry students process skills observation checklists (CSPSOC). The study found that students interact most with each other in the lab, followed by with teachers, and least with interfaces (apparatus, reagent, and manuals). The relationship between the student-interface interaction pattern and basic CPS ($r = .25$; $p < .01$) and integrated CPS ($r = .19$; $p < .01$) was significant. The student-teacher interaction pattern predicted the student CPS the most ($\beta = .61$; $p < .01$) and accounted for 36% of the variance. In addition, the combination of student-student and indirect interaction patterns predicted CPS ($\beta = .18$; $p < .01$) and accounted for 39% of the variance. The paper discusses the implications for understanding interactions in a face-to-face laboratory from a cognitive, social, and teaching perspective. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Practical lab activities are an extremely important component when implementing the science curriculum, as they help students gain 21st-century abilities [1], [2], [24, 27, 31]. For example, Chemistry, which is a required course for all 100-level Science, Technology, Engineering, and Mathematics (STEM) majors, uses lab activities to help students apply chemical concepts learned in theory to tackle real-world challenges [2]. Students are often required to experiment with reagents and equipment in a quantitative practical classroom in order to develop their understanding of acid, base, and salt and maintain their enthusiasm for science. However, it has been noted that in most public schools in Nigeria, practical work, especially in overcrowded classrooms, has been limited to teacher demonstrations, limited supplies of resources, recipe-type activities, and ineffective instructional methods used by teachers [21].

Over time, the problem of overcrowded classrooms and a lack of resources and supplies has primarily been solved by introducing virtual laboratories to complement face-to-face practical lessons and even encourage science students to participate in lab activities. However, these virtual labs involve the physical isolation of students and equipment, thereby reducing the student's acquisition of psychomotor skills in science. Wei et al. [40] noted that the virtual laboratory's failure to allow students to physically control equipment, materials, and apparatus in real time may undermine students' chemistry process skills (CPS). This could have led to differences between the students' attitudes and the scientific attitudes needed by the industry [30], and the lab activities have often been shown to be ineffective [37].

As a result, in order to bridge the gap between students' attitudes toward chemistry and the scientific attitude required by industry, process skills should be encouraged as early as high school chemistry lab activities. Thus, CPS-enhancing therapies [5, 10, 33] have also been developed for students to improve these skills, but studies have revealed that students were only exposed to the basic chemistry process skills, while integrated skills remained unacquired [3, 4], [5,] and [17]. The result of the non-acquisition of an integrated CPS may have a detrimental influence on students' learning results in chemistry and other science subjects. Researchers discovered that students who performed well in four of the seven CPS tests still performed poorly in stoichiometry-related chemistry tests [3], [19], [21] [43]. The skills for an integrated process can be acquired by improving the patterns of interaction that students engage in the laboratory because man is a social being that incorporates relationships between human behaviors and the environment. More importantly, research has shown that different patterns of interaction help students succeed in online programs.

Therefore, the present study was carried out to test the effect of the research-proven student-student, student-teacher, and student-interface (apparatus, reagents, and manual) interaction patterns to improve chemistry process skills in the face-to-face laboratory classroom. The study presents ways to help students acquire integrated chemistry process skills and will assist teachers in planning and implementing interactive student laboratory activities. One research question and two hypotheses were addressed to achieve these goals.

Research Questions

1. What interaction pattern is prevalent among secondary school students during chemistry quantitative analysis lessons in the laboratory?

Research Hypotheses

- $H_0$1: There is no significant relationship between the student's interaction patterns and basic and integrated chemistry process skills.
- $H_0$2: There is no significant predictive ability of the interaction patterns in the development of students' science process skills.

LITERATURE REVIEW

The Concept of Chemistry Process Skills (CPS)

Chemistry Process Skills (CPS) are the cognitive and psychomotor skills used in problem solving and the tools and abilities needed to apply scientific concepts to laboratory and practical work. It involves learning to do, define, refine, and resolve activities in the laboratory. [42, 32]. These skills encourage children's active participation in the learning process and include tools for information gathering, problem solving, decision-making, and adaptation [19] [26] [43]. Chemistry process skills are often grouped into two categories: basic and integrated skills.

The basic skills include observation, communication, classification, measurement, predicting, and inference, while the integrated skills are formulating hypotheses, naming, and controlling variables, experimenting, transforming, and interpreting data. According to research, junior high and secondary students performed poorly on the science process scale [19]. According to studies, while basic process skills are easily acquired by students, integrated skills are consistently reported as low [19] [26] 43].

Different methods to improve students' processing skills have been suggested, like the Bouabdaulah [9] study, which emphasized that prospective chemistry teachers may need to introduce concept maps to teach practical chemistry topics to address students' skill acquisition problems. Furthermore, a study investigated the effect of a modified laboratory learning environment (MLLE) on secondary school students' biology process skills [33]. It was found that the process skills of the students improved when they were taught in a modified laboratory learning environment. It was also found that the biology process skills of low achievers improved significantly and had a significant effect on students' retention [33]. Most of these studies have provided novel instructional approaches to help students acquire the basic and integrated skills they need to succeed in a scientific world but only a few have recognized the potential inherent in the interactions that take place among students, teachers, and the apparatus and reagents used to carry out these activities. Thus, the interaction patterns of students can influence the acquisition of basic and integrated CPS in laboratories. Any method of teaching will only be effective if students interact with their environments because they are social beings. This includes interacting with other students, teachers, and the equipment, apparatus, and materials in a laboratory setting.

Interaction Patterns that Take Place in the Face-to-Face Laboratory

Interactions are communication or direct involvement with someone or something that can occur between individuals that are essential elements in any social discourse, particularly for students in both formal and online learning environments. While much research on laboratories has focused on the products of learning and skills developed and used by students, an important aspect of laboratory learning is understanding the interactions in which students engage when carrying out laboratory activities. Indeed, interactions in laboratories between students and their environment have a direct impact on learners' performance and their learning outcomes according to the theory of distributed cognition [12] [25]. Other students, instructors, equipment, computers, and laboratory manuals can all be found in science laboratories [11]. Accordingly, the main interactions between the learner and the environment in science laboratories can be classified into four categories.

1. Student–student (S–S) interactions, which refer to interactions among students within or between groups;

2. Student–Teacher (S–T) interactions, which refer to interactions between students and the teacher;
3. student–interface (S–I) interactions, which refer to students manipulating equipment such as glassware, using chemicals, consulting the laboratory manual, or accessing the Internet in the laboratories; and
4. Indirect or vicarious interactions (I–I), in which students learn by watching or listening to what other people do.

The first two forms of interactions (S–S and S–T) are interpersonal and include two-way communication, whereas S–I and I–I are one-way in face-to-face laboratories because students only get information from materials and do not receive immediate answers.

A study showed that learner-instructor and learner-learner interactions, when used synchronously or asynchronously, were perceived as effective discussion modes and played an important role in the success of students [13]. Another study determined the perceptions of graduate students in distance education classes as regards student-to-student interaction. It was found that while some students desired student-to-student interaction, many of the respondents did not particularly like or want student-to-student interaction. It was also showed in a study that student-student relationships play a significant role as they can relate to and retain whatever they learn from their peers more than any other relationship [36]. In a study carried out by [17], it was revealed that the influence of interactions on student academic performance is significant. The predictor variable was also discovered to have significant contributions to the dependent variable. It has also been documented the type and number of interactions observed between students and graduate teacher assistants versus undergraduate teacher assistants [27].

It was found that students showed no significant differences in their interaction patterns in the laboratory. It also concluded that students generally feel more comfortable interacting with the UTA. Student-content, student-peer, and student-teacher patterns are documented in the literature and have been used to facilitate the academic performance of distance education students in various studies [23] [6]. One area that has been scarcely researched is student-interface interaction, which is defined in this study as the relationship that takes place between students and the equipment, laboratory manual, and tools (e.g., technological software) needed to perform the required task in the laboratory [41].

In addition, it has been observed that students are usually exposed to practicals at the tail end of writing external practical exams. This practice compels teachers to set up the practical apparatus themselves while students document the result obtained by the teacher. The adverse effect of this practice is that students graduate from secondary schools most of the time and cannot set up the apparatus or equipment needed to carry out simple titration activities. The implication will be that students will not be able to internalize and practice whatever they have been taught in theory. The learning environment in which students carry out laboratory activities should be distinguished as either a productive or non-productive environment. Therefore, it is apt to evaluate the interaction pattern that operates in the secondary school laboratory and investigate its predictive ability for the acquisition of students' CPS.

Theoretical Framework of the Study

Interaction is considered crucial to learning experiences from the sociocultural constructivist perspective (Vygotsky, 1962), which theorized that participation in the discursive practices of the community supports knowledge construction. The theory evolved into "Community of Inquiry" (COI), which recognizes that the presence and interaction of cognitive, social, and teaching presences support teacher practices for students' success. The theory of COI has been recognized for its applicability to computer-mediated communication (CMC) in synchronous and asynchronous educational interactions. Meanwhile, its applicability to face-to-face practical laboratories is lacking in the literature. Garrison, Anderson, and Archer (2000) posited that educational setups are supported by the presence and interaction of elements of cognitive, social, and teaching presences. It is used in this paper to describe the interaction that takes place between the four students' interaction patterns and their enabling ability to develop their chemistry process skills.

Studies have emphasized the active participation of students in the learning process, where the construction of knowledge emerges due to the interactions of students with their environment (other students, teachers, educational materials, and so on). Research identified learner-content interaction, learner-instructor interaction, and learner-learner interaction as types of interaction patterns [25]. Student–student (S–S) interactions are the interactions that take place among students within or between groups. Student–Instructor (S–I) interactions, used in the study as "student-teacher," refer to interactions between students and the teacher; student–equipment (S–E) interactions refer to students manipulating equipment such as glassware, using chemicals, consulting the laboratory manual, or accessing the Internet in the laboratories; and indirect interactions (I–I), often referred to as "vicarious learning," refer to students' learning by observing others or listening to others' conversations. Several researchers have carried out studies on interactions that take place both online and in a physical environment.

METHODOLOGY

This study adopted a descriptive survey design where observations were made of all laboratory activities during practical sessions. These observations were gotten from a 5-minute video recording of verbal interactions between students, teachers, and the apparatus. Observation checklists and rating forms were completed based on the observations of these students in the 10 recordings of the 5-minute video.

Participants, Research Instruments and Procedure

The population of the study comprised all senior secondary school three (SSSIII) students in Ekiti State during 2019/2020 session. Sample for the study were 197 students (62.4% female, 37.6% male) randomly selected from three 16 local governments of Ekiti State. Ages ranged from 16 to 20 years (M = 17.5 years, SD = 8.3). A multistage sampling technique was employed in selecting the sample. Three Local Government Areas (LGAs) were selected through a simple random sampling technique. One secondary school was randomly selected from the three local government areas. Students in their intact classes participated in the study.

Two instruments were employed in collecting data for the study. The students interaction pattern rating scale (SIPRS) and the Chemistry students process skills observation checklists (CSPSOC).

Students-interaction pattern rating scale (SIPRS) is a modified instrument of the interaction questionnaire from the study of [41]. It consists of four dimensions namely student-student interaction, students-teacher interaction, student-interface interaction, and indirect-interaction. Students' interaction pattern rating scale consists of two sections; section A, consists of the bio-data information of the respondents and Section B consists of 19 questions which were rated as frequently (4), occasionally (3), rarely (2) and never (1). It was used to gather information on students' interaction pattern levels in the classroom. The instrument was re-validated and reliability coefficient was computed using Cronbach alpha and a reliability coefficient was calculated as r = 0.94, 0.66, 0.88, 0.84 for students-students, students-teacher, student interface and indirect observation interaction pattern (for the different sections of the instrument) respectively.

Science Process Skills Observation Checklists for Chemistry Students (SPSOCCS); The SPSOCCS is a rating scale used in the classroom to assess students' basic and integrated skills during quantitative analysis. The instrument was adapted from the study of Ugwu, (2009). Under each science process skill, the instrument statements of practical activities with which students were observed. Experts in the fields of chemistry, measurement and evaluation validated the instruments. They made the necessary changes to the items, and their feedback was incorporated into the instrument's final draft. After validation the final copy of the instrument was subjected to a reliability test using Cronbach's Alpha-statistics. The reliability co-efficient was calculated to be 0.80. This value indicates that the instrument was reliable and suitable to be use for the study.

The research was carried out in two stages during the third term of the 2019/2020 academic session. The study will last for about twelve weeks of third term of the selected schools i.e from May 5 to June 27, 2019. At the pre-data collection stage, the researcher will visit the selected secondary schools in Ekiti State to seek the permission of the school principals and solicited for support of the teachers and students' cooperation. The researcher went ahead to meet with the Chemistry teachers of SSII to be sure that the students have been engaging in practical activities. The researcher also employed research assistants who were trained for two weeks before the commencement of the field study. They were trained on how to observe the students on Chemistry Students Science Process Skill Rating Scale and administration of the students-interaction pattern questionnaire. The schools were visited during practical activities and students were observed and rated while the student's interaction scale was administered to the students during the period they were writing their lab report. The rated scale and questionnaire were collected and collated. The two scales were coded and sorted out for the missing data.

Data Analysis and Results

Checking for normalcy, missing data, extreme data, and outliers was performed during the initial data screening. The rating scale was dichotomized by combining the frequently and occasionally engaged interaction pattern values together and adding the seldom and never engaged interaction pattern values. Research question one was analyzed using descriptive statistics such as mean, frequency, and percentages. The hypotheses were respectively analyzed using Pearson Product Moment Correlation (PPMC) and hierarchical regression analysis.

RESULTS

Research Question 1: What interaction pattern is prevalent among secondary school students during chemistry quantitative analysis lessons in the laboratory?

Table 1: Descriptive Statistics of Mean, Standard Deviation and percentage of Students Interaction Pattern N =197

		Percentage Frequently/ ocassionally	Rarely/Never	Mean	Standard Deviation
	Student-Student Interaction				
1	The student was seen talking to another student to learn about the procedures/lab equipment.	182(92.4)	15(7.6%)	4.97	1.19

2	Student was discussing with other students about lab procedures/equipment	182(92.4)	15(7.6)	5.11	1.14
3	Student was observed to be communicating their titre values with other students	182(92.4)	15(7.6)	4.97	1.15
4	Student contacted with fellow students on how to analyse results while carrying out titration activities	183(92.9)	14(7.1)	4.99	1.15
5	Student was active in the small groups/teams he/she belonged	183(92.9)	14(7.1)	5.04	0.13
	Dimension Mean	25.04			2.52
	Students-Teachers Interaction				
6	The student interacted with the teacher on a clicker question and the instructor is answering student questions	174(88.3)	23(11.7)	4.95	1.29
7	There was evidence in teacher provided feedback on student work by commenting in his/her notes	173(87.8)	24(12.2)	4.76	1.24
8	Students was able to put forth effort and submitted practical note for teacher feedback before leaving the laboratory	172(87.3)	25.5(12.7)	4.53	1.15
	Students-Interface Interaction				
11	Students engage with the equipments/apparatus during acid – base titration	39(19.8)	158(80.2)	1.91	0.44
12	All the equipments were functional	28(14.2)	169(85.8)	1.63	0.35
13	The student followed procedures as stated in the laboratory manual	21(79)	176(89.3)	1.66	0.24
14	The student clamped the burette with the retort stand and pipetted the base	21(10.7)	176(89.3)	1.60	0.21

16	The student did not just leave the teacher with the setup, rather was seen to engage with lab procedures/equipment and basic concepts	50(25.4)	147(74.6)	1.80	0.14
	Dimension Mean	10.25			3.60
	Indirect Interaction (I-I)				
17	The student observed other students' experimental setup and behavior's when carrying out titration activities	160(81.2)	37(18.8)	3.52	0.46
18	The student listened to other student-student conversations to make the necessary corrections in his/her lab work	157(79.7)	40(20.3)	4.64	1.49
19	The student listened to other student-instructor conversations to adjust his/her lab activities	163(82.7)	34(17.3)	2.12	1.48
	Dimension Mean	14.60			4.21
	Grand Mean			25.09	5.52

Note: N=197 X < 2.5 low, X > 2.6 moderate X > 4.1 High

Table 1 shows that a larger percentage of the students about 182 (92.4%) engaged in student-student interaction pattern during titration activities. About 172 (87.3%) engaged in student-teacher interaction pattern, while fewer students were engaged with the interfaces and about 27(14.2%) and 157(79.7%) engaged in indirect interaction pattern. It could infer from the result that among the four-interaction pattern examined in the study, the most prevalent interaction pattern students engage in was the student-student interaction pattern, followed by student-teacher interaction pattern, the indirect interaction pattern, while the least interaction took place between student-apparatus/equipment pattern.

Hypothesis 1: There is no significant relationship between the interaction patterns and basic and integrated CPS.

Table 3: Correlations of the variables in the Study

Variables	SS	ST	SE	II	BasicPSkills	INTPSkills
SS	-					
ST	.717**	-				
SinT	.165*	.311**	-			
II	.451**	.510**	.253**	-		
BasicPSkills	.497**	.587**	.253**	.397**	-	
INTPSkills	.366**	.393**	.199**	.342**	.377**	-

SS-Student-Student Interaction, STI- Student-Teacher Interaction, SinT- Student-Interface Interaction, II- Indirect Interaction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 3 showed that there was a positive relationship between Student-student interaction pattern and students basic ($r = .49; p < .01$) and integrated process skills ($r = .37; p < .01$). Student-teacher was related to basic process skills and integrated process skills ($r = .39, p < .01$). There was a moderate significant relationship between student-interface interaction pattern and basic ($r = .19: p < .01$) and integrated skills ($r = .25: p < .01$). Although, the relationship could be regarded as weak¸ a significant relationship was still established. The result showed that student-indirect interaction patterns have relationships with both basic ($r = .39: p < .01$) and integrated process skills ($r = .34: p < .01$)).

Hypotheses 2: There is no significant predictive ability of the interaction patterns in the development of students' CPS.

Table 3: Regression Analysis of the Predictor Variables on the Dependent Variable

Pattern		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R
		B	Std. Error	Beta			
1	Model 1						
	(Constant)	58.933	3.449		17.088	.000	
	ST	1.541	.145	.604	10.596	.000	.36
	Model 2						
	(Constant)	55.404	3.599		15.396	.000	
2	ST	1.296	.166	.508	7.807	.000	.39
	II	.629	.217	.188	2.892	.004	
	Model 3						
3	(Constant)	52.149	3.897		13.382	.000	
	ST	1.015	.213	.398	4.769	.000	
	II	.565	.218	.169	2.593	.010	.41
	SS	.425	.205	.167	2.078	.039	
	Model 4						
	(Constant)	50.433	3.846		13.112	.000	
	ST	.903	.211	.354	4.280	.000	.44
	II	.478	.215	.143	2.227	.027	
	SS	.496	.201	.195	2.468	.014	
	SE	.092	1.1566	.119	.112	.881	

The 2 variables of measure here are not properly defined, so, how were they captured or measured? (Interaction pattern and science process skills?) What statistic was used to produce table 3?

a. Dependent Variable: SPS
b. Predictors in the Pattern: (Constant), ST
c. Predictors in the Pattern: (Constant), ST, II
d. Predictors in the Pattern: (Constant), ST, II, SS
e. Predictors in the Pattern: (Constant), ST, II, SS, SE

Table 3 showed that in Student-teacher interaction pattern ($\beta = .61$; $p < .01$), predicted SPS, while another variable that has a predictive ability as regards the results in Table 3 is the indirect-interaction pattern ($\beta = .18$; $p < .01$). Student-student interaction pattern also predicted SPS ($\beta = .17$; $p < .01$), however, student-interface interaction pattern did not predict SPS.

DISCUSSION

Understanding the interaction pattern that takes place in the classroom enables teachers to address the cognitive and psychomotor skills students lack. It also helps teachers ensure that both teachers and students achieve the objective with which they engage in laboratory activities. Experienced teachers describe, explain, and predict student interactions by drawing on their professional knowledge about the types of student interaction patterns that are associated with cognitive, affective, and psychomotive outcomes. In the present study, the results from analyzing student interaction patterns and observations both established that the student–student interaction pattern occurred most frequently, while student–teacher interaction occurred second most frequently, and both the student-interface and indirect-interaction patterns occurred less frequently. This result is consistent with ideas of socio-constructivism and community of inquiry (COI) theory, which postulate that meaningful learning for students is situated in social collaboration and interactions with other people, most frequently with colleagues or friends.

Similar studies indicate that students engage more with their colleagues [23], [36], and [6]. The result is also consistent with recent research by [40]. It was discovered that student-student interaction is the type of interaction that students view as being most relevant to their laboratory work [40]. One reason that may have necessitated the prevalence of student-student and student-teacher interaction in the laboratory is that students' notes are usually graded at the end of practical classes, and the grade will be used to judge students' performance.

Therefore, students in a rush to get grades ask their colleagues who are smarter for their notes to give dumb answers to the practical questions without necessarily carrying out the experiment. Moreover, Senocak and Tatar [36], in a study examining factors contributing to students' failure in the laboratory, observed that students scored highly on the item "worrying about being unable to complete experiments." Therefore, students tend to focus more on turning in their notes to earn good grades than performing the experimentation themselves. Though student-student interaction patterns in classes contribute to the development of teamwork and collaboration skills, these interaction patterns need to be guided by teachers to bring about the desired CPS in individual students. More activities that require students to work in groups or on sequential aspects of real-world projects should also be designed [34].

Students should be allowed to work collaboratively with other students and their teacher, but should be encouraged to participate in all the interactions that take place in the laboratory because they will retain more when they interact with the equipment and apparatus themselves. This differentiates between what students can perform by themselves and what they can perform with others in Vygotsky’s "zone of proximal development."

Moreover, the results from the study showed that all students' interaction patterns investigated had significant relationships with both the basic and integrated CPS. Studies have confirmed this finding, demonstrating that student-student interaction has a significant influence on student academic performance [36].Some other studies that have determined the levels of students' science process skills have reported that participants most of the time possess the basic skills of observation, measurement, communication, and recording but lack or rank low in the integrated skills of experimenting, manipulating variables, formulating models, identifying, and controlling variables. The present study showed that both basic and integrated skills were acquired and improved by engaging them in productive interaction patterns.

The third finding revealed that student-student, student-teacher, and student-indirect interaction patterns were important predictors of CPS and contributed up to 41% to students' process skill development. This discovery is in line with the findings of [23], who showed that students' levels of interaction influence their grades. It was also supported by [1] in a study that found that all three types of interaction investigated were significant predictors of academic performance among distance education students. Hence, the present study suggests that students' CPS will also require direct manipulation of interfaces (equipment, apparatus, reagents, and materials) by them when engaging in laboratory activities. As a result, it is critical for both teachers and students to recognize and connect the cognitive, social, and teaching presences to achieve the written and unwritten goals of the science curriculum.

CONCLUSION

In examining the interaction that takes place between students, teachers, equipment, and content, the findings from this study suggest that the interaction between student-student and student-teacher occurs frequently in laboratory classrooms, whereas student-equipment and interactive interaction need to be reemphasized. It also concluded that the studied student interaction patterns have the potential to develop students' chemical process skills in practical classrooms.

These findings could guide greater experimentation by educators in extending the range of student interactions that occur in face-to-face practical environments, especially in distant education studies. From the sociocultural constructivist perspective, the learner has the potential capacity for intellectual growth and could be able to do so, enhanced by scaffolding different interaction patterns.

RECOMMENDATIONS

It is therefore recommended that:

1. A new practice debugged of only one type of interaction, recitation book styles, should be adopted by teachers to enhance awareness of the influence of the three mutually interacting elements of cognitive, social, and teaching presences in the practical classroom.

2. Students should be encouraged to interact and participate in all possible interactions when carrying out laboratory activities to enhance the development of 21st century skills.
3. Teachers should ensure that the mode of interaction pattern adopted is unique to different activities in the sciences.
4. Laboratory technicians and subject teachers should be provided with suitable training seminars and programmes to create awareness of the different interactions that take place in the laboratory and methods that can be used to engage students actively in the laboratory.

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USING EXEMPLARY MATERIALS TO ENHANCE STUDENTS' PERFORMANCE AND RETENTION IN HYBRIDIZATION

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ABSTRACT

This study examined how exemplary materials improve students' performance and retention in hybridisation. A quasi-experimental pretest-posttest-post-posttest non-equivalent design was used with a modified Solomon four-group design, using hybridisation conception achievement tests (HCATs). A multistage sampling technique was used to sample four intact chemistry classes from four senior high schools in Kwabre East, Ashanti, Ghana, who had not been exposed to hybridisation. The control and experimental groups had two classes each. The experimental group learnt with exemplary materials in the form of models, balloons, and computer simulations. Data were analysed with SPSS 20.0. No pretest sensitization was observed, as no statistically significant differences were found between the posttest scores of the pretested experimental group and those not pretested ($p = 0.07$) and the posttest scores of the pretested control groups and those without pretest ($p = 0.06$). The posttest findings showed a significant increase in performance ($p < 0.001$) of the experimental group a week after the treatment. Experimental groups significantly performed better than control groups ($p < 0.001$). The experimental groups' retention significantly increased three weeks after the posttest ($p = 0.03$). Again, experimental groups' retention was better than the control ($p < 0.001$). Learning chemistry (and science) should involve using exemplary materials and student-centred pedagogies to improve the performance and memory of chemical concepts like hybridisation. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Improving students' performance and retention of scientific concepts is essential in science education. The instructional approaches employed to teach scientific concepts influence the attitudes, performance, and retention of scientific concepts considerably among students [1, 2, 3, 4]. Retention of scientific concepts is known [5] to depend largely on the teaching methods and strategies the teacher adopts. These instructional methods and approaches, which are mostly learner-centred, include web-based learning activities, discussion and collaborative methods, demonstrations and practical activities, and exemplary materials like computer simulation and models. In all these, the conceptual knowledge of the teacher, who is to facilitate the science learning experience, also contributes significantly to the achievement and retention of the students [2, 4, 6, 7, 8, 9, 10, 11].

A number of studies have been conducted on hybridisation to ascertain students' conceptions of the concept and appropriate instructional approaches that would enhance their conception [12, 13, 14]. In one such study [14], the conceptual teaching approach in line with the cognitive theory was found to enhance the conception of pre-service teachers. Though suggestions have been given to enhance the performance and retention of learners in hybridisations [13, 14], the lack of understanding and poor performance of Senior High School students over the years in hybridisation in Ghana, in particular, is worrying as the performance of SHS candidates in the West African Senior Secondary Certificate Examinations on hybridisation has always been reported as low [15, 16, 17]. Again, preliminary observations made by the researchers in the Kwabre East Municipality and [18] showed that most of the lessons on hybridisation have been abstract and teacher-centred. Teachers have been using the conventional (traditional) method, which is known to be problematic and misconceived [7, 19] and have not utilised their Science Resource Centres, believed to be equipped with materials for the learning of the concept. Based on these studies therein, the current study employed the use of exemplary materials in learner-centred activities and the Solomon-four group design with Senior High School (SHS) students to see how it would affect their understanding of the concept of hybridisation. There is an urgent need to explore how the use of exemplary materials would affect students' performance and retention in hybridisation.

To provide an evidence-based approach to the effectiveness of using exemplary materials to enhance students' performance and retention in the concept of hybridisation, this study sought to answer the following research questions:

(1) How would pretesting affect students' performance on hybridisation?
(2) What is the effect of the use of exemplary materials on students' performance on hybridisation? and
(3) How would the use of exemplary materials enhance the retention of the concept of hybridisation among students?

Eight null hypotheses were tested at a 95% confidence interval to guide this study and answer the research questions. The study utilised the Solomon four-group design to answer research question 1 by formulating null hypotheses 1 and 2 as follows:

Ho1: There is no statistically significant difference between the mean posttest scores of the experimental groups with pretest and without pretest, and

Ho2: There is no statistically significant difference between the mean posttest scores of the control groups with pretest and without pretest.

Null hypotheses 3, 4, and 5 were set to answer research question 2 to ascertain the effect of the use of exemplary materials on students' performance in hybridisation.

Ho3: There is statistically no significant difference in students' mean pretest and posttest scores in the control groups.

Ho4: There is statistically no significant difference in the mean pretest scores and posttest scores of the students in the experimental groups.

Ho5: There is no statistically significant difference in the mean posttest scores of students in the experimental and control groups.

Null hypotheses 6, 7, and 8 were set to answer research question 3.

Ho6: There is no statistically significant difference between the mean posttest scores and post-posttest scores of the control groups.

Ho7: There is statistically no significant difference between the experimental groups' mean posttest and post-posttest scores.

Ho8: There is no statistically significant difference between the mean post-posttest scores of the experimental groups and the control groups.

METHODS AND MATERIALS

Description of the Study Area

The study was conducted in four different Senior High Schools in the Kwabre East Municipal area of the Ashanti Region of Ghana.

Research design

The study employed a quasi-experimental design using a modified Solomon four-group design. The pretest-posttest-post-posttest non-equivalent design from Arah, *et al.* [20] was adapted as a modification to the Solomon four-group design [21] to ascertain the students' retention of the concept of hybridisation. The research design layout is shown in Table 1.

Table 1: Research design layout

Group	Pretest		Posttest		Post-posttest
Experimental Group 1 (E1)	O_1	X	O_3	Y	O_7
Control Group 1 (C1)	O_2	-	O_4	Y	O_8
Experimental Group 2 (E2)	-	X	O_5	Y	O_9
Control Group 2 (C2)	-	-	O_6	Y	O_{10}

Where **X** = Experimental treatment (using exemplary materials); **Y** = A delayed period of three weeks after the posttest.

The Solomon four-group design combines the posttest only and pretest-posttest experimental designs used to ascertain the effect of pretesting (pretest sensitisation) on the instrument and, in this case, using exemplary materials [21]. The design is used to determine the extent to which the pretest affects the effectiveness of the treatment. That is to say that if there is enhanced performance in the students' conception of hybridisation, would it be because of or as a result of the pretest, or was it because of the effectiveness of the treatment? The design also has higher external validity than the other experimental designs. Again, with the Solomon four-group design, the generalisability increases, and the treatment can be replicated.

Population, Sample and Sampling Procedure

The target population for this study was the chemistry students in the Kwabre East municipality, with the accessible population being the first-year chemistry students in the municipality. The Kwabre East municipality can boast of eight senior high schools; six government-assisted schools and two private mission schools. A multistage sampling technique was used for this study. Firstly, four schools whose students were yet to be exposed to the concept were conveniently and purposively selected to ensure that the students did not interact with each other [22]. Then, a chemistry class was randomly selected from each of the four schools. Finally, two of the four selected classes were randomly selected as the control group and the other two as the experimental group.

In all, one hundred and four (104) students were sampled for the study. Forty-five formed the control, with twenty-three (23) taking a pretest (C1) and twenty-two (22) without a pretest. The experimental groups were made up of fifty-nine (59) subjects, having thirty-one (31) of them in the experimental group with the pretest and twenty-eight (28) in the group without a pretest.

Research Instrument

The instrument used was an achievement test (pretest, posttest, and post-posttest), known as the hybridisation concept achievement test (HCAT) adapted from Nakiboglu [13], Hanson *et al*. [14], and Cobbinah [18] based on the Ghana Education Service [23] and West Africa Examination Council's chemistry syllabi. The first part of the test contained eleven open-ended questions, while the second part had six multiple-choice items with two, three, or four-choice responses.

The pretest (PrHCAT) was administered to only two groups before the treatment – one from each of the experimental (E1) and control groups (C1). The posttest (PoHCAT), was administered to all four groups a week after learning to ascertain any changes in their performance. The post-posttest (PpHCAT), which was also the retention test, was administered to all respondents three weeks after the posttest to ascertain the effect of the exemplary materials on their retention of the concept of hybridisation. The researchers and two SHS teachers assessed the instrument's validity, format, and difficulty level for the students before it was pilot tested [21] with a sample of twelve SHS 2 students from the S. D. A. Senior High School. These students did not participate in the actual study. The HCAT had a good test-retest reliability of 0.861 over three weeks.

Data Collection and Analysis

Both the experimental and control groups were taught by the reseachers for three weeks. The control groups were taught with the conventional teaching method, with no teaching learning resources. The students were completely passive in this case; this embodied the use of the researcher's explanations and textbooks. The fundamental principle is that knowledge is transferred from the teacher to the students. The experimental groups were taught using exemplary materials - latex balloons, Molymob® Chemistry Organic Molecular Model kits (students' set) and computer-assisted animations on hybridisation. The concept of hybridisation was introduced, adopting the idea of hybrid fruits in agriculture, where oranges, tangerine and "orangerine" (a hybrid of orange and tangerine) were used [18]. The balloons, molecular model kits and computer simulations gave the students a three-dimensional real view of the orbitals to enable them to relate the types of hybridisation, shapes and bond angles of the various types of hybridisation through group discussions and presentations. Additionally, various relevant portions of the videos from www.YouTube.com [24, 25, 26, 27, 28] were also used. The group discussions facilitated collaborative learning, critical thinking, and imaginative and problem-solving abilities. Additionally, the groupings allowed the students to interact with the exemplary materials. The groups occasionally shared their views with the entire class through group presentations and whole-class discussions.

The data collected was analysed using version 20.0 of SPSS. Responses from both the experimental and control groups were analysed using independent-sampled and paired t-tests to test the null hypotheses. The t-tests were performed with the assumptions that the data collected was continuous, normally distributed, and with homogeneity of variance [21].

RESULTS

One of the strengths of the Solomon four-group design was to ascertain the effect of pretesting on the students' performance or treatment (pretest sensitisation). In effect, pretest sensitisation determines the effectiveness of the treatment. In essence, this determines whether the mere act of taking a pretest influenced the scores on subsequent administration of the posttest. It was then essential to identify the extent of the pretesting and how it affected the students' performance. This addressed the first and second null hypotheses.

The effectiveness of the treatment and that of pretesting on the performance of the students were determined by comparing the scores of the experimental group with the pretest (E1) with those without the pretest (E2), and the control group with the pretest (C1) with those without pretest (C2). Independent-samples t-tests were used to determine whether there is any statistically significant difference between the two sets of groups at a 95% confidence level. Table 2 compares the mean scores obtained from the experimental group with the pretest (E1) and those without the pretest (E2) at a 95% confidence level.

Table 2: Independent-sample t-test of posttest scores of experimental groups with and without pretest

Test	N	Mean	SD	*t*	Sig
E1 posttest	31	54.87	7.898		
E2 posttest	28	50.96	8.144	1.869	.07

Table 2 showed that the performance of the experimental group with the pretest was higher than the group without the pretest; however, there was no statistically significant difference in the posttest scores of the experimental group with the pretest (M = 54.87, SD = 7.90) and those without pretest (M = 50.96, SD = 8.14); $t(57) = 1.87$; $p = 0.07$. The result suggests that the pretest did not significantly affect the performance of the experimental group with the pretest and that the increased performance was not due to pretesting. The result is in support of null hypothesis 1 and was not rejected.

To confirm the effect of the pretest on the posttests, the posttests of the control groups were also tested for significance (and to test null hypothesis 2) at a 95% confidence level. The result is shown in Table 3.

Table 3: Independent-samples t-test of means posttest scores of control groups

Test	N	Mean	SD	*t*	Sig
C1 posttest	23	33.52	8.10		
C2 posttest	22	27.59	11.60	1.98	.06

There was statistically no significant difference in the posttest scores of the control groups with pretest (M = 33.52, SD = 88.10) and those without pretest (M = 27.59, SD = 11.60); $t(37.37)$ = 1.98; p = 0.06. The result suggests that the pretest did not significantly affect the control group's performance independent of the treatment and that the increased performance was not due to the pretesting. The result supported null hypothesis 2 and was therefore not rejected. This confirmed the earlier assertion that the pretests (or pretesting) did not significantly affect the posttests or the students' performance (as also shown in Table 2). Hence, the increased or improved means (performance) was, to a considerable extent, due to the effectiveness of the treatment and not the pretest.

Since the data from Tables 2 and 3 showed that the pretesting did not affect the performance (posttests) significantly and that there was no statistical difference between the posttest of the two main groups, the posttest and post-posttest data from both groups (those with and without pretests) were considered together. In this regard, data for the control group was a combination of the two control groups (C1 and C2), with a total of 45 and that of the experimental group (E1 and E2), with a total of 59.

To ascertain any statistically significant difference in the pretest and control posttest scores, an independent t-test was done between the pretest and posttest of the control group at a 95% confidence level. The result is shown in Table 4.

Table 4: Independent t-test of pretest and posttest of the control groups

Test	N	Mean	SD	*t*	Sig
Pretest	54	10.54	4.64		
C_posttest	45	30.62	10.30	-12.86	.00

Table 4 showed there was a statistically significant difference in the pretest scores (M = 10.54, SD = 4.64) and the posttest scores of the control group (M = 30.62, SD = 10.30); $t(97) = -12.86$; $p < 0.001$. The result suggests that there was an improvement in the students' performance on hybridisation in the control group after learning with the conventional method. The null hypothesis 3 was then rejected. Table 5 compares the mean scores of the pretests and the posttest of the experimental group.

Table 5: Independent t-test of mean scores of pretest and posttest of the experimental groups

Test	N	Mean	SD	*t*	Sig
Pretest	54	10.54	4.64		
E_posttest	59	53.03	8.20	-34.27	.00

Table 5 showed that there was a statistically significant difference in the scores of the pretest (M = 10.54, SD = 4.64) and posttest of the experimental group (M = 53.03, SD = 8.20); t(111) = -34.27; $p < 0.001$. The result suggests that the students in the experimental group performed better after learning with the exemplary materials. The null hypothesis 2 was therefore rejected.

Since Tables 4 and 5 showed that there was an improvement in the performance of both control and experimental groups, which did not support the null hypotheses 1 and 2, there was a need to compare the posttest mean scores of the control and experimental groups to ascertain any significant difference and the extent of improvement between them. This analysis is presented in Table 6, which shows the independent t-test of the control and experimental groups to ascertain any significant difference.

Table 6: Independent t-test of posttest of combined control and experimental groups

Test	N	Mean	SD	*t*	Sig
C_POSTTEST	45	30.62	10.30		
E_POSTTEST	59	53.03	8.20	-12.36	.00

The results from Table 6 showed that there was a statistically significant difference in the posttest scores of the control group (*M* = 30.62, *SD* = 10.30) and posttest of the experimental group (*M* = 53.03, *SD* = 8.20); $t(102) = -12.36$; $p < 0.001$. The result suggests that using exemplary materials for learning hybridisation enhanced the performance significantly more than using the conventional method. The null hypothesis 3 was therefore rejected.

To ascertain students' retention of the concept of hybridisation, the results from the posttests were compared with those of the posttests. Additionally, to ascertain the extent to which the use of exemplary materials affected the performance, the results from the experimental groups were compared with those of the control group to test the null hypotheses 6, 7 and 8. Again, the post-posttest results from the control and experimental groups were analysed to ascertain any change in their conceptions. In Tables 7, 8, and 9, the mean scores of the posttests and post-posttests of both the control and experimental groups (at 95% confidence level) were compared.

Table 7 shows the paired samples t-test of the control group's mean scores of the posttest and post-posttest to ascertain the extent of retention due to the use of the conventional teaching method as demanded by null hypothesis 6 (Ho6).

Table 7: Paired samples t-test of mean scores of posttest and post-posttest of the control group (N = 45)

Test	Mean	SD	*t*	Sig
C_POSTTEST	30.62	10.30		
C_POST-POSTTEST	29.40	8.96	0.73	.47

The results from Table 7 showed that there was no statistically significant difference in the control groups' posttest (*M* = 30.62, *SD* = 10.30) and post-posttest (*M* = 29.40, *SD* = 8.96) scores; $t(44) = 0.73$; $p = 0.47$. The result suggests that the performance of the students who used the conventional method for learning hybridisation three weeks after taking the posttest was the same as their posttest performance and that there was no change in their retention. This supports the null hypothesis 6; hence, the null hypothesis was not rejected.

A comparison of the experimental groups' mean posttest and post-posttest scores to ascertain any statistically significant difference between them and then determine the extent of their retention is shown in Table 8.

Table 8: Paired samples t-test of mean scores of posttest and post-posttest of the experimental group (N = 59)

Test	Mean	SD	*t*	Sig
E_POSTTEST	53.03	8.20		
E_POST-POSTTEST	55.83	7.64	-2.27	.03

A statistically significant difference was observed between the experimental groups' posttest (*M* = 53.03, *SD* = 8.20) and post-posttest (*M* = 55.83, *SD* = 7.64) scores; $t(58) = -2.27$; $p = 0.03$. The result suggests a significant increase in the retention of students' conception of hybridisation after learning with exemplary materials. The results support null hypothesis 7; hence, the null hypothesis was not rejected.

Table 9 compares the mean post-posttest scores of the control and experimental groups to ascertain any statistically significant difference between them and determine the extent to which the use of exemplary materials affected the retention of the students.

Table 9: Independent sample t-test of mean scores post-posttests of experimental and control groups

Test	N	Mean	SD	*t*	Sig
C_POST-POSTTEST	45	29.40	8.96		
E_POST-POSTTEST	59	55.83	7.64	-16.21	.00

Table 9 showed a statistically significant difference in the post-posttest scores of the control groups (M = 29.40, SD = 8.96) and experimental groups (M = 55.83, SD = 7.64); t(58) = -16.21; p < 0.001. The result suggests that students who learnt the concept of hybridisation with exemplary materials had higher retention than those who learnt with the conventional method. The results did not support null hypothesis 8; hence, the hypothesis was rejected.

DISCUSSION

Before beginning an intervention or treatment, educational researchers typically want to understand their subject's behaviour by pretesting, which may have an impact on the instrument's internal and external validity [21]. One of the common internal validity threats is the testing threat, which occurs when the scores of the posttest are influenced by the subjects being exposed to the pretest. It happens that after pretesting, the subjects (students in this case) gain experience that may affect their next score, whether they participated in the treatment or intervention. Their experience with the stress and pressure of the test environment (and other factors) would enable them to perform the next time differently. Even if the students would not participate in any treatment or intervention, they could decide to find answers to the previously unfamiliar questions, and this might cause an improvement in their performance if they are to take any subsequent test (posttest). One of the strengths of the Solomon four-group design is identifying the possible effects of pretesting. It utilises four different groups, with two control groups and two experimental groups. One of each of the control and experimental groups would be pretested, while all four groups would be posttested [21].

Best and Khan [21] assert that comparing the posttests of the two experimental groups allows the researcher to determine the effect the pretest had on the treatment. If the comparison of the results of the posttest for the two groups differ (where there is a significant difference), then the pretest affected the treatment. Additionally, the posttests of the control groups could be compared to ascertain any significant difference. This would similarly show whether the pretest itself affected behaviour, independently of the treatment. If the outcomes of the comparison are significantly different, the pretesting process has affected the outcomes and needs to be improved. From Table 2, although the mean of the posttest scores of the experimental group with pretest (M = 54.87, SD = 7.90) was higher than those without pretest (M = 50.96, SD = 8.14), the result showed no statistically significant difference between the two groups (p = 0.07). This was in support of null hypothesis 1. So the null hypothesis was not rejected. This showed that the higher performance was not due to the pretest but largely as a result of the effectiveness of the treatment. Again, Table 3 also showed a similar relation between the posttest scores of the control groups. The control group with pretest (C1) had a higher mean (*M* = 33.52, *SD* = 88.10) than the control group without pretest (C2) (*M* = 27.59, *SD* = 11.60). However, no statistical difference was observed between the groups ($p = 0.06$), showing that the pretest did not affect the behaviour of the students, independent of the treatment. This confirmed the earlier observation with the experimental groups. Tables 2 and 3 then supported the null hypotheses 1 and 2; hence, null hypotheses 1 and 2 were not rejected. Although the mean scores of the groups with pretests (E1 and C1) were higher than that of those without pretests (E2 and C2), there was statistically no significant difference between the performance of the experimental group with pretest (E1) and without pretest (E2) and between the control group with pretest (C1) and without pretest (C2). Pretesting, therefore, did not significantly affect the performance and treatment. The increased or enhanced performance of the students from the experimental group was, to a very large extent, due to the effectiveness of the treatment.

From Table 5, the mean scores of the experimental groups (*M* = 53.03, *SD* = 8.20) were higher than those of the pretest (*M* = 10.54, *SD* = 4.64). This increase in the mean score was statistically significant ($p < 0.001$) at a 0.05 level of significance, which did not support null hypothesis 4. So the null hypothesis was rejected. Again, Table 4 showed a significant increase in the control groups' mean scores (*M* = 30.62, *SD* = 10.30). A statistical difference was observed between the control group's pretest and posttest ($p < 0.001$). So from Tables 4 and 5, there were improvements in the students' performance in hybridisation after learning with the conventional method and with exemplary materials. This was in agreement with [22], who also found no significant pretest sensitisation, with improvement in the experimental group's performance over that of the control group. Although there was a significant increase in the performance of the students in both the experimental and control groups, Table 6 showed that the mean score of the experimental group was higher (M = 55.83, SD = 7.64) than the control group (M = 30.62, SD = 10.30). There was a statistically significant ($p < 0.001$) difference between the mean posttest scores of the control and experimental groups. This showed that the exemplary materials used for learning hybridisation significantly improved students' performance. This supported the assertion that using exemplary materials and activity-based learning enhances students' understanding [1, 29]. Also, using meaningful teaching and instructional methodologies has been recommended [30] to improve students' performance and retention in hybridisation, which was done in this study (instead of the conventional teaching approaches).

Every effective learning is expected to have a lasting effect on the conception of students, and they would be able to recall these learning experiences after some time [31, 32]. Tables 7 to 9 showed how the posttest and post-posttest performance of students in the control and experimental groups differ from each other. Table 7 showed that the control group's mean posttest score (M = 30.62, SD = 10.30) reduced on taking the post-posttest (M = 29.40, SD = 8.96) three weeks after taking the posttest. Although there was a reduction in the performance of the students after the posttest, no statistically significant difference was observed between the posttest and post-posttest scores of the control group; $t(44) = 0.73$; $p = 0.47$. This supported the null hypothesis 6, and hence, the null hypothesis was not rejected. In effect, even though there was a reduction in the performance, as shown in their mean scores, the reduction was not significant, and hence their retention did not change significantly after the three weeks delay time. The control group's conception was therefore retained.

In comparing the posttest scores of the experimental group with their post-posttest scores, Table 8 showed that the students performed better in the post-posttest ($M = 55.83$, $SD = 7.64$) than in the posttest ($M = 53.03$, $SD = 8.20$). This increase in performance three weeks after taking the posttest was found to be statistically significant; $t(58) = -2.27$; $p = 0.03$. The statistical significance supported null hypothesis 7, and the hypothesis was rejected. This suggested a significant increase in the retention of the students after learning with exemplary materials. To ascertain the performance of the experimental group in the post-posttest compared to that of the control group, the independent t-test in Table 9 showed how the use of exemplary materials affected the retention of students in hybridisation. Table 9 revealed that the students from the experimental group performed far better than those from the control group in the post-posttest. The mean score of the experimental group ($M = 55.83$, $SD = 7.64$) was almost twice that of the control group ($M = 29.40$, $SD = 8.96$). This high performance was statistically significant ($p < 0.001$). The result did not support null hypothesis 8, so the null hypothesis was rejected. This supported the claim that using student-centred teaching strategies and concrete learning materials improves students' knowledge for lifelong learning [11, 12]. Using the conventional approach led to a decrease in retention. The concept learned seemed to have been stored in the short-term memory and was forgotten in a short while [31]. On the other hand, the use of concrete concept-depicting materials resulted in the concept being stored in long-term memory and unconsciously solidifying the students' understanding of the concept, the retention of learners who used the conventional method could not be significantly enhanced [12, 33, 34].

The posttest and postposttest results suggested that using exemplary materials to learn the meaning of hybridisation enhanced their performance, retention, and retrieval of the concepts. This supported the view that the use of the constructivist approach to learning enhances conception, where students were allowed to explore, find answers or meanings on their own through the use of concrete materials and interact with these materials and colleagues [35, 36]. This reduction in performance when the conventional method was used for the learning of hybridisation could be the cause of the poor performance of SHS students in responding to questions on hybridisation in the WASSCE [15, 16, 17]. As observed from the study, students who learned with the conventional method had a decline in their already low performance of hybridisation just after three weeks. Their performance is obvious after a year or two, as against those who learnt with exemplary materials. Those who learnt with exemplary materials had their interest in and understanding of the concept of hybridisation sustained during and even long after learning, as their retention of the concept was higher. This sustained understanding of concepts was also observed when students' retention were improved through the use of laboratory-based learning [37]. In this regard, retention of the concept may not be significantly different after a year or two. Chemistry teachers are thus encouraged to use student-centred learning approaches and materials, such as exemplary materials, to improve chemical concept retention and promote lifelong learning in general.

CONCLUSION

The findings from this study showed that there was no significant pretest sensitisation. While the performance of the learners who learnt with exemplary materials was significantly better than those who learnt without these materials, their performance increased significantly. There was, however, a significant reduction in the performance of the learners who learnt without the exemplary materials. The retention of learners in the experimental groups significantly increased three weeks after taking the posttest. There was, however, a reduction in the performance of the learners in the control group. The use of exemplary materials for learning hybridisation helped in the formation of concrete images and concepts in long-term memories, which had a long-lasting effect on the learners' conception. In effect, using exemplary materials such as balloons, molecular kit (ball-and-stick) models, and computer simulations in activity-based learning has the potential to improve students' performance and retention of the concept hybridisation.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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STUDENTS' PERCEPTIONS OF A STEM-BASED CURRICULUM: A PHENOMENOGRAPHIC APPROACH

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ABSTRACT

Students can perceive STEM in a number of ways that can affect what they gain from STEM curricula. This qualitative study characterises secondary school students' perspectives of integrated STEM lessons using the theoretical framework of phenomenography, to see how they interpret and conceptualise STEM for now and the future. Thirteen participants were engaged in guided conversations that revealed their perspectives of integrated STEM lessons that they had earlier engaged in. Ten qualitatively different ways in which students perceived STEM were uncovered and a possible outcome space for developing STEM curricula was derived. Participants perceived that they had developed deeper intellectual abilities, collaborative skills, understanding of assigned projects, and professional identities. The findings of this work are intended to inform a design of STEM curriculum that will improve STEM learning and outcomes in a holistic manner. Implications and suggestions for the design and integration of STEM based on the results of this work are also presented. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Science in conjunction with mathematics, engineering and technology play a concerted role in the sustainable development of any industrialized society through motivation which is embedded in a constructivist approach [1]. It is predicted that 47% of today's jobs will require technological development [2], possibly from the study of science, technology, engineering and mathematics (STEM). However, figures from literature indicate that only few people are in the field [3], regardless the demand for workforce in STEM related occupations [4]. Countries that wish to progress technologically, therefore, have to take interest in STEM studies to ensure that their citizens fit into future technological and STEM-related jobs appropriately.

These anticipated STEM-related jobs have led to a demand in a holistic integration between Science, Technology, Engineering and Mathematics [5, 4] to help students make interdisciplinary connections between concepts [6]. In this wise, STEM must be considered a crucial element towards sustainable development [1, 7]. Experts agree that the knowledge of STEM, when integrated, could be applied to solve problems and sustain the world [7]. STEM lessons begin with real-world (indigenous) issues that offer opportunities to learners to experience real-world contexts in interdisciplinary ways, with the belief that tomorrow's occupations are found in it.

The objectives of STEM integration are solid knowledgebase among students and enhancing of their interest in science, technology and mathematics, as well as strengthening their abilities to integrate and apply knowledge and skills gained. Integrated STEM encourages 'systems thinking' about sustainability [8]. It seeks to nurture students' creativity, collaboration, and problem-solving skills [3]. In other words, it attempts to increase learners' STEM literacy towards knowledge gain and understand scientific and mathematical concepts and processes required for personal decision making and participation in civic and cultural affairs for economic productivity. This leads to increased awareness of societal needs and improvements, cognition, and positive beliefs of students as observed by York, et al. [9] in their study of systems thinking in STEM education.

STEM requires that students engage in hands-on real time projects that give them opportunities to take risks with mistakes, so that they can appreciate its underlying concept [10] and view science literacy as a composite system. This implies that students must understand the nature of their environment so that they can be fit to live in and be lived with, as each contributes their own quota positively towards technological development and sustainability. This could also expose them to STEM-related careers that are needed for now and the future. Students' achievements in inventive science and pathways that create STEM-literate graduates could create generate innovators, making STEM different from traditional instruction [11, 12].

BACKGROUND

STEM instruction in Ghana is monodisciplinary rather than interdisciplinary, where students are taught STEM as individual subjects. This could make it difficult for students to see connections between science disciplines and to appreciate the entirety of science studies and its connection to other non-science disciplines. According to York and Orgill [13], skills associated with the interdisciplinary approach or integrative ‘systems thinking’ are part of science literacy so that the development of learning skills can prepare students to understand and address complex real-world problems.

In order to attempt a reversal of the current lag in STEM efforts, and to begin the integration, deliberate efforts were made to integrate STEM in lessons in selected deprived Ghanaian high schools, with rich culture and communal support in an interdisciplinary approach [10]. This was to make participants impact their local communities positively in their everyday activities and appreciate the principles of STEM. It was to further raise the awareness of STEM among students and their community through real-world problems in teams. Information about STEM models and related stories were told with enthusiasm and passion to stimulate a liking for STEM-based careers, after which context-based projects that involved community members were assigned to students. Constructivist-based teaching and learning approaches were adopted so that students could develop their own valid knowledge and perceptions about STEM and desired content knowledge. Attributes such as carefulness, honesty, patience, analytical deductions, predictive skills, time management skills, critical thinking, deductive and reflective skills necessary for the development of STEM disciplines were embedded into the community-based STEM projects. An example of such a project was the study of polluted water beneath a bridge from biological, chemical and social perspectives, after which the design of a durable bridge with appropriate metals over the water (river) to save aquatic life was required in miniature form.

The integrated STEM programme in a previous study was designed partly to inculcate the desire for STEM careers at an early age, improve innovation and ensure social equity to boost up female representation as suggested by Sias, Nadelson, Juth and Seifert [5]. The females, especially, were observed to be prepared to learn from risks, which traditional learning spaces mitigate. Pre-project interviews and observations were carried out to assess students' perceptions of STEM caused by the integrated real-world nature of STEM projects. These findings have been reported in another paper [10].

The framework for the STEM integration (prior to the current research) assumed a phenomenological approach, where STEM domains, bound by STEM practices within authentic contexts for the purpose of connecting subjects to enhance student learning were included [14]. The phenomenological approach studies the diverse ways in which people perceive phenomena and present findings as perceived within a particular study. Its integration framework included six tenets, which were to motivate students for STEM subjects, use constructivist student-centred pedagogies, apply engineering designs, include teamwork and communication, and adopt developmental learning [1]. The tenets of constructivism, prominent to active learner participation in problem-solving of real-life contexts was employed as students interacted with the environment, such that knowledge, as a function of cognition, could be used to organize their experiential world [15].

This current study assessed a mix of all three major research paths that are commonly undertaken in STEM studies as well as York, et al.'s [9] systems thinking approach. Based on reviewed studies, the researcher attempted to ascertain students who had engaged in integrated STEM's perceptions about their engagement [10] in and out of regular classroom sessions. The current study further attempted to find out unexplored perceptions, as well as define an outcome space, with respect to the concept of STEM.

PERCEPTION

The concept of perception is the sensory experience of the world that involves recognizing environmental stimulus and actions in response to it through perceptual processes that enable one to gain information about the properties and elements of the environment that are critical for survival [16]. It is a process in which people are aware of objects and events in their external worlds as they go through five events of stimulation, organization, interpretation, evaluation and memory, and recall [16]. Perception is described as the awareness, comprehension or understanding of 'something', and must be marked by the exhibition of three major elements: motivational state, emotional state and experience, with the first two elements contributing largely to how a person perceives a situation [17]. In other words, people determine their attitudes and preferences by interpreting the meaning of their own (self) behavior. Some other times, observation of the attitudes of others could affect an individual with a sense of merged identity [18, 17].

The principles that guide the perception theory are that perception is relative and not absolute. It is selective and has arrangement that may differ from one person to another, although the environmental conditions could be the same [17].

The self-perception theory posits that people determine their attitudes and preferences by interpreting the meaning of their behavior. Perception is, therefore, the realization of human brain processes that manifest as a view about phenomena. Feelings, needs, motivation, experiences, and many more of affective expressions are involved [19].

Perception starts from the five basic senses and the brain's ability to accept a relayed information in a sequential manner. Perception, therefore, becomes the realization of processes of one's brain about a phenomenon, followed by a reaction to the object and concluded by an arrival of meaningful interpretation of a stimulus [20]. This is a complex process that is physical, physiological, and psychological.

Empirical studies on students' perspectives of integrated STEM activities

There have been several studies in recent years about awareness creation and the engagement of students in STEM activities towards the development of STEM attitudes and skills for lifelong learning and STEM careers [21, 22, 23, 9]. Baran et al. (2016) studied the perceptions of 18 females who were engaged in out-of-school STEM activities and how these influenced their STEM skills cognitively. Roberts et al. (2018) similarly elucidated perceptions of STEM learning after engaging learners in an informal summer STEM activity and found out how these impacted on their in-school STEM skills. Participants in the different studies expressed diverse ideas with descriptions of discipline personalities that could influence their abilities to take on STEM role identities. Verdin, Godwin and Ross [23] went beyond students' perceptions on cognition to find out the ontological beliefs of students with specific attention to the ways in which they described characteristics of STEM personalities and how these influenced their own abilities to take on those role identities. York et al. [9] also studied STEM in a more holistic manner by employing the idea of systems thinking in STEM education.

It was observed from literature that participants commonly perceived STEM as fun, enlightening, availing an enabling environment for hands-on activities, and supporting classroom learning. A significant implication is to identify the expansiveness or otherwise of other perceptions, which were not found in reviewed literature, and incorporate them into the design of STEM curricula to further uncover unexplored areas of STEM.

THEORETICAL FRAMEWORK: PHENOMENOGRAPHY

The theory that informed the study stemmed from theories on perception that was directed by the phenomenological approach. Here, perception is the sensory experience of the world that involves recognising stimulus and actions [16]. This has consequences in the current study as perception principles imply that though students may be exposed to a common learning concept under one environment setting, their views could differ, based on their physiological and psychological inclinations and what they deem selectively important [24, 18]. One other factor to perception could be the perceiver's own past experiences that could bear on their current perception [25].

Justification for adopting a phenomenographic approach

The current study focused on assessment of individual perceptions of an integrated STEM phenomenon through phenomenography. Phenomenography is a qualitative research methodology, within the interpretivist paradigm, that investigates different ways in which people experience or think of something [26]. Its ontological assumptions are subjectivism but as it has the character of knowledge, the ontological assumptions are also epistemological assumptions [27]. The different ways in which students experience, interpret, understand, perceive and conceptualize the STEM phenomenon or aspect of reality was defined [28]. Here, sample and experience were considered as a whole and experiences based on the relationship between a person and the world around them. Thus, how participants conceptualized STEM is regarded truthful by the researcher [29]. In phenomenography, it is assumed that there are no wrongs or rights in the phenomenon under investigation, as the researcher is not interested in what is truly 'real' but in how a person conceptualizes a phenomenon under study.

Phenomenography differs from phenomenology in that phenomenographers adopt an empirical orientation and investigate the experiences of others. Phenomenology focuses on the essence of a phenomenon, whereas phenomenography focuses on the essence of the experiences and the subsequent perceptions of the phenomenon. Once data is collected in phenomenography, it is organized and reviewed to identify the number of ways that a phenomenon has been experienced or conceptualized. The three main principles for the identification process are:

i. Categories should be extracted from participants' responses;

ii. Categories should not be mutually exclusive or inclusive, but distinguishable;

iii. Responses must be explicit for categorization.

'Categories' describe the qualitatively distinct perceptions which emerge from collected data in phenomenographic studies. These categories of descriptions are the main outcomes of the research, and these are often presented in increasing levels of understanding. Phenomenography, unlike other qualitative studies, is different in its major premise, assumption, and principles of categorization [30].

This phenomenographic framework was suited for the current research as the main interest (objective) was in students' qualitative perspectives about the integrated STEM approach in an outcome space and contribute new findings to literature.

An Outcome Space

A phenomenographic framework allows for the definition of an outcome space that describes how students' perspectives are related and fit into an experience as a whole [31]. Outcome spaces can be developed in different ways. Some could be hierarchical in nature or assume developmental progression [32]. Each category of description often has a focus that is examined and arranged on the expansiveness or otherwise of other perspectives. This current study took a look into students' STEM perspectives, to subtly find out perceptions about integrated STEM in relation to the environment and possibly, sustainability.

RESEARCH QUESTION AND SIGNIFICANCE

This study examined students' perspectives of a STEM project using a framework of phenomenography. In view of the desired goals, the overarching research question was:

- What are the different ways in which students perceive the concept of STEM in integrated-STEM lessons and projects?

The primary goal of the study is to contribute obtained data on integrated STEM to educators and curriculum designers to build STEM lessons and projects that meet the goals of STEM for national STEM plans. It is also to promote student learning of content, address students' lack of interest in STEM and poor enrolment through a friendly curriculum and help them to gain the necessary STEM skills for lifelong living and national development.

METHODOLOGY

A phenomenographic qualitative approach [26] that employs purposeful sampling was used to drive the defined objective and answer the research question. The phenomenological lens used in this study enabled the researcher to understand how students perceived integrated STEM through their broad description of experiences and subsequently assessed them phenomenographically. The object of phenomenographic study is not the phenomenon per se, but the relationship between the actors and phenomenon [33].

A purposeful homogenous sample of 13 students aged between 15 and 17 years, which was a little over 10% [34] of the sample in the preliminary study, was voluntarily chosen to provide the needed data on their perceptions of integrated STEM lessons. The sample necessarily had to consist of those who had experienced integrated STEM and indicated a predisposition for STEM lessons for one school term in an earlier phenomenological study (Author, 2020a) and could provide information-rich data. Borrows, Nowak and Mooring [29] followed a similar protocol to assess students' perceptions of a laboratory environment.

After permission was obtained from the institution's headteacher, students were briefed about the intended study. The sample read and signed consent forms before the researcher engaged in a guided conversation with them. The guided, focus group conversation involved six boys and seven girls and was conducted using a semi-structured protocol which lasted between 8 and 22 minutes with an average time of 15 minutes per item. Follow-up questions were used to clarify students' responses to initial questions when necessary. Participants' responses in the course of their projects and during the focus group conversation (interview) were not prompted or suggested in any way by the researcher. Conversations lasted until data saturation [35] was reached and no new perspectives were uncovered. Pseudonyms were employed in the descriptions.

Some of the conversation questions are shown as Appendix A.

To establish the trustworthiness of results, two rounds of debriefing were used to establish the consistency, dependability, and credibility of the coding system. Two colleagues with experience in qualitative research but no experience regarding this integrated STEM study served as analytic audience. Transcripts were read and coded using NVivo 12 for MAC. The codes were revisited, revised, and elaborated after several comparisons. Codes were collapsed to organize the data into themes and further analyzed to ensure reliability. Further analysis was carried out to develop semantic themes, which attempt to identify obvious meanings in statements, theorise the significance of the patterns- their broader meanings and implications [36, 29] and compare obtained data with that of the past to draw inferences. The students' perspectives were considered to be important products of phenomenographic research because they described the diverse ways that they perceived integrated STEM lessons.

The analysis was expected to be a compilation of a series of categories and descriptions which was fitted into an outcome space to reflect the increasing complexity of perspectives, with the view that the adopted method would tease out students' perceptions about STEM for use by curriculum developers.

RESULTS

From the guided conversation, it was clear that students had fair perceptions of what STEM was, as they had worked through STEM projects for one school term. Some of their perceptive responses were:

- *'STEM is doing science or Math in a new way by connecting them more.'*

- *‘It is integrating Math into practical science.’*
- *‘It is practical science and technology.’*

The responses suggest that STEM is ‘hands-on’-based, allows for practice and skill development and is multidisciplinary. STEM is also seen as real-life or real-world practice of science theory, in the comment:

- ‘STEM means merging all sciences and *taking it to the community* to *solve problems* practically’.

In this response, STEM is again perceived as multidisciplinary. It is perceived to go beyond mere school practice, to *solve* ‘real-world’ problems. Students in this category could be said to perceive STEM from a *problem-solving* perspective.

When asked about their future careers, a response was:

- *‘To be a STEM teacher and not just a Math or science teacher ‘.*

This interesting answer was probed further and the response was:

- *‘You see, the STEM does it all and students see science, math and tech work together in unison. It is good to combine the subjects like that for understanding… you apply them to solve given problems faster as each subject bears on the other’.*

This response that said that '*STEM does it all'*, could be interpreted to mean that students view STEM as an all-encompassing discipline (multidisciplinary), and could be problem-solving inherent.

Other career-oriented responses were:

- *'To be an architect as I love math and design activities'*
- *'To be an engineer because I like the physics and math part of projects'*
- *'Pharmacist; I will learn about human beings and how to administer hospital or traditional medicine properly to heal the sick: not a doctor, really'.*
- *'I found out about many STEM careers than I could think of but have not settled on any.'*

Other STEM careers like dentist, actuary, software developer, physician assistant, civil engineer, cartographer and many others came up.

Students further expressed their views about their experiences in the STEM projects, some of the inventive things that they came up with, some challenges, and how these influenced their decisions to pursue some of the STEM-related careers that they had expressed interest in.

Ama said that it was *fun, interesting and engaging*. Hetty said that it led to *peer discussions and teaching, which was very helpful*.

Hetty and Ama appeared to perceive STEM from social and collaborative viewpoints.

James said: '*Remember that I designed scientific and time-saving machine for the coconut and palm oil producers close to the market? Hetty in my group did a similar thing for the fish smokers*'.

According to Tricia, '*group members James and Grace helped to identify resilient types of metals and clay for efficiency after several trials and suggested them to the potters and metal works craftsmen. We can be managers or consultants or something of the kind for small-scale businesses. Yes? (Colleagues nod in agreement). We also share the main things that we have to do and everybody does internet research for ideas and solutions for our project'*.

The mention of 'several trials, consultancy, and internet research, could be interpreted to imply the perception that STEM is viewed as *exploratory, research-inherent and provides high-profile career orientation*. Again, the use of *skills* and *content knowledge* are inherent in STEM, as submitted by Tricia. Furthermore, Tricia's group perceive STEM from a *research perspective* as problems have to be analyzed. *Skills* and *content knowledge* have to be perused and solutions deduced from the possible trial of ideas.

To the question on how the STEM project *impacted on their learning*, all the students except one, unanimously responded positively. Some said that it made them *learn harder* as they often needed to *apply theories* in their out-of-class projects without textbooks. Others said that *realization* dawned on them that *everything that they learned in school mattered for understanding*, for example, 'how things like machines and the world 'ticked''.

The researcher, content mastery and application of knowledge, as well as problem-solving perspectives were implied in these unanimous answers. The perceived multidisciplinary nature of STEM became more obvious in responses to how STEM impacted on their learning, than when the question was asked on what STEM was. Students also perceived that content knowledge was an important variable in the multidisciplinary STEM approach, as reiterated by Eric.

Eric said: almost *all science subjects work together as one*, in order to achieve good results.

Eric's response was probed further. Responses that came up answered the question on students' views about the integrated STEM approach. Students perceived that to be able to solve real problems successfully, one needed to acquaint themselves with *content knowledge* from *all the STEM disciplines and apply* 'bits' of each to *deal with problems* successfully and so STEM disciplines should not be taught in 'isolation' like independent islands. Again, almost all the students in this study perceived that the project *contributed to their learning in class and vice versa*.

Ama disagreed with the positive attributes of integrated STEM from her colleagues. She was quite vocal on her answer about the difficulty in implementation of the projects.

Ama: *Mmm, I am not sure…. In the beginning it was not easy. Too many things to remember and apply. It was difficult. The outdoor was good, but the project…. not fun. Later, I did learn though (shrugs)*.

Though Ama's response appears to be negative, in effect she perceives that STEM is *all-encompassing (multidisciplinary)* and requires *mastery of STEM principles* for one to be successful.

She nonetheless reiterated the fun and social part of the project. She enjoyed going out of class with colleagues, nonetheless.

An overview of the entire STEM projects and students' candid perceptions were gathered and analyzed into categories as stated earlier. Most of the students' views have been paraphrased with highlights on important perceptive phrases. Most of these perspectives focused on the *unexplored aspects of science* within the communities. Students reiterated that they were *prepared for challenges* that could arise with projects because they could *solve problems in innovative and exciting ways*. They perceived that STEM was more of *'real science'*. They reported that projects made them feel like *real scientists*. They recapped the fact that they were happy to *expand their school science knowledge* and *apply it to the unknown for a better world*.

It is obvious from the phrases italicized that the students saw STEM from the explorer, innovative, mastery of content, skills acquisition, application of knowledge, and problem-solving perspectives. Some of their perceptions were:

- 'I think the STEM work is cool. I loved to *apply my ideas from class to new situations*. In fact, in this new type of lesson, you *feel free to do things*..., I mean *try them out* without restrictions, but safely.'
- 'I felt very much at home when we visited the pharmaceutical industry. I said to myself that, 'ah, *that's the job for me''*.

- 'I think I have already *gained so many skills* for the future, Ma'am …. just one term of STEM. I can hardly wait for more of such all-inclusive lessons this new term'.

STEM is being perceived as *career-oriented*, *skills-developing*, and *exploratory* in these responses.

Generally, almost all participants reported that the integrated STEM was *effective*, *interesting*, and *engaging* (hands-on and collaborative) which enhanced their *acquisition of innovative and STEM skills.* They perceived that the real-time experiences allowed for prediction, observation, hypothesising, conceptualisation, communication, manipulation, computation, elucidation of patterns, reflection, assertiveness, and articulacy in science language as observed in an earlier study [37].

Outcomes from the guided conversation sessions further showed that students had some degree of positive perceptions about the flexible constructivist STEM environment. These participant-statements and many more which have not been presented allowed for the categorization and definition of an outcome space that describes how the obtained perspectives relate and fit into a whole experience.

SUMMARY OF OBTAINED DATA

Ten distinct perspectives were uncovered as students' perceptions about STEM (Table 1) interpretively. The columns are filled with the researcher's categorizations and interpretations and not exact student phrases.

Table 1: Students' perspectives and focus on STEM

Student perspectives	Students' focus
Multidisciplinary perspective	Acknowledging usefulness of STEM's interdisciplinary nature
Researcher perspective	Applying acquired skills to gather data, interpret, analyse, find patterns, and arrive at conclusions
Content mastery perspective	Building and deepening content knowledge
Skill developer perspective	Developing and practising STEM skills for lifelong learning
Career-oriented perspective	Understanding importance and application of STEM skills for future careers & economic independence
Collaboration perspective	Interacting on a higher level to augment purposeful learning
Real-life practice perspective	Applying 'school science' to 'out-of-school' or 'real-world' situations through hands-on and minds-on activities
Problem-solving perspective	Developing innovative and pragmatic approaches to identified challenges and new situations
Socialisation perspective	Social interaction for fun
Explorer perspective	Exploring the unknown in STEM

It is important to note that the study participants do not belong to only one categorized description since they expressed their views among several of the categorizations. The descriptions of the ten categories that exemplify the identified perspectives in Table 1 are discussed more clearly below.

Analysis of perspectives for construction of outcome space

Multidisciplinary perspective

Students identified the interconnectedness of the STEM by responding to the nature of STEM as being encompassed by '*all disciplines in one bag'*.

- *'You see, the STEM does it all and students see how science and math work together in unison. It is perfect to combine the subjects like that for understanding… you apply all to solve same or given problem constructively'.*
- *Adzo: The STEM combines all the different sciences, technical drawing and math and so it is like a one-stop or one-shot subject …. or teaching that employs everything... Here you learn everything in one lesson, even though the lessons are longer. But Ma'am it is better than attending a standalone Physics class (chuckles). Math is a challenge but my colleagues in my group helped out.*

These perspectives describe the important integrated nature of STEM which must be embodied into the design of STEM programs. The students' perspectives are in line with how More et al. [1] also describe integrated STEM. It further affirms what York et al. [9] also found in their studies on systems thinking in STEM education.

Researcher perspective

Students with such researcher perspectives focused on using the STEM environment to explore their learning environment through scientific methods. They shared tasks, gathered necessary information, and analyzed them for best options and practices methodically. This is supported with the response: *We do online research to get more ideas and solutions*.

This portion from Tricia's response suggests the researcher perspective description: *I loved to play the science investigator and problem-solver, all in one…*

Then there was Adzo*: The hands-on activities or the project, I should say, make you engage with work at a deep-thinking level. It's like you have to reflect really deep, but before all that, the real work is searching for helpful information.*

Carrying out research involves a scientific process. Interpretively, this equips researchers with data collection skills, analysis of information from different sources, critical thinking, planning, report writing and a complement and extension of classroom learning. This is a notable aspect of STEM to be included in its design as it will not only create independent and critical thinking persons, but also independent problem-solvers as identified from literature studies [3].

Content mastery perspective

The integrated STEM environment was seen as favorable for deepening of concepts and skills that appeared far-fetched and abstract to students.

- Tricia: *The activities were intricate and cut across many subjects that we know……like math hands-on activities, chemistry practical activities, biology activities…..and engineering. We actually needed all many concepts from different subjects to complete our project.*
- *Eric: I loved the 'out of class' science in the community and relatives saw us as real scientists. Parents think it is prestigious to read science so I loved that my community saw me. It made me learn harder to understand better and will strive hard to be a great engineer to build modern roads and bridges … with some new materials that will come up.*

The perception, that knowledge gained from lectures could be used to solve problems in the 'real-world', is important as it spurs students on to learn intensely to apply content knowledge to real life problems practically (Author, 2020a). This is summarized in '*We actually needed to always learn different concepts from different subjects to complete projects.*

Students who expressed this 'content mastery' perspective were interested in applying previously acquired knowledge to solve problems and to deepen their overall learning experience. This implies that the design of STEM projects should scaffold content and their applications. A similar observation was made by Wang, Moore, Roehrig and Park [7].

Skill developer perspective

Some respondents perceived that the integrated STEM provided access to hands-on activities and set a stage for them to meet professionals in STEM who they wished to model as well as learn on-the-job skills. They were happy that the skills learned through the STEM projects could have practical significance and application for the future. A student with such a perspective develops understanding and finds joy in the application of developed skills. They look forward to engaging in 'real' activities that involve the practice of mathematics and physics, they alluded. Students perceived that they built their self-confidence, cognition, and prepared themselves for their future career paths through STEM. Pursuance of the development of such skills and perceptions among students would help to close the existing gap in STEM skills and careers and fit the projections made by Frey and Osborne [2]

- *Roy: We engaged in more real activities than ever before in areas like math and physics where we hardly did activities. Sometimes we improvised some of our materials which worked like what we find in books. I built my confidence level with using the scientific instruments.*
- *James noted, "I love to build things like planes, trains, some toys for play, but I never knew that I had to do a bit of chemistry….like, knowing about the types of useful materials and ….properties and the best ones for efficiency. See, with the Ship project, we revised properties of alloys in our group, weighed, measured…put the manufactured toy in water and discussed density, then the real field activity was great. I felt like a proper scientist"*

- *Grace added, "I loved it best when an industrialist, vets and lady pharmacist came to help us to learn procedures (skills) to prepare tablets and suspension medication for ailments. I can even prepare drugs if I can get the raw materials because now I know how".*
- *Tutu: I can handle the micro equipment and take measures better than before. I enjoyed using it at home and during in-field activities.*

Career-oriented perspective

Eric had expressed, in addition to how peer engagement benefitted him, that integrated STEM lessons and work in the community made him want to be an engineer to build roads and bridges. Other participants had similar ideas about moving into STEM careers.

- *Tutu: This project exposed me to different kinds of work (careers) that we could purse. The pharmaceutical lab would be my career. It was fun to be allowed to spend a day at the pharmaceutical industry. I was excited, yet apprehensive. When the realization set in that I could also be like them…woow….*
- *Effuah: I see a lot of chemistry, technology, engineering and how to keep our environment in the petrol industry. I loved to combine chemistry and environmental science in our projects so I would like to pursue a career like that as I want to be like the females. I will choose a university course for that.*

- *Hetty: You see the science in many things that our parents do at home like the 'banku' (corn meal), beads, pottery, and pito (fermented cereal drink), if the science and technology in the process is explained such local businesses can expand to empower the women financially.*
- *Ama: That is very true. The indigenous women practise more science unknowingly, until we explained to them how they could improve and expand their business in more scientific ways.*
- *Yaw: Most of the local industrialist looked…mmmm. poor or something, but with our knowledge we can teach them to do their profit and loss, whether they are gaining or not, and then teach them to improve on their style of production and sales. I think if we engage in such trades more scientifically and technologically, we could improve local industries……I think..*

The 'career-oriented' perceived STEM through the lens of career training. Understanding of concepts, mastery of concepts and skills and their application were developed based on how they could be applied to future careers.

Collaboration and higher-order thinking perspective

Higher order thinking perspectives were perceived a illustrated with Hilda and Manu.

- *Hilda: I got excited with ideas during STEM lessons. The activities were thought-provoking. Working alone would have been difficult for me. My Math is bad …. eish! We contemplated expansive ideas outside the box for common success.*

- *Manu: Yes, my team members and I supported each other with our knowledge in different areas, even if the grouping was changed. The group work helped us to understand the main connections in projects in bigger ways.*

Practice-oriented perspective

Engaging students in hands-on activities or constant practice leads to the acquisition of desired skills and retention of knowledge.

- *Ama: Ms. Attu's math always led to something concrete like using the knowledge to prepare aspirin, gather materials to make a particular extent of a wall, model something concrete. That prepares me for the world of a surveyor, engineer, pharmacist, agric engineer …. Even when we had to make farm beds, it was measurement. Math is in every career.*
- *Hilda: Activities were involving because you apply things from mathematics and science theories and solve real community problems, but it makes you understand and remember.*

Hilda's perspective could easily be captured as a problem-solving perspective; an indication that some students expressed more than one categorized perception of STEM. The 'practice-oriented' participants perceived STEM through practical hands-on activities of some learned theories. They perceived that mastery of knowledge and skills come through practice. They further perceived that developed conceptual understanding, from practice, could be applied usefully in future careers.

Problem-solving perspective

Some students found the integrated STEM projects as fun and yet challenging- a ground for solving what they commonly referred to as 'real science' problems.

- *Tricia: The exposure to real life problems and how we solve them helps to connect all the dots in what we learn. I loved to play the science investigator and problem-solver, all in one (Chuckles). There is always some real practical activity to do to solve a given problem. The hands-on activities were engaging. You figured out solutions like in a puzzle to solve problems.*
- *James buttressed the problem-solving perspective with: You feel an air of success when you solve scientific tasks in the community or classroom successfully. It's a good feeling. Like, you understand how science, math and engineering designs and technology, give expected solutions. Every task is a challenge that must be solved in a scientific manner, Prof.*
- *Hetty: The STEM has made me wiser, smarter, with techniques to solve community and our house problems. Like using bicarbonate, lemon and charcoal to sanitise and clean things. I look impressive when I put my STEM ideas to work.*
- *Tutu: I think of the assignments (projects) given and assemble in my mind, knowledge I need from everywhere. I reflect and then decide the specific scientific principles to combine for solving the group's problems. All the other members have to do same.*

These students are focused on the application and extension of gained skills and knowledge to solve ‘real’ problems. The problem-solving nature of STEM is epitomized in their responses. They relied on and applied acquired knowledge to solve problems.

Socialization perspective

Collaboration is a desirable characteristic but must be ‘useful’ and geared towards a desired and intended goal and not merely for socialization and fun. It is true that collaboration can ensure knowledge creation [3], but must stem from within, in an academic environment, to steer one onto to the creation and acquisition of knowledge.

- *Hetty: I loved the ‘out-of-class’ projects.*
- *Yaw: Even Doreen and Mansa (not interviewed) engaged actively in the STEM projects. It’s fun working collaboratively.*

The concept of STEM, as presented by Hetty and Yaw, does not truly spell out the implied STEM objectives.

The perception of STEM being for fun or socialization is limited. To ‘love’ the project and be ‘active’ towards no goal achievement is a limited perspective. ‘Social perspective’ students perceived STEM projects as environments for pursuing social interactions. A similar observation was made by Burrows, Nowak and Mooring [29] when they carried out a similar study. They, however, placed their socialization perspective at a higher level as they felt motivated by the 'fun' side of STEM lessons and projects.

Explorer perspective

Students with the 'explorer' perspective described opportunities that were inherent in the STEM for finding out more about their environment and identifying links between the school and 'real-world' environments for growth and development. They emphasized on how acquired knowledge and skills could be applied in both situations, as shown in the excerpt:

- *Tricia: Working with community members was interesting …. learning about their local science and we explaining our school science in their real work. I think we can learn harder and truly help the traditional local science potters, kenkey makers and bead people…. and the blacksmith and other people who use some kind of science.*

The explorer perspective could be an advantage as various routes to achieving an ultimate could be explored for best, innovative, and inventive solutions. This also increases students' initiative and decision-making skills. This is summarised in: '*In fact, in these new lessons, you feel free to do things...,try activities without restrictions*'.

DISCUSSION OF THE OUTCOME SPACE

An outcome space that describes how students' perspectives are related and connect into the STEM experience as a whole is characteristic of phenomenography [38]. In this study, the primary emphasis of each category of description was examined and arranged in levels based on how inadequate or extensive the perspective of STEM is. Levels were constructed on the basis of reviewed literature that could provide reasonable grounding for designing, analyzing, and suggesting optimal activities for the integration of STEM through a multidisciplinary approach in real classrooms.

Perspectives on higher levels have broader views of STEM, while those on lower levels are limited in coverage. Furthermore, each of the derived perspectives was compared to the objectives of STEM (integrated) as outlined in this manuscript to arrive at the classification of levels. The objectives of STEM include developing solid knowledgebase, enhancing interest in STEM, strengthening abilities to integrate and apply the knowledge and skills gained, and nurturing students' creativity, collaboration and problem-solving skills. An outcome space, based upon a summary of identified levels is shown in Figure 1.

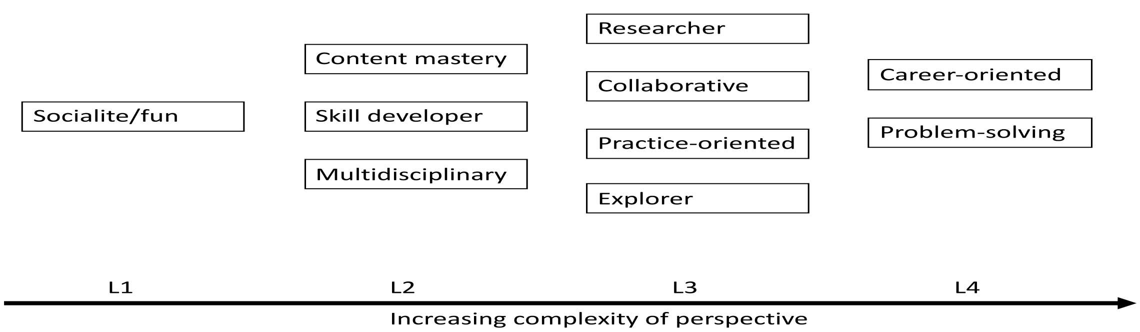

Figure 1: Outcome space describing increasing complexity of students' perspective of STEM

From Figure 1, the socialization perspective in Level 1 represents the lowest level of perceptions because this was the least frequently mentioned perspective among the categorizations. The focus of students' expressions in this group does not portray commitment to explore the integration of STEM or achieve its objective but have 'fun'. There is, however, a fair amount of interest in the fun side of project activities and so cannot be ruled out completely as trivial.

The multidisciplinary, content mastery and skill developer perspectives were viewed as more complex than the socialization perspective in Level 1. This is because students focused on notable goals of STEM; that is, to master content and develop the necessary skills for STEM. However, they lacked the entirety of the STEM objectives. There is no emphasis or mention of the use of gained skills in an interconnected manner nor their application to real world issues. There is no suggestion on how these skills could be augmented through collaboration.

The third level perspectives are deemed more sophisticated in outlook. These are the 'researcher, collaborative, practice-oriented, and explorer' perspectives. These perspectives are on a higher level because they seem to be more aligned with the objectives of STEM. Students with these foci perceived that STEM increased their opportunities to apply acquired skills and transfer knowledge in new situations, interact with others to share useful ideas on a higher level to solve real problems, and explore other ways of attaining better outcomes for identified challenges than have fun [10, 3]. Here, the perspectives included integration and application of knowledge and other gained skills, for lifelong learning.

In Level 4, the ‘career-oriented and problem-solving perspectives’ were chosen as the highest level of the outcome space because they are more encompassing, spelling out the implied ultimate aim of STEM and beyond. These perspectives suggest that mastering and applying gained skills in collaborative and explorative ways could lead to interventive and innovative approaches to solve real-world problems; this would ultimately lead STEM students to STEM-related careers for sustainable, environmental, technological and economic growth. The awareness of STEM-based careers which could lead to technologically sustainable societies was implied as connections between theory and practice. Concepts, skills and problem-solving attitudes were expressed. This is epitomized in Hetty’s problem-solving perception: *The STEM has made me wiser, smarter, and equipped me to solve community/house problems. We will get good work in future.*

In summary, Hetty’s statement covers the tenets of the second major STEM objective, which is for personal informed decision making and participation in civic and cultural affairs for economic productivity. It also underpins another charter of STEM- to equip students with skills to be employable in STEM-related jobs for the future [4].

Findings from the analyzed guided conversations suggest that the flexible learning space provided by the STEM project proved to be an interesting experience and impacted positively on students. They alluded that the high percentage of hands-on activities included in their STEM curricula was the reason for their success in assigned projects. Students perceived that the engagement made them think at a higher intellectual level and demonstrated that contextualizing teaching could afford improved quality of learning. Many of the students admitted to positive changes in cognitive, affective, social, perseverance, self-respect, respect for others, collaborative, and process skills.

It must be emphasized that most students were found to be sitting across a range of different perspectives and not confined to any one particular perspective.

The creation of a STEM community by inviting role models, sending students out into the community to solve real-life problems, engaging with people in indigenous industries and discussing the underlying science principles in their work helped to bridge the gap among industrial, indigenous and school science. In this study, most of the community projects involved indigenous science, where men and women, especially, were observed at using traditional/indigenous science to make local foods, beads, pottery, blacksmithing (production of alloys) and alcohol. The decision to engage with more women in small-scale business was to partly encourage females on the STEM project. These women explained the science in their indigenous crafts and spurred the students on to learn harder to develop contemporary ways of improving their arts scientifically. These real-life meaningful contexts were seen by students as important to themselves and the nation. They had the opportunity to improve on their tolerance and collaborative skills through activities.

It could be inferred from students' guided conversations that they began to develop diverse professional identities where they suggested that they were not merely students learning about scientific theories but people who could analyze situations and propose workable solutions to them, as Roy said.:

- '*The projects gave us … at least me …. more insight in how real work or profession in our course area is like. It is all about the different parts of science into one composite unit in the real adult working world; and developing solutions to the assigned challenges was great. It gives me so much confidence now with regards to learning science from all angles and using it to work confidently in future'*.

It is clear that integrated STEM education could educate students about the role and importance of STEM for sustainable development in order to manage socio-scientific issues related to the application of science-related technologies innovatively. The seeming increase in the positive appreciation of STEM could be due to a sense of merged identity as suggested by Goldstein and Cialdini [20] and by holistic teaching as intimated by York, et al. [9].

CONCLUSION

This study provided an overview of what students perceived integrated STEM education could look like in practice in the contemporary science classrooms [39, 40, 41]. This study provided students in an underrepresented environment access to variety of practices in STEM fields and contact with professionals at their workplace through visits and hands-on projects. Outcomes of their

STEM projects gave them the propensity to want to change societal and natural orientations and to be less reliant on teachers.

Reviewed research articles suggest that STEM education has the potential to help students to learn more meaningfully through an integrated approach and prepare them for future careers, ethical actions, and sustainability [42]. The incorporation of the degree of importance (from the levels of categorisation) of what students perceived to gain from STEM curricula was not identified from previous literature. It was perceived from the guided conversation that students developed and demonstrated almost all of the known researched objectives of STEM and a few more new ones.

Ten main student perceptions about STEM were uncovered, though some students possessed more than one major perspective [11]. These perspectives related to career orientations, application of scientific concepts, innovation, cognition, affection, and skill-based components of STEM. Designing STEM curriculum with such student perspectives could move students into higher or engaging levels of STEM through meaningful experiences. Students perceived that out-of-class activities connect them to 'real science', technology and mathematics, and allow them to explore various design routes, or at least give them suggestive ideas.

The STEM also deepened their understanding of concepts that had a theoretical significance for them. From the arranged categories of descriptions of perceptions (in Figure 1) where perspectives were on the fun side of the out-of-class, STEM skills and understanding of theories were gained. Some students identified a practical application of some of the theories that had been learned in class in some of the indigenous science that they engaged in or observed. They described how they could improve on the indigenous science through principles that they acquired from their school science. The implication is that skills obtained through STEM could have practical significance for the future, especially career-wise [4].

The study further highlighted how integrated STEM approach could influence students' perceptions about STEM, based on students' own impressions. The use of problem-based mini projects allowed students to connect to real-world experiences and observed from first-hand how STEM-integrated lessons holistically led to successful designs and construction of an intended outcomes. It helped to awaken their innovative skills also. The skills obtained could have practical, personal and national significance for the future. They also perceived that knowledge gained from real-world situations could be used to solve problems in school and vice versa.

The STEM perspectives uncovered in this study encourage future research on STEM that can employ a longitudinal study of students, especially, for those who display more than one main perspective. It also shows how students' perspectives operate holistically when design elements have to be considered. These observations suggest the near supremacy of interdisciplinary teaching and learning over unidisciplinary teaching and learning as identified by other researchers [39, 5, 21, 1, 7].

All identified perspectives are important for STEM development and must form part of STEM-designed curricula, in general school curricula. It is hoped that the categorization or creation of levels of outcome space in this STEM study would provide guidance (through later development of an exemplar curriculum model) for teachers and curriculum planners about essential goals of multidisciplinary education as perceived for integrated STEM education. Considering the existing findings from literature as well as this current study, that increased workforce in STEM-related careers would be required in the coming years [11, 3, 2], it is important that students who have participated in STEM-integrated projects are engaged to articulate their perceptions to see whether they fit intended objectives and ultimate goals. Findings from data-based categories in this study further suggests the importance of STEM studies and how gathered data could contribute significantly in advancing STEM education research and practice across all levels of education.

IMPLICATIONS

These findings contribute to the existing literature on integrated STEM. Understanding the different student perspectives present in an integrated STEM classroom (noted in this study) could be of use to teachers and STEM educators, because teachers could develop lessons to emphasize how ‘classroom’ knowledge could be enacted to solve ‘real-world’ problems in homes and communities. They could also use integrated STEM classrooms to provide context to students about how acquired knowledge could be applied in their future careers. Furthermore, allowing an element of freedom in one’s classroom could allow for exploration of answers to higher-order problems through various research routes. This could also equip students with the needed inventive and innovative skills for future careers and national development. Students' perceptions and rating about the interesting and effective or other teaching methods is a way to suggest improvements in the teaching-learning process.

It must, however, be noted that perception is a complex phenomenon that is relative, selective, has its own arrangement and differs from person to person even if the same environmental conditions are provided, due to one's past experiences and their psychological makeup [25]. This knowledge must inform zealous teachers about expectations with innovations on STEM in their classrooms.

LIMITATIONS

The study investigated the perceptions of students engaged in an integrated STEM approach from a single class in an institution. This might not be reflective of all other classes or institutions, though the diversity of participants lends to a wide scope. Not all the 103 participants who enrolled on the project in the beginning in the session engaged in the guided group conversation. Their views could have been different from that captured in this study. Nonetheless, data saturation was reached for the 13 participants who engaged in the guided conversation. Their performance based on the new approach was assessed in an earlier study and so was not addressed in the current study. Besides, there was lack of pre-measurement of the STEM projects that participants engaged in, as this was a baseline or initial study of such a kind in the study area.

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Appendix A

a. What does STEM mean to you?
b. What would you like to be when you grow up?
c. Can you tell me about your experiences and values gained in projects that you undertook?
d. What were some of your difficult and fascinating experiences?
e. Describe some inventive things that happened during the project and how they bear on your future career.
f. How did the project activities contribute to your learning?
g. Did the projects relate concepts in class/lab to things in the home or community and vice versa?
h. What are your views about this method of teaching science with different disciplines integrated into a unit?
i. How has the integrated STEM approach affected your perceptions about science, science careers and STEM in general? Kindly give an overview.

SCIENCE EDUCATION, CURRICULA AND THE HEARING IMPAIRED

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ABSTRACT

Science education plays a crucial role in fostering scientific literacy and promoting intellectual development among students. However, individuals with hearing impairments face unique challenges in accessing and comprehending science curricula due to barriers in communication, limited accessibility of instructional materials, and inadequate support systems. This review aims to critically examine the current state of science education for the hearing impaired and explore potential future perspectives. The review highlights the need for inclusive educational practices that address these challenges and promote equal opportunities for hearing-impaired students to engage with science. The review further explores existing strategies and technologies employed in science education for the hearing impaired. Additionally, it examines the role of supportive educational environments, teacher training programs, and collaboration between educators, parents, and professionals in facilitating effective science instruction for hearing-impaired students. The review emphasizes the importance of incorporating universal design principles in science curricula to create accessible and inclusive learning environments. It advocates for the development of educational resources specifically designed for hearing-impaired students. The review concludes by outlining future perspectives for science education and the hearing impaired. It emphasizes the need for ongoing research, collaboration, and innovation to continuously improve instructional practices and support systems. It highlights the potential of emerging technologies, such as virtual reality and augmented reality, in enhancing science education for the hearing impaired and encourages the integration of these tools into curricula. Overall, this review provides a comprehensive overview of the current state of science education for the hearing impaired, identifies challenges and opportunities, and offers insights into future directions. By addressing the unique needs of the hearing-impaired population, science education can become more inclusive, empowering, and engaging for all students, contributing to the development of a scientifically literate society. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Science education is a vital component of contemporary education systems, aiming to foster scientific literacy, critical thinking, and problem-solving skills among students. However, individuals with hearing impairments face unique challenges in accessing and comprehending science curricula, which may hinder their ability to fully engage with scientific concepts and practices. This comprehensive review examines the current state of science education for the hearing impaired, explores existing strategies and technologies employed in this field, and identifies areas for improvement and future perspectives.

Science education plays a crucial role in equipping individuals with the knowledge and skills necessary to understand and participate in an increasingly complex and technology-driven world. It promotes scientific literacy, enabling individuals to critically analyze information, make informed decisions, and contribute to societal advancements [1]. By engaging in science education, students develop the ability to think scientifically, solve problems, and appreciate the natural world.

Individuals with hearing impairments face unique barriers in accessing and comprehending science curricula. Understanding spoken language, accessing auditory information, and participating in hands-on experiments and classroom discussions can be particularly challenging [2]. Limited access to verbal communication may impede their ability to grasp complex scientific concepts and engage in collaborative learning experiences [3]. Furthermore, the lack of appropriate instructional materials and resources tailored to the needs of the hearing impaired further exacerbates these challenges.

Efforts have been made to address the challenges faced by hearing-impaired students in science education. Various strategies and technologies have been employed to enhance their learning experiences. Sign language interpretation, captioning, visual aids, and assistive technologies, such as hearing aids and cochlear implants, have been utilized to facilitate comprehension and participation [2, 4]. These interventions aim to bridge the communication gap and provide access to auditory information through alternative means.

Creating inclusive educational environments is crucial for ensuring equal opportunities for all students, including those with hearing impairments. Support systems that encompass educators, parents, and professionals play a vital role in providing appropriate accommodations and fostering an inclusive learning atmosphere [5] Teacher training programs that emphasize effective instructional strategies and awareness of the needs of hearing-impaired students are essential for improving science education outcomes [2].

Despite progress in accommodating the needs of the hearing impaired in science education, several areas for improvement persist. Universal design principles, which advocate for creating learning environments that are accessible to all learners, need to be integrated into science curricula [4]. Additionally, there is a need for educational resources specifically designed for the hearing impaired, such as visual representations, interactive simulations, and multimedia materials that effectively convey scientific concepts [2].

Looking ahead, continuous research, collaboration, and innovation are essential for advancing science education for the hearing impaired. Emerging technologies, such as virtual reality and augmented reality, hold promise in enhancing learning experiences and making science education more accessible [4]. By leveraging these tools, educators can create immersive and interactive environments that engage hearing-impaired students and foster their scientific understanding.

In conclusion, this comprehensive review aims to critically examine the current state of science education for the hearing impaired. By identifying challenges, exploring existing strategies and technologies, and highlighting areas for improvement and future perspectives, this review seeks to contribute to the development of inclusive and empowering science education practices that cater to the needs of hearing-impaired students. By addressing these challenges, science education can become more accessible, engaging, and equitable, enabling all students, including the hearing impaired, to develop scientific literacy and contribute to a scientifically informed society.

RESEARCH METHODOLOGY

The objective of this research methodology is to outline the approach and methods used in conducting the review titled "Science Education, Curricula, and the Hearing Impaired: Current State and Future Perspectives."

Literature Review

A comprehensive literature review was conducted to gather relevant research articles, reports, and studies related to science education for the hearing impaired. Databases such as Google Scholar, ERIC, and academic journals were searched using keywords such as "science education," "curricula," "hearing impaired," "deaf education," and "inclusive practices." The literature review provided a foundation for understanding the current state of science education for the hearing impaired and identifying gaps and challenges.

Data Selection

Based on the literature review, relevant articles, reports, and studies were selected for inclusion in the review. The selection criteria included the publication's relevance to the topic, the credibility of the source, and the significance of the findings. Primary focus was given to recent publications within the last decade to ensure the inclusion of up-to-date information.

Data Extraction and Analysis

Data from the selected publications were extracted and organized based on key themes and topics related to science education for the hearing impaired. This covered information on barriers faced by hearing-impaired students, strategies and technologies employed, inclusive practices, support systems, challenges, and future perspectives. The extracted data was analyzed to identify patterns, trends, and recurring themes.

Synthesis and Writing

The synthesized findings from the data analysis were used to structure the review in a coherent and logical manner. The review was organized according to relevant sections, such as introduction, barriers, strategies and technologies, inclusive practices, challenges, and future perspectives. The information was presented in a narrative format, providing a comprehensive overview of the current state of science education for the hearing impaired and discussing future perspectives.

Incorporation of References

Throughout the review, proper referencing was ensured. The selected publications were appropriately cited using the APA to acknowledge the sources and provide credibility to the information presented.

Iterative Process

The research methodology was implemented in an iterative process, involving regular feedback and discussions with experts in the field of science education, special education, and deaf education. This helped refine the selection criteria, analysis process, and ensured the inclusion of diverse perspectives.

Ethical Considerations

In conducting the review, ethical considerations were considered. Proper citation and acknowledgement of the original authors' work were maintained. Permissions were sought for the use of any copyrighted materials, such as figures, tables, or excerpts from publications.

Limitations

The review acknowledged limitations, such as the availability of literature on specific topics, potential bias in the selection of publications, and the generalizability of findings.

Review Completion

The review was completed by synthesizing and presenting the findings in a coherent and informative manner, providing insights into the current state of science education for the hearing impaired and highlighting future perspectives.

RESULTS AND DISCUSSION

Importance of Science Education

Science education plays a fundamental role in equipping individuals with the knowledge and skills necessary to understand and engage with the world around them. It is a critical component of education systems worldwide, aiming to develop scientific literacy, foster critical thinking, and promote problem-solving skills among students. This comprehensive section explores the importance of science education and its impact on individuals and society, supported by relevant in-text references.

Promoting Scientific Literacy

Science education is essential for promoting scientific literacy, which encompasses the understanding of scientific concepts, principles, and processes. Scientific literacy empowers individuals to critically evaluate scientific information, make informed decisions, and actively participate in civic and societal issues [1]. Through science education, individuals gain the necessary knowledge to comprehend scientific phenomena, interpret research findings, and navigate the increasingly complex world driven by scientific advancements.

Developing Critical Thinking Skills

Science education fosters critical thinking skills, enabling individuals to analyze information, evaluate evidence, and form evidence-based conclusions. Science requires individuals to question assumptions, conduct experiments, and make logical connections between concepts and observations [6]. By engaging in science education, students learn to think critically, solve problems systematically, and develop a mindset that values evidence and scientific inquiry.

Nurturing Problem-Solving Abilities

Science education cultivates problem-solving skills that are vital in various aspects of life. Through scientific inquiry and experimentation, students learn to identify problems, formulate hypotheses, design investigations, collect data, and analyze results [1]. These problem-solving abilities are transferable to real-world situations, equipping individuals with the capacity to tackle complex challenges and contribute to scientific advancements and societal progress.

Fostering Curiosity and Wonder

Science education inspires curiosity and wonder about the natural world. By exploring scientific concepts and conducting hands-on experiments, students develop a sense of awe and appreciation for the wonders of the universe [7]. This curiosity drives further exploration, encourages lifelong learning, and nurtures a sense of curiosity that extends beyond the classroom.

Enhancing Career Opportunities

Science education opens up a wide range of career opportunities. In an increasingly technology-driven world, individuals with a solid foundation in science are well-equipped for careers in fields such as medicine, engineering, environmental science, and technology [6]. Science education provides the necessary knowledge and skills for individuals to pursue advanced studies in scientific disciplines and contribute to scientific research and innovation.

Science education holds immense importance in equipping individuals with scientific literacy, critical thinking skills, problem-solving abilities, and a sense of curiosity about the natural world. It promotes informed decision-making, fosters an appreciation for scientific advancements, and prepares individuals for diverse career opportunities. By emphasizing the importance of science education, society can nurture a scientifically literate population capable of addressing complex challenges and contributing to the advancement of knowledge and societal well-being.

Challenges in Science Education for the Hearing Impaired

Science education plays a crucial role in equipping students with the knowledge and skills necessary to understand and engage with the scientific world. However, individuals with hearing impairments face unique challenges in accessing and comprehending science curricula, which can hinder their ability to fully participate and benefit from science education. This comprehensive section explores the challenges faced by the hearing impaired in science education, including communication barriers, limited access to auditory information, and difficulties in hands-on experiences and classroom discussions. Relevant in-text references support the discussion of these challenges.

Communication Barriers

Communication is a central aspect of science education, involving the exchange of ideas, explanations, and discussions. However, individuals with hearing impairments face challenges in understanding spoken language, as it relies heavily on auditory cues [2]. Accessing and comprehending verbal instructions, explanations, and classroom discussions can be particularly difficult for those with hearing impairments, which can hinder their ability to grasp complex scientific concepts.

Limited Access to Auditory Information

Science education often involves demonstrations, experiments, and multimedia resources that rely on auditory information. Hearing-impaired students may struggle to access and comprehend these auditory elements, leading to difficulties in fully understanding the content [2]. This limited access to auditory information can impede their ability to engage with scientific investigations, demonstrations, and audiovisual resources, potentially hindering their overall learning experience.

Challenges in Hands-on Experiences

Science education emphasizes hands-on experiences, where students actively engage in experiments, observations, and data collection. However, hearing-impaired students may face challenges in participating fully in these activities [3]. Communication barriers and limited access to auditory cues during hands-on experiences can hinder their ability to understand instructions, collaborate effectively with peers, and engage in scientific inquiry, limiting their opportunities for practical learning.

Difficulties in Classroom Discussions

Classroom discussions play a crucial role in science education, fostering critical thinking, collaboration, and the sharing of ideas. However, hearing-impaired students may struggle to fully participate in these discussions due to difficulties in following verbal conversations, particularly in group settings [3]. This limitation can hinder their ability to contribute to class discussions, share insights, and engage in collaborative problem-solving, potentially affecting their overall learning experience.

Limited Availability of Resources and Materials

Science education relies on various instructional resources, including textbooks, visual aids, multimedia materials, and online resources. However, there is often a lack of educational resources specifically designed for the hearing impaired [2]. The limited availability of visual representations, captions, and other accessible materials can pose challenges for hearing-impaired students in understanding and engaging with scientific content.

The challenges faced by the hearing impaired in science education, including communication barriers, limited access to auditory information, difficulties in hands-on experiences, and limitations in classroom discussions, highlight the need for inclusive practices and targeted support. Efforts to address these challenges should focus on providing accessible instructional materials, leveraging technology, fostering inclusive learning environments, and promoting collaboration among educators, parents, and professionals. By addressing these challenges, science education can become more inclusive, accessible, and empowering for hearing-impaired students, ensuring equal opportunities for scientific learning and engagement.

Strategies and Technologies in Science Education for the Hearing Impaired

Science education plays a vital role in equipping students with the knowledge and skills necessary to understand and engage with scientific concepts. For individuals with hearing impairments, accessing and comprehending science curricula can pose unique challenges. However, there are various strategies and technologies that have been developed to enhance science education experiences for the hearing impaired. This comprehensive section explores some of these strategies and technologies, including sign language interpretation, captioning, visual aids, and assistive technologies like hearing aids and cochlear implants. In-text references support the discussion of these strategies and technologies.

Sign Language Interpretation

Sign language interpretation is a crucial strategy for facilitating communication between teachers and hearing-impaired students in science classrooms. Trained interpreters can effectively translate spoken language into sign language, allowing students to access instructional content [2]. This strategy ensures that hearing-impaired students can receive real-time information and participate actively in classroom discussions, fostering their understanding of scientific concepts.

Captioning

Captioning involves the display of written text synchronized with audiovisual content, making it accessible to individuals with hearing impairments. In science education, captioning can be used for videos, multimedia presentations, and online resources [2]. By providing visual text alongside audio information, captioning enables hearing-impaired students to access auditory content and enhances their comprehension of scientific materials.

Visual Aids

Visual aids are instrumental in supporting the learning experiences of hearing-impaired students in science education. Graphs, diagrams, illustrations, and other visual representations can effectively convey scientific concepts and provide additional context and support [2]. Visual aids facilitate understanding, promote independent learning, and allow students to engage with scientific information through visual means.

Assistive Technologies

Assistive technologies play a crucial role in enhancing science education experiences for the hearing impaired. Hearing aids and cochlear implants are examples of assistive devices that amplify sound or provide direct stimulation to the auditory nerves, respectively [4]. These technologies improve the audibility and clarity of spoken language, allowing hearing-impaired students to access auditory information and engage more effectively with scientific content.

Multimodal Approaches

Multimodal approaches involve the integration of various sensory modalities to enhance learning experiences for hearing-impaired students. These approaches combine visual, auditory, and tactile elements to present scientific information [4]. For example, teachers may use videos with captioning, sign language interpretation, and visual aids to present scientific concepts, providing multiple means of access for students with hearing impairments.

Interactive Simulations and Multimedia

Interactive simulations and multimedia resources can significantly benefit hearing-impaired students in science education. These resources provide interactive and engaging experiences that allow students to explore scientific phenomena and conduct virtual experiments [4]. By incorporating visual and interactive elements, these technologies promote understanding, provide hands-on experiences, and cater to different learning styles.

Strategies and technologies such as sign language interpretation, captioning, visual aids, assistive technologies, multimodal approaches, interactive simulations, and multimedia resources have been instrumental in enhancing science education experiences for the hearing impaired. By leveraging these tools, educators can bridge communication gaps, provide accessible content, and engage hearing-impaired students in meaningful ways. It is essential to continue exploring and implementing innovative approaches to ensure that science education is inclusive, empowering, and accessible for all learners, regardless of their hearing abilities.

INCLUSIVE PRACTICES AND SUPPORT SYSTEMS

Inclusive education aims to ensure that all learners, including those with hearing impairments, have equal access to quality education. In Ghana, efforts have been made to promote inclusive practices and establish support systems for students with hearing impairments. This comprehensive section explores inclusive practices and support systems for the hearing impaired in Ghana, including policy frameworks, specialized educational programs, teacher training, and community engagement. In-text references support the discussion of these inclusive practices and support systems.

Policy Frameworks

Ghana has made strides in developing policy frameworks that promote inclusive education for students with disabilities, including hearing impairments. The Ghana Education Service (GES) has implemented policies such as the Inclusive Education Policy and the Special Education Policy, which emphasize the inclusion of students with disabilities in mainstream schools [8]. These policies provide a foundation for inclusive practices and support systems for hearing-impaired students.

Specialized Educational Programs

In Ghana, specialized educational programs have been established to cater to the unique learning needs of hearing-impaired students. Schools for the Deaf, such as the Cape Coast School for the Deaf and the Akropong School for the Deaf, provide a supportive and inclusive learning environment for hearing-impaired students [10]. These schools offer specialized curriculum adaptations, sign language instruction, and a range of support services to enhance the educational experiences of hearing-impaired students.

Teacher Training

Teacher training programs play a critical role in equipping educators with the knowledge and skills necessary to support hearing-impaired students effectively. In Ghana, the GES has initiated teacher training programs that focus on inclusive education and the needs of students with disabilities [8]. These programs provide teachers with specialized training in sign language communication, instructional strategies for hearing-impaired students, and the use of assistive technologies.

Assistive Technologies

The use of assistive technologies can significantly enhance the learning experiences of hearing-impaired students. In Ghana, efforts have been made to provide assistive devices, such as hearing aids and cochlear implants, to students with hearing impairments [11]. These technologies improve auditory access and facilitate communication, enabling hearing-impaired students to actively engage in the learning process.

Community Engagement

Inclusive practices for hearing-impaired students in Ghana extend beyond the classroom. Community engagement plays a vital role in raising awareness, promoting acceptance, and fostering inclusion. Organizations, such as the Ghana National Association of the Deaf, advocate for the rights and inclusion of individuals with hearing impairments [12]. Through community outreach programs and public awareness campaigns, these organizations work to eliminate stigmas and create an inclusive society for hearing-impaired individuals.

Inclusive practices and support systems for hearing-impaired students in Ghana are gradually being strengthened. Policy frameworks specialized educational programs, teacher training initiatives, assistive technologies, and community engagement efforts are all contributing to creating an inclusive educational landscape for students with hearing impairments. By continuing to prioritize inclusive education and investing in targeted support systems, Ghana can ensure that hearing-impaired students have equal opportunities to access quality education, fulfill their potential, and actively participate in society.

Current State and Areas for Improvement

The current state of science education for the hearing impaired in Ghana reflects a mix of progress and challenges. Efforts have been made to integrate hearing-impaired students into mainstream schools, allowing them to access science education alongside their hearing peers. However, there are still significant gaps in the provision of specialized resources, teacher training, and inclusive instructional practices [10]. Limited availability of accessible science materials, including textbooks and instructional aids, poses a significant barrier to effective science learning for hearing-impaired students.

In Ghana, efforts have been made to enhance science education for hearing-impaired students through inclusive practices and specialized curricula. This comprehensive section examines the current state of science education, curricula, and support systems for the hearing impaired in Ghana, while also highlighting areas for improvement. In-text references support the discussion of the current state and areas for improvement in science education for the hearing impaired in Ghana.

Inclusive Curricula and Adaptations

In recent years, efforts have been made to develop inclusive curricula and adapt existing materials to cater to the needs of hearing-impaired students in science education. The Ghana Education Service (GES) has worked to align curricula with the principles of inclusive education, aiming to ensure that science instruction is accessible and engaging for all learners [8]. However, there is still a need for further development and dissemination of adapted science curricula that incorporate visual aids, sign language, and other accessible formats.

Teacher Training and Professional Development

Teacher training plays a crucial role in equipping educators with the knowledge and skills necessary to support hearing-impaired students effectively. In Ghana, teacher training programs have been initiated to provide educators with specialized training in inclusive science education and strategies for accommodating hearing-impaired students [8]. However, there is a need to expand and strengthen these training initiatives to ensure that teachers have the necessary competencies to address the unique learning needs of hearing-impaired students in science classrooms.

Access to Assistive Technologies

Assistive technologies can greatly enhance the learning experiences of hearing-impaired students in science education. While there have been efforts to provide assistive devices, such as hearing aids and cochlear implants, to students with hearing impairments in Ghana [11], there is still a need to ensure the availability and accessibility of these technologies for all who require them. Furthermore, integrating digital tools and resources, such as captioning, interactive simulations, and multimedia, can further enhance the accessibility and engagement of science education for hearing-impaired students.

Collaboration and Partnerships

Collaboration among stakeholders, including educators, policymakers, parents, and organizations supporting the hearing impaired, is crucial for advancing science education for hearing-impaired students in Ghana. Strengthening collaboration and partnerships can lead to the sharing of best practices, the development of innovative solutions, and the mobilization of resources to address the specific needs and challenges faced by hearing-impaired students in science education. While there have been notable efforts to improve science education, curricula, and support systems for the hearing impaired in Ghana, there is still work to be done to ensure equitable and inclusive access to quality science education. Enhancements in adapted curricula, teacher training, access to assistive technologies, and collaborative partnerships are essential for addressing the current gaps and providing an inclusive and empowering science education experience for hearing-impaired students in Ghana. By investing in these areas and prioritizing inclusive practices, Ghana can foster a more inclusive educational landscape that promotes the engagement and success of hearing-impaired students in science education.

Future Perspectives

The future of science education for the hearing impaired in Ghana holds immense potential for growth and improvement. As technology advances and inclusive practices gain recognition, there are several key areas that can shape the future perspectives of science education for the hearing impaired in Ghana. This comprehensive section explores these future perspectives, including advancements in accessible curricula, inclusive instructional approaches, technological innovations, and collaborative partnerships. In-text references support the discussion of the future perspectives of science education for the hearing impaired in Ghana.

Accessible Curricula

In the future, there is a need to further develop and refine accessible curricula that cater to the unique learning needs of hearing-impaired students. This includes the creation of visually rich materials, use of clear and concise language, incorporation of sign language resources, and integration of interactive elements [8]. By ensuring that science curricula are inclusive and designed with the needs of hearing-impaired students in mind, Ghana can foster a more equitable and engaging learning environment.

Inclusive Instructional Approaches

Adopting inclusive instructional approaches is vital for promoting active participation and engagement among hearing-impaired students in science education. In the future, educators can explore strategies such as project-based learning, hands-on experiments, group discussions, and collaborative activities that encourage active learning and foster critical thinking skills [10]. These approaches promote a student-centered learning environment and create opportunities for hearing-impaired students to interact with their peers and construct knowledge together.

Technological Innovations

Advancements in technology offer promising prospects for enhancing science education for the hearing impaired in Ghana. Assistive technologies, such as real-time captioning, video conferencing tools, and immersive virtual reality experiences, can facilitate access to scientific content and create interactive learning experiences [11]. Future developments in technology, coupled with affordable and accessible solutions, can further bridge the communication and learning gaps for hearing-impaired students in science classrooms.

Professional Development for Educators

Ongoing professional development for educators is essential to equip them with the knowledge and skills necessary to effectively teach science to hearing-impaired students. Future perspectives should prioritize the provision of specialized training programs, workshops, and mentoring opportunities for teachers to enhance their understanding of inclusive practices, effective instructional strategies, and the use of assistive technologies [8]. By investing in professional development, Ghana can empower educators to create inclusive science classrooms that cater to the diverse needs of hearing-impaired students.

Collaborative Partnerships

Collaborative partnerships among educational institutions, organizations, and stakeholders are crucial for shaping the future of science education for the hearing impaired in Ghana. By fostering collaborations, sharing best practices, and pooling resources, Ghana can develop a more comprehensive and integrated approach to inclusive science education. Partnerships with the Ghana Education Service, specialized schools for the deaf, disability organizations, and the scientific community can contribute to the development of inclusive policies, innovative instructional practices, and accessible resources.

The future of science education for the hearing impaired in Ghana holds immense potential for growth and improvement. By focusing on accessible curricula, inclusive instructional approaches, technological innovations, professional development for educators, and collaborative partnerships, Ghana can ensure a more equitable and engaging science education experience for hearing-impaired students. It is through these future perspectives that Ghana can create an inclusive educational landscape that nurtures the talents and potential of all students, regardless of their hearing abilities.

DISCUSSION

Science education plays a crucial role in the intellectual development and future success of all students, including those with hearing impairments. This section provides a general discussion on science education, curricula, and the challenges and strategies specific to the hearing impaired. Drawing upon the reviewed literature, it highlights the importance of inclusive practices, the need for specialized curricula, the role of technology, and the significance of teacher training in promoting effective science education for the hearing impaired. In-text references are included to support the discussion.

Inclusive science education aims to provide equal opportunities for students with hearing impairments to access and engage with science learning. Science education fosters critical thinking, problem-solving, and scientific literacy, which are essential for individuals to participate in and contribute to society [9]. It is crucial to recognize that hearing-impaired students possess the same potential and curiosity for scientific exploration as their hearing peers [2]. By embracing inclusive practices, educators can ensure that hearing-impaired students have equitable access to science education, fostering their intellectual growth and future prospects.

Developing specialized curricula that accommodate the learning needs of hearing-impaired students is vital for effective science education. Traditional science curricula may heavily rely on auditory information, making it inaccessible to students with hearing impairments. Adaptations to the curriculum should include visual representations, graphic organizers, and real-world examples that facilitate comprehension and promote active engagement [2]. Incorporating sign language, visual aids, and multimedia resources can enhance the learning experiences of hearing-impaired students, ensuring that they can access and understand scientific concepts.

Technology offers significant opportunities to support science education for the hearing impaired. Assistive technologies, such as captioning, video conferencing, and interactive simulations, can bridge communication gaps and enhance access to scientific content [13].

Accessible digital resources, including online databases, virtual laboratories, and interactive multimedia, can provide hearing-impaired students with additional avenues for exploration and understanding [10]. Technological advancements continue to expand the possibilities for inclusive science education, promoting active learning and enhancing the engagement of hearing-impaired students.

Effective science education for the hearing impaired relies on well-prepared and trained educators. Teacher training programs should address the specific needs of hearing-impaired students, including instruction in sign language, strategies for visual-based teaching, and knowledge of assistive technologies [2]. Teachers should be equipped with the skills to create inclusive classrooms, adapt instructional materials, and implement effective teaching strategies that cater to the diverse learning needs of hearing-impaired students [10]. Ongoing professional development opportunities and collaboration among educators are crucial for continuously improving science instruction and meeting the evolving needs of the hearing impaired.

Science education, curricula, and support systems for the hearing impaired are essential components of an inclusive educational landscape. By embracing inclusive practices, developing specialized curricula, leveraging technology, and providing comprehensive teacher training, educators can ensure that hearing-impaired students have equal access to quality science education. The challenges posed by auditory-based instruction can be overcome by incorporating visual elements, sign language, and assistive technologies. By prioritizing inclusive science education, we can foster the intellectual growth and future success of hearing-impaired students, empowering them to pursue careers in science and contribute to the scientific community.

CONCLUSION

Science education for the hearing impaired is a vital component of inclusive education systems. This review has examined the importance of inclusive practices, the need for specialized curricula, the role of technology, and the significance of teacher training in promoting effective science education for students with hearing impairments.

It is clear that inclusive science education is crucial for ensuring equitable access to educational opportunities and fostering the intellectual growth and development of hearing-impaired students. By embracing inclusive practices, educators can create learning environments that cater to the diverse needs of all students, including those with hearing impairments.

Specialized curricula that incorporate visual aids, sign language, and multimedia resources are essential for making science education accessible and engaging for hearing-impaired students. These adaptations facilitate comprehension, promote active participation, and enable students to grasp scientific concepts effectively.

Technology plays a significant role in enhancing science education for the hearing impaired. Assistive technologies, online resources, and multimedia tools provide additional avenues for exploration, communication, and understanding. Continued advancements in technology hold great promise for further improving access to science education for hearing-impaired students.

Teacher training and professional development are crucial for equipping educators with the knowledge and skills to effectively teach science to hearing-impaired students. By providing teachers with training in inclusive practices, sign language, and assistive technologies, educational systems can ensure that teachers are prepared to meet the unique needs of hearing-impaired students in science classrooms.

In conclusion, science education, curricula, and support systems for the hearing impaired should be an integral part of inclusive educational practices. By embracing inclusive approaches, developing specialized curricula, leveraging technology, and providing comprehensive teacher training, we can create an educational environment that empowers hearing-impaired students to succeed in science and contribute to the scientific community. It is through these efforts that we can foster an inclusive society that values the talents and potential of all learners, regardless of their hearing abilities.

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CONTEXT-BASED APPROACH IN CHEMISTRY EDUCATION: A SYSTEMATIC REVIEW

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ABSTRACT

The implementation of context-based chemistry programs has been started before 40 years ago since 1980's in an attempt to make the learning of chemistry more meaningful for students. Consequent to its lengthy, there has been a steady increase in the number of interventional context-based (ICB) approach chemistry studies investigating the effect of various instructional strategies on students' learning outcomes from primary to post-secondary levels. However, there is a limitation of literature review conducted on interventional context-based chemistry studies. Hence, the present review was carried out to evaluate interventional context-based chemistry studies using six research questions based on the following categories (main headings): (1) countries or continents in which ICB chemistry studies were conducted in; (2) research methodologies implemented in ICB studies; (3) topics in which ICB chemistry studies used; (4) learning variables measured by ICB studies; (5) teaching methods and instructional strategies adopted by ICB studies; and (6) the effectiveness of context-based instructions on students' learning outcomes. Moreover, some sub-headings also followed the main headings. To achieve this objective, a rigorous systematic literature review has been executed using 25 selected ICB chemistry studies published between the years 2009 and 2022 based on the specific inclusion and exclusion criteria. These studies were accessed in internationally well-known databases (Google Scholar, ERIC, Semantic Scholar, and Mendeley); and the studies were organized and reviewed thematically. To summarize and present the findings of the studies, matrices, constructed by the researcher, were used. The review analysis results revealed and shed light on the critical appraisal of interventional context-based chemistry studies, missing parts of the context-based approach, and implications and suggestions for future studies. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

The word context, literally, is derived from the Latin words ‘contexere’, ‘con’- meaning together and ‘texere’- meaning to weave [B17]. Its meaning is then weaving together. A context is also related to a noun ‘*contextus*’ which expresses ‘coherence’, ‘connection’, or ‘relationship’ [B3]. It might be also an authentic situation in daily life involving chemistry like industrial, social, economic, environmental, technological and/or a research setting [B1, B19]. Mahaffy, likewise, termed the word context as ‘human element’ when he modified a two-dimensional ‘triangular’ chemistry education into a three-dimensional ‘tetrahedral’ chemistry education [B8]. In general sense, for younger students, contexts are those having direct applications to students’ lives, whereas more advanced students, contexts are ‘what scientists do’ may be more common [B19].

Instructional Approach

An instructional approach refers to a view of looking at things, a set of principles, beliefs, or ideas about the nature of instructional activities [B6]. An instructional approach provides philosophy to the whole process of instruction and gives the overall wisdom, general principle, and direction to the entire spectrum of the teaching process to make learning possible [B6]. The authors also stated that instructional approach provides a basis for the development of teaching methods, and strategies and to define their components as well. That is, a teaching approach is a universal set from which we get teaching methods. Teaching methods also give teaching strategies. The concepts of teaching methods and instructional strategies are discussed in the next paragraphs.

A teaching (or an instructional) approach can be broadly classified into deductive and inductive, direct and indirect, or teacher-centered and learner-centered. In the learner-centered or constructivist approach students participate actively in learning and the teacher has facilitator role while in the teacher-centered instruction students are passive learners and the teacher has mainly authoritative role. Constructivist approach is an example of learner-centered approach in which students build their learning in the context [B3]. In this approach, the teaching-learning process begins at the context, and it is called as context-based approach.

Context-Based Approach

A context-based approach is an instructional approach starts with a context and gives equal emphasis to both content and context of chemistry [B3]. Metaphorically, context-based instructional approach can be viewed as the two sides of the chemical coin [B2]. Philosophically, a context-based approach is founded on a pragmatic philosophy. That is, education should be applied to the real-world environment making the process of teaching-learning more meaningful and effective [B11]. It believes that no truth is absolute and permanent as it is ever changing from time to time and place to place and from circumstance to circumstance. Thus, philosophers and educators believe that since life is dynamic the aims of education should also need to be dynamic.

Context-based approach is aligned with a social constructivist perspective. Social constructivism is a learning theory propounded by Lev Vygotsky in 1968 [B6], however, it emerged as the leading view of human learning in the 1980s. Social constructivism is a popular idea that is being used to guide teaching, learning, and research in science education. It stresses the importance of what is already in the students' minds as a place to initiate instruction. In its perspective, learning does not limit only to the school compounds but rather any social interaction, outside the compounds, with anybody may also well lead to learning. This implies that learning occurs in the interaction between the learner and others. Social constructivism is based on the assumption that learners do not discover existing knowledge rather they actively construct it [B10]. They are not empty vessels to be filled by their teachers rather they come to the class with preconceived ideas, and prior knowledge [B10]. Therefore, every learner has prior knowledge on which the teacher builds a bridge to connect it with the new knowledge.

Teaching Methods and Instructional Strategies

Teaching methods and strategies are the two different concepts used by teachers during classroom instructions. The term teaching method refers to the general pedagogy used for classroom instruction [B4]. A teaching method could be *participatory* (e.g., hands-on activities, group discussions, questioning and answering, problem-based learning, and so on) or *non-participatory* (e.g., lecturing, and demonstration) method. It is a scientific way of teaching of a subject matter based on a selected approach and method [B4] in accordance with a defined plan of actions (strategy).

An instructional strategy is a careful plan of action designed to achieve a specific or series of goal(s) of instruction [B5]. It was also stated that an instructional strategy is a pattern of teaching-learning activities that helps students to a better understanding of the material, and attains the learning objectives of the course under the teaching method. For every lesson, at the planning stage of instructional strategy, the teacher decides what method of teaching to adopt, whether participatory or non- participatory. Upon deciding which method to adopt for a specific topic, the teacher begins to carefully plan teaching activities (strategies) which can help to achieve learning objectives. Hence, a teaching method is a wider term covers a teaching strategy and helps for the practical realization of an approach.

Context-Based Instructional Strategies

A context-based approach (CBA) should have a clear instructional strategy and has to be explicitly reported by researchers. Such instructional strategy adopted in a context-based approach under the selected teaching method is a context-based instructional strategy. There are various context-based instructional strategies to be employed in CBA. These are REACT [A15], storyline [A7], 7E learning cycle [A16], 5E learning cycle [A6], ARCS [A17], EEKPST [A12], and scrum methodology [A24]. Amongst these, REACT is the first and the most frequently used instructional strategy in many CBA studies while scrum methodology has been used in CBA research in recent years.

Review Questions

In this review, the following review questions were addressed:

- Which continent and/or country dominate in conducting interventional context-based chemistry studies?
- What kinds of experimental designs and data analysis methods have been adopted in the interventional context-based chemistry studies?
- In what topics of chemistry is context-based approach used?
- What are the research variables investigated in interventional context-based chemistry studies?
- What are the teaching methods and instructional strategies adopted in interventional context-based approach of chemistry studies?
- What is the effectiveness of context-based instructional strategies in chemistry education with respect to chemistry topics and measured variables?

Significance of the Review Study

A review and synthesis of the interventional context-based approach studies has much to offer policy makers, curriculum developers, chemistry educators, education researchers, and teachers. A reviewing of the overall research methodologies being adopted and the effects of interventional context-based approach on students' learning outcomes will not only reveal the motives of the researchers who undertook it, but also guide future research towards poorly researched issues. As the interventional context-based approach leads students towards making links between real life and chemistry, teachers will be able to harness methods used for research into classroom practice to achieve a better level of students' engagement in chemistry.

Limitation of the Review Study

The review has the following two main limitations:

- There was a scarcity of interventional context-based approach chemistry studies that conducted on different countries across the world; especially in developed countries (such as USA, UK, and South Africa) those started context-based programs earlier in 1980s, 1990s or 2000s. Hence, the review study was limited to only seven countries.
- The search strategy was limited only to the open access Journals, and English literature.

REVIEW METHODS AND MATERIALS

Search Sources

The methods of systematic literature review for the current paper were mainly adopted from the two sources, [B8] and [B10]. The paper consists of articles published in the last fourteen years on the use of context-based approach instruction in chemistry education. Papers published between January 2009 and October 2022 was searched in four electronic databases: Google Scholar, ERIC, Semantic Scholar, and Mendeley. To be included in the review, each article had to present a study in which context-based instructional approach had been implemented in action, which has to be an interventional study, and involving student participants in any grade level in which chemistry is offered as a separated subject matter including post-secondary level students.

Exclusion/Inclusion Criteria

The exclusion criteria— a study must not fall into any one of the following categories: *Exclusion 1*: exclusion on approach (not context-based approach and not studying the effect of context-based approach on students' learning); *Exclusion 2*: exclusion on design (not experimental/ interventional studies); *Exclusion 3*: exclusion on participant types (not student participants, and not in primary, secondary and ternary levels); *Exclusion 4*: exclusion on study type (not empirical study). That is, original empirical studies, including unpublished doctoral theses, were included. In other hand, centre or government reports, policy documents, other systematic reviews, meta-analyses, commentaries, technical/methodological notes, short notes, and books or book chapters, master theses, were not included. *Exclusion 5*: exclusion on text (i.e., if full-text of the study is not available); *Exclusion 6*: exclusion on contexts/settings in which the study was carried out (i.e., the study is written in a language other than English); and *Exclusion 7*: exclusion on publication date (not published in the period of 2009–2022).

Limits and Methodology of the Search

The search strategy was carried out using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PRISMA statement was very helpful to the researchers to the critical appraisal of published articles and improves the reporting of the current systematic review.

Procedures

The review was carried out between March and April 2022 and being updated in September and October 2022. Initially, the criteria for selecting the studies that could be part of the review were drawn up, as well as the selection of inclusions/exclusions and the databases. Afterwards, the selection of the databases for the bibliographic search was carried out. Four digital databases were selected for the following reasons. These databases were chosen because they are online databases with vital articles in the field of education. They are also the most important citation databases in the world and are highly regarded by the scientific community, so the researchers the current review considered them essential to include in the review.

All study articles were identified from the four databases using the following search strings [B8]. The search string was encompassing the following keywords:

1. (The effect of or impact of or influence of)
2. (Context-based or context-led or context-oriented)
3. (Contextualized or contextualized)
4. (Real life or everyday life or daily life or authentic life)
5. (Chemistry education or chemistry instruction or chemistry program or chemistry curricula, chemistry material or chemistry project or chemistry learning or chemical education or

chemical instruction)

6. #1 and #2 or #3 or #4 and #5 and (student's learning or pupils' learning or learner's learning outcomes or student's learning outcomes or pupils' learning outcomes)
7. #2 or #3 or #4 and #5
8. #7 and (on student's learning or pupils' learning or learner's learning outcomes or students' learning outcomes or pupils' learning outcomes)
9. Limit #7 and #8 to (English language and (lower elementary education or upper elementary education or lower secondary education or upper secondary education) and (Journal articles, conference proceedings or dissertations) and yr=2009-2022)

With these inclusion/exclusion criteria, primarily, 190 studies were obtained. Amongst these, 109 studies were from Google scholar, 41 studies from ERIC, 26 studies from Semantic scholar, and 14 studies from Mendeley. The process of analysis of the studies was carried out by three researchers. They worked independently and shared the results at the end of the work. On the second level of exclusion, 32 studies were excluded and only 25 studies accepted (Figure 1).

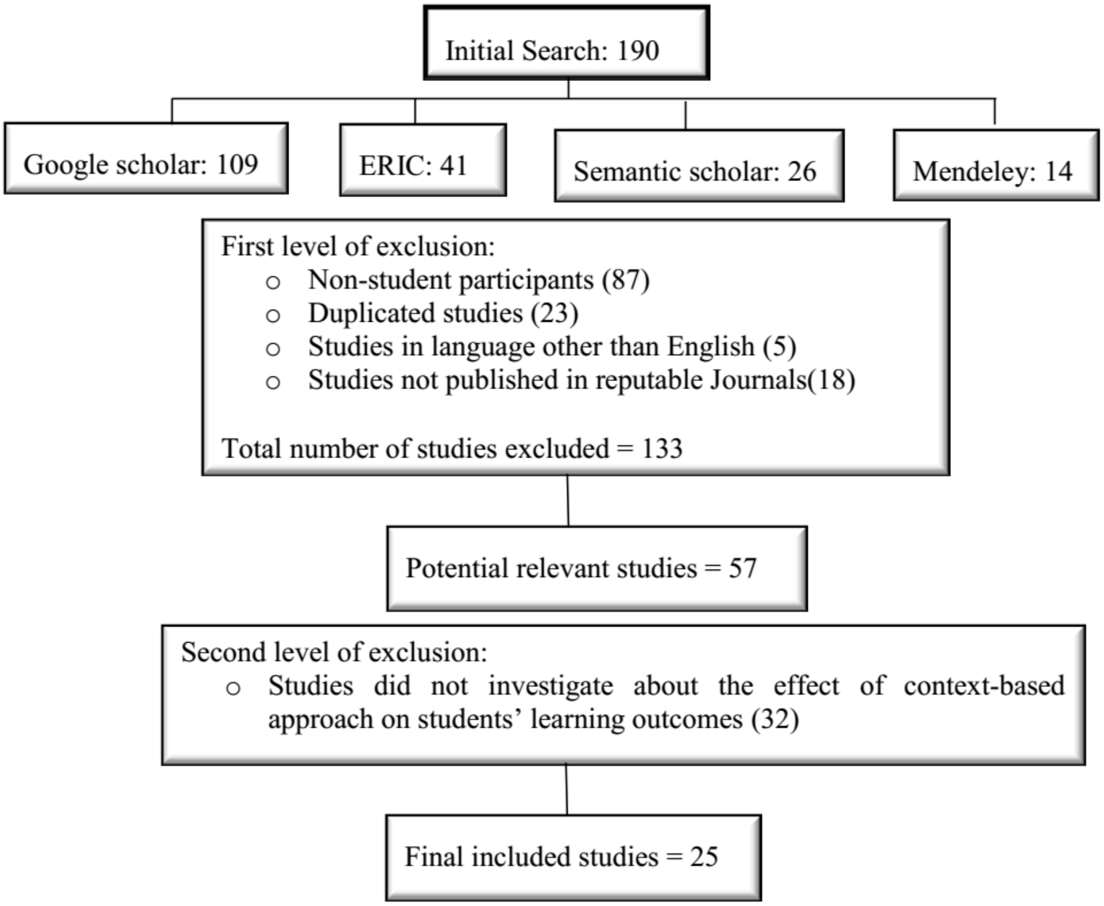

Figure 1. Flow Chart of Systematic Literature Review

With the final 25 study articles selected (Figure 2), following a systematic and thorough review process, each study was categorized, in relation to participant type, on the basis of the following categories: primary, secondary, and post-secondary levels. As it can be shown in the figure, 72 percent (18 out of 25) of the studies were undertaken with secondary school students, 24 percent (6 out of 25) using post-secondary level students, and 4 percent (1 out of 25) with primary school students. This implies that significant numbers of the studies were carried out in secondary schools, and few in primary schools. Hence, it can be stated that most of the studies were carried out in secondary school students, next in post-secondary students and, lastly, in primary school students.

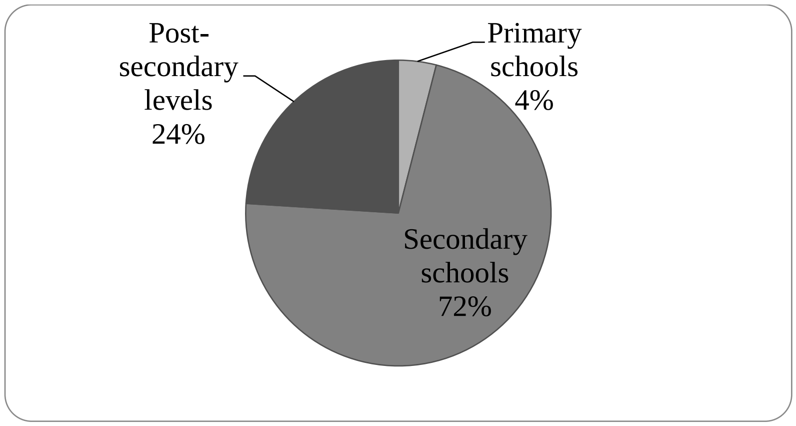

Figure 2. Percentage of ICB Chemistry Studies Conducted in Primary, Secondary, and Post-Secondary Level Student Participants

Quality Assurance Process

To assure the quality of studies, Journals were initially identified whether they are reputable. In addition, quality assurance procedures were also implemented by decisions on key-wording, title screening, abstract reviewing, full text examination, and in-depth data extraction. Furthermore, the PRISMA guidelines were essentially used as its guidelines include an evidence-based set of items to assess the quality of systematic reviews and meta-analysis.

RESULTS AND DISCUSSIONS

ICB Chemistry Studies per Continents/Countries

The first part of this section focuses on the countries and continents in which interventional context-based (ICB) chemistry studies were conducted. As illustrated in Figure 3, seven countries and three continents where such studies were being undertaken are identified. A total of twenty-five ICB studies were identified in these countries for the purpose of review. Except one of the studies [A13], the country of each study, where it was conducted in, is apparently stated by authors. The number and percentage of ICB chemistry studies of each country and continent is demonstrated in the figure. More than half (56) percent (14 out of 25) of the studies were undertaken in Turkey, and Nigeria (15.4) is next to Turkey. The other countries such as Indonesia (7.7 percent), Israel (3.8 percent), Netherland (3.8 percent), and Serbia (3.8 percent) are following to Nigeria.

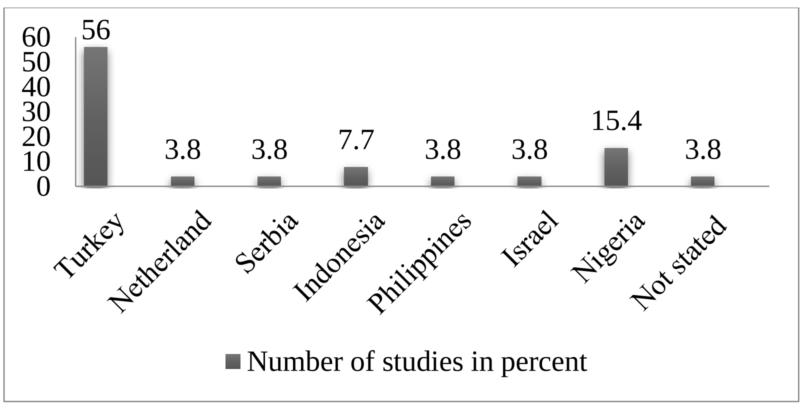

Figure 3. Percentage of ICB Chemistry Studies per Continents/Countries in Which They Were Conducted In

These indicate that the ICB chemistry studies, searched for this review, were exclusively found in three continents, namely, Africa (N = 4, 16 percent), Europe (N = 16, 64 percent), and Asia (N = 4, 16 percent). The three countries in Europe, where 16 studies were carried out, are Turkey, Netherland, and Serbia. Similarly, in Asia, there are also three countries (Indonesia, Philippines, and Israel) in which 4 studies were conducted in. But, the only country in Africa in which four ICB chemistry studies were conducted was Nigeria. Here, more than half percent (56, N = 14) of the total ICB chemistry studies was carried out in Turkey while the minimum, 4 percent (N =1), was conducted in each of the five countries (Netherland, Serbia, Philippines, Israel, and another country where its name was not mentioned). Generally, it can be suggested that Europe and Asia dominate the interventional context-based chemistry studies regarding to the number of countries, while Africa is poorly represented with only one country, Nigeria.

Research Methodologies Adopted in the ICB Approach of Chemistry Studies

Kinds of Experimental Design and Research Methods Adopted in ICB Chemistry Studies

Table 1 below shows the nature of experimental design and research methods adopted by ICB chemistry studies (N = 25). Amongst these, 76 percent (19 out of 25), 20 percent (5 out of 25), and zero percent of the studies had quasi-experimental, pre-experimental, and true-experimental designs respectively. But one of the studies, [A22], didn’t explicitly state the nature of experimental design whether it was quasi-, pre-, or true-experimental. The table indicates that no study was conducted with true-experimental design as random sampling of human subjects is not generally possible in experimental studies [A6, A12, A23]. But most of the review studies (76.0 percent, 19 out of 25) adopted quasi-experimental designs. Among the total number of studies (N = 25), only few (32 percent, N = 8) of them selected mixed-method research procedures, though all didn't state the priority/weighting and sequence/timing of the methods.

Table 10. The Nature of Experimental Design and Research Method (N = 25)

Design	Total N(%)	Mixed Method N(%)	Priority/weight		Sequence/timing	
			Stated N(%)	Not stated N(%)	Stated N(%)	Not stated N(%)
Pre-experimental	5(20.0)	3(60)	0(0)	3(100)	0(0)	3(100)
True-experimental	0(0)					
Quasi-experimental	19(76.0)	5(26.3)	0(0)	5(100)	0(0)	5(100)
Not stated	1(4.0)	0				
Total	25	8(32.0)	0(0)	8(100)	0(0)	8(100)

Data Analysis Methods Adopted in ICB Studies

Table 2 provides an overview of the types and frequencies of analysis methods adopted by the 25 studies. Majority of the chemistry studies adopted inferential statistics, except two studies [A3, A21] that used exclusively descriptive statistics. Besides, some kinds of qualitative data analysis methods such as NVivo [A4, A17], content analysis [A4], and thematically [A25] had been employed by those studies having mixed method reasearch procedures.

Amongst the inferential statistical analysis, t-tests [A1, A7, A10, A13, A14, A16, A17, A18, A22] and ANOVA/ANCOVA [A3, A5, A7, A8, A9, A11, A14, A19, A24, A25] are the most frequently used (F = 12 and 11 respectively) amongst the tests. In the case of t-tests, most studies clearly specified whether the test was dependent or independent, while three [A1, A7, A22] of them didn't mention at all. For the case of ANOVA/ANCOVA, many of the studies (10 out of 11) used one-way ANOVA, while one of them [A11] had used two-way ANOVA.

Table 11. Data Analysis Methods of ICB Chemistry Studies (N = 25)

Data Analysis Method	Specific Type of DAM	CB study	N	N total
	Dependent t-test	A10, A13, A16, A17	4	
t-test	Independent t-test	A10, A13, A14, A16, A18	5	12
	Not stated	A1, A7, A22	3	
	One-way	A3, A5, A7, A8, A9, A14, A11, A19, A24, A25	10	
	Two-way	A11	1	
ANOVA or ANCOVA				11
MANOVA or MANCOVA	One-way	A6, A19, A23	3	4
	Two-way	A12	1	
Mann-Whitney U-Test		A15	1	1
Wilcoxon		A4, A15	2	2
Chi-square		A11	1	1
Descriptive statistics	M, SD, F	A2, A21	2	2
Qualitative method	NVivo	A14, A17	2	
	Content analysis	A4	1	4
	Thematically	A25	1	

Note: M- mean; SD- standard deviation; F- frequency; DAM- Data Analysis Method

Besides, four other studies [A6, A12, A19, A23] used MANOVA to analyze their quantitative data. Three of them [A6, A19, A23) used one-way MANOVA while one of the studies [A12] used two-way MANOVA. Furthermore, non-parametric tests such as Mann-Whitney U-Test [A15], Wilcoxon [A4, A15], and Chi-square [A11] were also used by five studies. However, these non-parametric tests were applied less frequently (5 out of 25) than parametric tests. It seems reasonable to conclude from this review that t-tests and ANOVA are the most frequently used inferential statistical (or parametric) tests in interventional context-based approach studies in chemistry education.

Methods of Data Analysis per Numbers of Variables

The table presented below (Table 3) indicates the inferential statistics used in relation to the number of groups and variables (dependent and independent) in ICB chemistry studies. Most studies (23 out of 25) had two study groups (one intervention and one comparison); while the other two studies [A5, A11] had three study groups (two interventions and one comparison). [A5] and A11] had employed ANOVA analysis instead of t-tests which seemed to correspond to the number of groups. Regarding to the number of independent variables, there are three studies [A6, A7, A23] that had two independent variables (groups and other one variable). Amongst these three studies, only [A6] had clearly stated that he used two-way MANOVA, while [A7], and [A23] didn't obviously explained whether they applied one- or two-way ANOVA/MANOVA in their studies.

Table 12. Number of Groups, Dependent Variables, and Independent Variables in Relation to Inferential Statistics

CB study	N of Gp	N of IV	N of DV	Method of Data Analysis
A1	2	1	3	t-test
A15	2	1	1	Mann-Whitney U-Test, Wilcoxon
A5	3	1	2	ANCOVA
A7	2	2	1	t-test and ANCOVA
A9	2	1	2	Independent t-test and ANCOVA
A10	2	1	1	Paired-samples t-test
A11	3	1	2	One-way ANOVA, Scheffé Post-hoc test, chi-square tests and two-way ANOVA
A12	2	1	2	Two-way MANCOVA
A13	2	1	1	Dependent- and independent t-test
A14	2	1	3	Independent sample t-test, ANCOVA and NVivo
A16	2	1	1	Independent sample t-test, paired sample t-test
A17	2	1	4	Dependent t-test and NVivo
A18	2	1	3	Independent samples t-test
A19	2	1	2	MANOVA and ANOVA
A20	2	1	3	ANCOVA
A21	2	1	1	Descriptive statistics
A22	2	1	1	t-test
A23	2	2	3	MANCOVA
A2	2	1	1	Descriptive analysis
A4	2	1	5	Wilcoxon signed-rank test and content analysis
A24	2	1	2	ANCOVA and ANOVA
A3	2	1	3	ANCOVA
A6	2	2	4	Two-way MANCOVA
A8	2	1	3	One-way ANOVA
A25	2	1	1	One-way ANOVA and thematically

Note: N: Number; IV: Independent variable; DV: Dependent variable; Gp: Group

Concerning to the number of dependent variables, as can be seen in Table 3, there are nine studies [A2, A7, A10, A13, A15, A16, A21, A22, A25] that measured only one dependent variable. But, the remaining studies measured two or more variables. Most of the nine studies had selected t-tests for their inferential statistics, except [A25] which applied one-way ANOVA. In addition, two of these studies [A2, A21], didn't use inferential statistics to make inferences from the samples about the populations from which they have been drawn; rather they used descriptive statistics. Descriptive statistics are used only to describe, summarize, or explain a given set of data [B15], not to infer.

The rest of sixteen studies, those having two or more dependent variables, had employed different inferential statistics such as t-tests, ANOVA, ANCOVA, MANOVA, Wilcoxon signed-rank test, Mann-Whitney U-Test, and other qualitative data analysis techniques like NVivo, thematically, and content analysis. For example, [A1] used exclusively t-tests for his study with many dependent variables though MANOVA is used when there are multiple dependent variables [B14]. Moreover, [A5] adopted ANCOVA; [A12] used two-way MANCOVA; [A7], and [A9] employed t-test and ANCOVA; [A11] adopted one-way ANOVA, Scheffé Post-hoc test, chi-square tests and two-way ANOVA. Similarly, [A14] used independent sample t-test, ANCOVA and NVivo; [A19] adopted MANOVA and ANOVA, and [A20] used ANCOVA.

Chemistry Topics Used in ICB Chemistry Studies

In Table 4, the topics of general chemistry used by ICB studies are summarized. In the 25 studies, 20 chemistry topics, used by these studies, are identified. These are hydrocarbons; alkanes;

chemical kinetics; thermodynamics; periodic table; physical and chemical changes; cleaning agents; acids, bases and salts; precipitation titration; matter and chemical reactions; acid-base chemistry; inorganic chemistry; separating mixtures; states of matter; chemistry experiments; green chemistry; chemical changes; chemical reactions and energy; and petroleum and polymer. Amongst these, Alkanes [A15, A22], thermodynamics [A4, A7], and states of matter [A8, A23] were the three chemistry topics applied for teaching and learning each by two studies.

Table 13. Chemistry Topics Investigated By Interventional CB Chemistry Studies (N = 25)

Chemistry topic	CB study	No. of study	Total study N(%)
Hydrocarbon	A1	1	
Alkane	A15, A22	2	
Chemical kinetics	A5	1	23(92)
Thermodynamics	A4, A7	2	
Chemical equilibrium	A14	1	
Periodic Table	A9	1	
Physical & chemical changes	A10	1	
Cleaning agent	A12	1	
Acids, Bases & Salts	A13	1	
Precipitation titration	A16	1	
Matter & chemical rxn	A18	1	
Acid-base chemistry	A19	1	
Inorganic chemistry	A20	1	
Separating mixtures	A21	1	
States of matter	A23, A8	2	
Chemistry experiment	A2	1	
Green Chemistry	A24	1	
Chemical changes	A3	1	
Chemical rxn & energy	A6	1	
Petroleum and polymer	A25	1	
Not stated	A11, A17	2	2(8)

Note: N: number; CB: context-based; rxn: reaction

The remaining chemistry topics such as hydrocarbons [A1], chemical kinetics [A5], periodic tables [A9], and so on were covred by single study. But two of the studies [A11, A17] didn't clearly specify the topic of chemistry for intervention. Generally, 92 percent (23 out of 25) ICB chemistry studies clearly reported the topics used for teaching-learning intervention, while 8 percent, 2 out of 25, [A11, A17] didn't obviously state the topic of chemistry to their readers. Thus, this review signifies those chemistry topics used by ICB studies. This implies that there are still several chemistry topics that will be used by future ICB chemistry researchers. But it doesn't mean that the aforementioned 20 chemistry topics will not be used in the future researches. One can use these topics using different instructional strategies and learning variables.

Research Variables Investigated by ICB Chemistry Studies

16 various learning (dependent) variables are illustrated in Table 5. From these variables, some of them (gender score, achievement, motivation, attitude, understanding, chemical literacy and retention) were studied by more than one studies, while most variables were investigated only by one study. Students' academic achievement is the prominent variable which was investigated by more than half percent (52 percent, 13 out of 25) of the studies [A1, A3, A4, A5, A6, A13, A14, A16, A17, A18, A19, A20, A23]. This shows that majority of the studies concentrated on measuring students' academic achievement. Next to achievement, conceptual understanding (36 percent, 9 of 25) and attitude (36 percent, 9 of 25) are the variables investigated by numerous studies.

Table 14. Types of Variables in Relation to Chemistry Topics

Dependent Variable	Chemistry Topic	N of Topic	CB Study	Study N(%)
Gender scores	Hydrocarbons; chemical kinetics; inorganic chemistry	3	A1, A5, A20	3(12)
Achievement	Hydrocarbons; chemical kinetics; acids, bases and salts; states of matter; thermodynamics; precipitation titration; matter and chemical reactions; acid-base chemistry; inorganic chemistry; chemical changes; chemical reactions and energy	11	A1, A3, A4, A5, A6, A13, A14, A16, A17, A18, A19, A20, A23	13(52)
Understanding	Alkane; periodic table; physical and chemical changes; cleaning agent; green chemistry; chemical reactions and energy; states of matter	7	A8, A9; A10, A11; A12, A15, A24, A6	9(36)
Attitude	Periodic table; cleaning agent; matter and chemical reactions; acid-base chemistry; states of matter; chemistry experiment; thermodynamics	7	A9, A12, A17, A18, A19, A23, A2, A4, A8	9(36)
Motivation	Hydrocarbons; periodic table; thermodynamics; states of matter	4	A4, A6, A14, A17, A18	5(20)
Retention	Thermodynamics; matter and chemical reactions; chemical reactions and energy	3	A1, A4, A8, A9, A17, A23	6(24)
Chemical literacy	Thermodynamics; alkane; chemical reactions and energy	3	A6, A7, A22	3(12)
Interest	Thermodynamics	1	A4	1(4)
Critical sc. Literacy	Green chemistry	1	A24	1(4)
Procedural knowledge	Not stated	1	A11	1(4)
Cons. l/envir.	Thermodynamics	1	A14	1(4)
Metacognition	Chemical changes	1	A3	1(4)
Multiple-intelligence	Chemical changes	1	A3	1(4)
Problem solving skills	Petroleum and polymer	1	A25	1(4)
Integrated sc. process skill	Separating mixtures	1	A21	1(4)
Residence	Inorganic chemistry	1	A20	1(4)
Total				25(100)

Note: N: Number; CB: context-based; sc.: science/scientific; ; Cons. l/envir.: constructivist learning environment

Subsequently, retention (24 percent), motivation (20 percent), gender scores (12 percent), and chemical literacy (12 percent) are investigated by more than one studies. But the rest of dependent variables (56.25 percent, 9 out of 16) such as students' interest, critical scientific literacy, procedural knowledge, constructivist learning environment, metacognition, multiple-intelligence, problem solving skills, integrated science process skill, and students' residence (rural/urban) are each studied by only one study. In general, many studies in this review focused on either students' achievement, conceptual understanding, attitude, motivation, or knowledge retention. From this review one can find out that there are still several variables yet not investigated by previous ICB chemistry studies. Moreover, amongst the 16 learning variables, future research can also carry out investigations using different chemistry topics and instructional strategies that were not used by past studies.

Table 5 also presents several dependent variables (students' learning outcomes, measured variables) that were investigated in correspondence to the various topics of chemistry. Except for one variable (i.e., procedural knowledge), the chemistry topics were obviously stated for most of the variables for which they were measured. But for procedural knowledge, the topic of intervention was not explicitly specified by the authors [A11]. Amongst the variables, the academic achievement of students was investigated by 52 percent (13 out of 25) of the studies using 11 chemistry topics (55 percent). These imply that the academic achievement is the most frequently studied learning outcome of students.

The two learning outcomes, conceptual understanding, and attitude of students are frequently investigated variables next to achievement. Each of them was studied with 7 chemistry topics (Table 5) and 8 studies (Table 5). Subsequently, understanding and attitude, retention, motivation, and chemical literacy were studied using 4, 3 and 3 chemistry topics, and 6, 5 and 3 empirical studies (Table 5) respectively. At last, interest, critical scientific literacy, procedural knowledge, constructivist learning environment, metacognition, multiple-intelligence, problem solving skills, integrated science process skill, and residence were the least frequently measured variables in ICB chemistry studies. Each variable was measured through 1 chemistry topic (out of 20).

In this review, it seems that there are variables and chemistry topics that are not still investigated by ICB chemistry studies. For example, student engagement, inquiry skills, decision-making skills, argumentation, and science process skills are some of the variables which are not yet studied. Atomic theory, chemistry of solutions, polarity and shapes of molecules, bonding theory, separation of mixtures, chemical calculations, and many are some of the chemistry topics that need attentions by future CB chemistry researchers. Thus, in general, it becomes clear for context-based chemistry researchers that which learning variables are not yet well studied in relation to chemistry topics, and which topics, in relation to variables, are not investigated by the twenty-five ICB chemistry studies.

Teaching Methods and Instructional Strategies Adopted in ICB Chemistry Studies

Teaching Methods and Interventional Strategies

In Table 6, the different participatory teaching methods under the umbrella of CB approach are presented in relation to the nature of instructional strategies adopted by 25 ICB chemistry studies. A teaching method is an effective scientific way of presentation of a subject matter based on a selected approach [B4]. It is then the practical realization of an approach. It is a wider term covers a strategy of teaching. It can be generally categorized into *participatory* (e.g., hands-on activities, group discussions, questioning and answering, problem-based learning, and so on), and *non-participatory* (e.g., lecturing, and demonstration) teaching method. Thus, since context-based approach follows constructivist's principles, ICB chemistry studies are expected to adopt participatory teaching methods.

Table 6. Types of Instructional Strategies and Teaching Methods

Instructional Strategy	Teaching Method [Study]
Reading & analyzing of articles	Metacognitive prompts [A11]
REACT	Worksheets, animation, molecule model [A15]
	Not stated [A15]
7E cycle	Computer-assisted instruction [A16]
ARCS	Experiments [A17]
PBL	Worksheet [A4]
Scrum methodology	Assignments, exercises [A24]
4Ex2 model	Experiments, worksheet [A2]
5E learning cycle	Spider web metaphor, demonstration [A6]
	Not stated [A23]
Storyline	Images, lab works, worksheet, discussion [A7]
	Not stated [A9, A10]
EEKPST	Not stated [A12]
5E+REACT	Not stated [A13]
Procedures without specific names	Spider web metaphor, simulation [A7]
	Not stated [A21]
	Group discussion, presentation [A25]
Not stated	Experiments [A18]
	Worksheet [A3]
	Problem-solving [A5]
	Not stated [A1, A14, A19, A20, A22]

Note: PPT: PowerPoint

Based on the above table, fourteen studies (56 percent, 14 out of 25) used certain kinds of participatory teaching methods with openly stated CB instructional strategies, otherwise lists of procedures. However, amongst the remaining studies (44 percent, 11 out of 25), some of them specified either the teaching methods [A3, A5, A18], or instructional strategies [A2, A4, A6, A7, A9, A10, A11, A12, A13, A15, A16, A17, A23, A24]; while the rest of the studies [A1, A14, A19, A20, A22] stated neither teaching methods nor instructional strategies under their context-based instructional approach. For instance, [A7] used spider web metaphor and computer simulations using storylines. One study [A15] also adopted REACT strategy under the four teaching methods: worksheets, animation, molecular model, and experiments. But, amongst the fourteen studies two of them [A7, A25] didn't obviously state the name of the instructional strategy rather the authors revealed the procedures of the teaching methods. Thus, this indicates that only 36 percent (9 out of 25) of the total studies (N = 25) were conducted with undoubtedly named teaching methods and instructional strategies.

This review identified 10 context-based instructional strategies adopted (with specific names) by ICB chemistry studies (Table 6). These are REACT, PBL, 4Ex2, 5E, 5E+REACT, 7E, storyline, EEKPST, ARCS, and scrum methodology. The other strategies like reading and analyzing of science articles [A11], procedure without specific names [A7, A21, A25] were not included in the total number of strategies as their specific names were not identified by the authors. 17 studies were undertaken with specified type of CB strategies whereas; 8 studies were conducted without obviously stated strategies. For example, [A9], [A10], and [A8] adopted similar strategy (i.e., storyline) when [A6], and [A23] employed 5E learning cycle in their context-based approach. But [A1, A3, A5, A14, A18, A19, A20, A22] didn't mention the names of the CB strategies or procedures they employed.

On the other hand, different from the two types of studies, mentioned above, there are three studies [A7, A21, A25] that had properly written the detail CB procedures though the appropriate names of the strategies were not noticeably reported. That is, in these reviewed studies, the procedures for the selected teaching methods under the CB approach were described well but the the names of the procedures were not stated to their readers. Thus, generally, 32 percent (8 out of 25) of the studies didn't not state the proper name of the strategy adopted in the context-based approach of instruction.

The Effectiveness of Context-Based Instructional Strategies per Chemistry Topics and Research Variables

Table 7 shows the various topics of chemistry corresponding to the adopted context-based instructional strategy and the number of studies using this strategy. As it can be seen in the table, different chemistry topics, by different studies, were investigated by the same instructional strategy, or the same chemistry topic was studied by using different strategies. For example, *alkane* was studied with the same strategy, REACT, by two different studies [A15, A22] (Table 6), while, a *state of matter* was studied using different strategies (viz., 5E learning cycle and storyline) by two different studies [A8, A23] (Table 6) at different time.

In addition, thermodynamics [A4, A7] was studied using PBL strategy and lists of procedures (unnamed strategy), periodic table [A9], and physical and chemical changes [A10] were investigated using storylines. Cleaning agents [A12] were also addressed by employing EEKPST (need-to-engage, need-to-explore, need-to-share, need-to-know, need- to-transfer and need-to-proceed) strategy. Acids, bases and salts were investigated with 5E+REACT strategy. Moreover, other studies [such as A3, A6, A16, A21, A24], and investigated precipitation titration, separating mixtures, green chemistry, chemical changes, and chemical reaction & energy by adopting 7E cycle, unnamed procedures, scrum methodology, 4Ex2 model, and 5E learning cycle respectively.

However, 7 extra chemistry topics such as hydrocarbon, chemical kinetics, chemistry experiments, chemical equilibrium, matter and chemical reactions, acid-base chemistry, and inorganic chemistry were not studied by using explicitly stated context-based instructional strategies. For instance, hydrocarbon was studied by [A1] with no clearly named strategy or properly listed procedures. Some studies didn't mention either the specific names of the strategies or lists of procedural activites during studying of the aforementioned chemistry topics [A1]. Therefore, this review makes clear, for readers, that which chemistry topic was studied by what instructional strategy and which one was with unclear (not stated) strategy.

Conventional science programs have focused on the idle forms of teaching of theoretical facts and concepts in a fixed, direct, and logical order [B16, B17]. Several secondary school science/chemistry education problems were associated with such kinds of courses that lack of the linking of concepts to the everyday life of students which ultimately leads to a decline of students' achievement, motivation, interest, and attitude towards science subjects. When science educators and researchers attempted to introduce contexts into science and chemistry courses, their focuses were to address these problems by connecting concepts with contexts and engaging students more in their own learning activities. Thus, theme 5 focuses on the effectiveness of context-based instructional strategies with respect to chemistry topics used and research variables measured in the studies.

Table 8 provides 22 ICB chemistry studies from the total of 25 studies as the remaining 3 studies did not clearly specify either the instructional strategies or chemistry topics. According to this table, most studies (81.8 percent, 18 out of 22) reported the effectiveness of context-based approach education using different instructional strategies in several chemistry topics (e.g., precipitation titration, separating mixtures, thermodynamics, states of matter, etc.). These studies have found that context-based chemistry instruction brought significant changes on students' learning outcomes. For example, two studies [A9, A10] were carried out on periodic table, and physical and chemical changes by employing the same strategy (i.e., storyline) on students' understanding, attitude, and retention. Both studies confirmed that a storyline is an effective context-based instructional strategy in both topics of chemistry (periodic table, and physical and chemical changes). Likewise, other 16 studies (out of 18) also approved that context-based approach, using a diverse instructional strategy, is an effective way of instructional approach over the conventional instructional approach.

Table 8. The Effectiveness of CB Instructional Strategy in Relation to Chemistry Topic and Measured Variables in ICB Studies

Strategy	Chemistry topic	Dependent variable	Effectiveness	Number of studies
REACT	Alkane	Understanding	Significant	2
		Achievements	Significant	
		Retention	Significant	1
PBL	Thermodynamics			
		Attitudes	Not significant	
		Motivation	Not significant	
		Interest	Significant	
	Petroleum and polymer	Problem solving skills	Significant	1
Storyline	Periodic table	Understanding	Significant	1
		Attitude	Significant	
		Retention	Significant	
	Physical & chemical changes	Understanding	Significant	1
EEKPST	Cleaning agent	Understanding	Significant	1
		Attitude	Not significant	
5E+REACT	Acids, Bases and Salts	Achievement	Significant	1
7E cycle	Precipitation titration	Achievement	Significant	1
List of procedure	Separating mixtures	Integrated science process skill	Effective	1
	Thermodynamics	Chemical literacy	Significant	1
5E learning cycle	Chemical reactions & energy	Understanding	Significant	
				1
		Achievement	Significant	
		Chem. literacy	Significant	
		Motivation	Not-significant	
		Gender scores	Not-significant	
	Hydrocarbon	Achievement	Significant	1
Not stated		Retention	Significant	
		Gender score	Not-significant	
	chemical kinetics	Achievement	Significant	1
		Gender score	Not-significant	
	Chemistry experiment	Attitude	Positive	1
	Chemical equilibrium	Achievement	Significant	
				1
		Motivation	Significant	
		Con. l/ envir.	Significant	
	Matter & chem. reactions	Achievement	Significant	1
		Motivation	Significant	
		Attitude	Significant	
	Acid-base chemistry	Achievement	Significant	1
		Attitude	Significant	
	Inorganic chemistry	Gender score	Not significant	1
		Residence score	Significant	
		Achievement	Significant	

Note: Cri. sc. lit: critical scientific literacy; multi. -intell.: multiple-intelligence; con. l/ envir.: constructivist learning environment

Moreover, there are four studies [A1, A5, A6, A20] reported on gender difference regarding to the mean scores of students' achievement. As stated by these studies, student scores have been appeared to have non-significant mean difference regardless of their gender in hydrocarbons, chemical kinetics, chemical reaction and energy, and inorganic chemistry achievement tests.

In contrast, four studies reported contradicting results with respect to students' motivation, attitude, and multiple intelligences in certain topics of chemistry. Three of the four studies [A3, A4, A12] argued that context-based approach using 4Ex2, PBL, and EEKPST strategies do not cause significant changes on students' multiple-intelligence, motivation, and attitude towards chemical changes, thermodynamics, and cleaning agents respectively. [A4], and [A6] also reported that teaching of thermodynamics, and chemical reactions and energy with PBL, and 5E learning cycle have no significant effects on students' attitude, and motivation in that order. Thus, studies on the context-based approach provided inconsistency and conflicting reports on certain learning outcomes of students like motivation, attitude, and multiple-intelligence. Hence, there is a need to conduct further studies and to resolve these contradictions.

SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

This systematic review of studies on interventional context-based approach in chemistry education is timely as this approach has gained popularity amongst chemistry and science researchers. It is essential to understand the current practices in the field to shed light on coming implementations. A total of twenty-five articles (64 percent in Europe, 16 percent in Africa, and 16 percent in Asia) were deeply analyzed and framed around six major research questions.

According to this in-depth analysis, it has been known that most ICB chemistry studies (76 percent) preferred to adopt quasi-experimental designs over the true- and pre-experimental design options. No true-experimental studies were identified, except few pre-experimental (20 percent, 5 out of 25) studies. Though most quasi-experimental studies employed quantitative approach, there were few studies (32 percent) selected mixed-method procedures. However, these mixed-method studies didn't clearly state the weight and timing of the quantitative and qualitative approaches. Thus, it can be said that the interventional context-based chemistry studies need to have explicitly stated research methods and designs to make more understandable by the readers.

When chemistry topics are considered, 20 topics are used by the interventional context-based studies. Although most of the studies (92 percent) reported the topics of study used, two of them [A11, A17] didn't noticeably state the kind of topics to their readers. This implies that there is a need to make clear the type of topics applied by studies, and there is also a need to carry out investigations by using other topics of chemistry which are still not yet addressed by interventional context-based chemistry studies. Not only this, but researchers can also conduct their studies using those identified chemistry topics with other dependent variables.

Regarding to research variables, the review identified 16 dependent variables measured by the 25 interventional context-based chemistry studies. This suggests that there are still other variables to be investigated by future studies. There is also a possibility to conduct studies amongst the 16 variables by varying chemistry topics in different matches. In relation to the data analysis techniques, most studies adopted t-tests and ANOVA for one and more than one dependent variables, except few studies those employ MANOVA [A6, A12, A19, A23]. Running MANOVA can help to reduce the occurrence of Type I error rather than conducting individual t-tests [B15].

Choosing appropriate teaching methods and instructional strategies under a particular approach is very crucial for a successful implementation of the approach. In context-based approach, it has been agreed that the adopted teaching methods should be participatory, and the instructional strategies should be context-based with descriptive procedures. Most ICB studies adopted proper teaching methods and instructional strategies. In this review, 11 context-based strategies were identified in the 25 studies. However, in some cases, the adopted teaching methods and instructional strategies were not explicitly stated by 44 and 32 percent of the studies respectively. Therefore, it is very helpful for researchers to identify what kinds of teaching methods are adopted with which instructional strategies and which are not.

The effectiveness of the context-based approach on students' learning is also an important issue that chemistry educators and researchers seek to know. It has been stated that the context-based approach is usually accompanied with specific teaching methods and instructional strategies adopted through it. In this regard, it seems that the effectiveness of the context-based approach may depend on the types of teaching methods and instructional strategies selected and used by researchers. Even though, in this review, more than 80 percent [e.g., A5, A6, A20] of the studies have claimed the effectiveness of context-based approach over the conventional instructional approach, there are some studies reported contradictory results.

For example, a context-based approach didn't bring a significant change in medical laboratory students' motivation and attitude towards thermodynamic chemistry using a specific instructional strategy (PBL) and teaching method (worksheet) [A4]. Similarly, [A3] argued that pre-service chemistry students did not show a statistically significance difference in their multiple-intelligence during learning of chemical changes using a context-based approach by adopting 4Ex2 model as instructional strategy, and experiments and worksheets as teaching methods. Thus, these indicate that there is a need of conducting research on such inconsistent findings by varying teaching methods, instructional strategies, chemistry topics, and contexts.

In sum, this systematic review is unique and has great importance in identifying research gaps and inconsistencies in a body of knowledge. According to the outcomes of this review, worldwide countries where interventional context-based approach studies are concentrated, chemistry topics used by context-based approach studies, dependent variables frequently measured, the appropriate instructional strategies used through context-based approach, and the teaching methods used under context-based approach are identified. In addition, inconsistency reports regarding to the effectiveness of the context-based approach on students' learning outcomes are also assessed in this review study. Generally, the findings from this systematic review provide a roadmap for future studies in context-based approach chemistry education.

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WATER - A WONDER CHEMICAL IN THE WORLD

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ABSTRACT

Water is one of the most precious resources for domestic uses, agriculture, and industrial processes. It is an essential atmospheric component that maintains a reasonably uniform and moderate temperature on the planet's surface. There is a growing realization that if humankind is to thrive in the future, we must make improvements in existing systems and practices. A quantum leap in the right direction is required to move forward on the water management issues, connecting what science requires and what the people of the world demand. A watershed moment can be reached with the active participation of society and markets. This paper highlights the physical characteristics, chemical properties, the place of water in nature, and water for humanity to help the real-world perspective of water and how water affects our lives. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Water has always been an integral part of everyday life and the world around us. It is essential to almost every form of life, and all body fluids are dilute water solutions. It is of crucial importance for sustaining the specific biochemical reactions that keep us alive and hence the most significant solvent in the world for human survival. Molecular dynamics and structural fluctuations of many molecules in an aqueous medium have direct consequences on their fundamental functional roles. One of the most significant aspects of water is that it acts as an influencing factor in weather and climate. The discernible positive aspect is that it helps moderate the earth's temperature. In the hydrologic cycle, water is used and returned to the environment by evaporation and precipitation.

The industrial growth of a country strongly depends on the proper use of water resources. The statement "The next big ***wars will be fought*** over ***water"*** underlines the importance of water in the future. Life as we know it would not exist without the unique and unusual properties of water. The demand for water is escalating with increasing world population, increase in agricultural, industrial, and mining activities, deforestation, and changes in lifestyles, contributing to social pressure among users. The population of the planet is expected to exceed 9 billion by 2050, and severe depletion of crucial resources, including water, is predicted.

Domestic water uses include drinking, bathing, laundering, cooking, housecleaning, and watering the garden**.** ***Industrial*** uses include the generation of steam, building construction, manufacture of hydrogen, oxygen, and water gas, agricultural irrigation, making steel, hydroelectricity generation, as a food additive, flame retardant material, and as an industrial solvent. Water is essential in the industry for cooling products and equipment, boiler feed, process requirements, and sanitary purposes. It can act as a solvent, transport medium, participant, and catalyst. It is also useful in navigation, recreation, mining, and ecosystem support. It is used as a powerful polar protic solvent in organic synthesis and as a moderately strong monodentate ligand in inorganic complexes in the laboratory. It is used in commercial establishments like restaurants and educational institutions such as schools and colleges.

Water has an exceptional ability to dissolve a wide variety of substances, which is considered the universal solvent. This solvent property is vital in the transfer of substances in biological systems and the hydrological cycle. Water is a common ingredient in many food products; and is used as an agent for mixing or washing operations. Significant applications of ice include food processing, preservation and distribution, chemical industries, and special applications such as cold treatment of metals, medical items, and construction work. Ice is used to maintain the quality of fish, vegetables, and fruits during processing and transportation to distant places. Fisheries use water as a medium for growing fish, and transportation in the tropics is an essential use of water. Ships, steamers, and boats sailing on the surface of the sea save our time, money, and energy. Hydroelectric power stations extract energy from water. Steam is useful in cooking, energy production, and transport systems. It can be found in food processing factories, refineries, and chemical plants. Water is used as a cooling and heating medium over a wide range of temperatures, as a cleaning material, as a fire-fighting agent, and in aquaculture. Pure clay water bottles or containers with modern designs provide a facility to keep water cold, especially during the summer.

Moreover, water has a religious significance as a fundamental life element. Hydrotherapy that involves the use of water for treatment or to maintain health is a part of alternative medicine. It is essential in flushing toxic byproducts from our bodies. Thus, water is a basic necessity for life and health, and the economy in general. It is the life force that entertains us and makes our life colorful.

People contribute to water stress through excessive exploitation of surface and groundwater, pollution of water resources, and inefficient use of freshwater. Both natural and human-induced flooding can cause massive destruction of properties with social, economic, political consequences and broader consequences. Adequate water supply for all can be limited by drought, overuse, and pollution by oil spills, industrial effluents, and other waste materials. The products of human activities, when entering the environment, disturb aquatic ecosystems, and water quality is affected by pollution.

Water scarcity affects plants, animals, and the entire ecosystem as it plays a critical role in the forest environment. The composition and diversity of species change drastically in forests that suffer water stress, which can lead to disastrous consequences. The world's water problems stem from a lack of sustainable water resource management. Sustainable water use involves the current and future rates of use and associated social policies for implementation to manage precious water resources. The water footprint of products, individual consumers, companies, and nations vary widely, and growing pressure on the available water supply and sanitation has a profound impact on our social, economic, and environmental health.

Electricity generation in hydroelectric power plants is considered to be a process having a low environmental impact. Water used for this purpose is not consumed, and there is no generation of harmful waste or emission of toxic gases. Further, this technology avoids the negative impacts of burning tons of coal in thermal power plants while preserving fossil fuel for future generations. Many of our recreational activities are based on water. Natural waterfalls in different parts of the globe attract tourists all over the world, and artificial musical water fountains installed in gardens in different parts of the world enhance happiness quotient. A fresh and exciting nature walk along the streams in the forest, enjoying the gentle breeze has caught the attention of youngsters and senior citizens alike. The panoramic view of waterfalls in the lap of nature, a safe pool of water that adorn the local landscape, a beautiful view of the coastline, or breezy beaches provide a refreshing break from the hectic life. Water can be considered as the world's most celebrated architect, as reflected in the glacial streams, gushing waterfalls, hills, valleys, shrubs, and landscape supporting plant and animal life. Water/ice is used for recreational purposes, such as swimming, rafting, surfing, and ice-skating. Some water sports and activities such as diving, water polo, water aerobics, surfing, and boat racing are becoming popular across the world.

World water day (WWD) is observed on March 22 every year, as recommended by the United Nations, to focus on international water issues. World environmental day (WED) is celebrated each year on June 5 to raise greater global public awareness and to promote actions to protect toxic-free nature for all. The primary usefulness of water in everyday life and its influence on modern society by creating several global job opportunities in water-related activities attract youngsters to have additional career options. Some subjects deal with the study of water-related topics. Hydrology deals with the occurrence, distribution, movement, monitoring, modeling, and properties of the water of the earth and related environmental interactions [1-5].

Limnology is a branch of ecology that deals with the study of inland waters, and oceanography is a branch of earth science that studies the ocean in great detail. The reader interested in understanding the subject matter by further reading can obtain specific information about water issues, quality, supply, and management in several dedicated websites and textbooks [6-11]. The recent developments in waterproofing technology for devices provide solutions to manufacturers regarding the actual use of electronics. The bottled water industry is rapidly growing, with a boost in sales across the globe. There are more than seventy journals publishing research studies on different aspects of water science and technology [12-13]. The top global water research institutes are working in different areas of specialization, such as membranes, desalination, drinking water and wastewater, nutrient recovery and infrastructure, and water reuse [14-15]. There is a growing body of research on different aspects of water, and it has a significant effect on how the sustainable use of water can change overall development.

Water is an essential substance in the literary ecosystem, and it is unique from multiple perspectives. It has been a source of inspiration for many centuries across the world, transforming life into literature. The people of early civilizations, such as the Indus Valley Civilization, Mesopotamian Civilization, and Egyptian Civilizations, settled near rivers as they needed water for drinking and their crops. In the historical context, water conflicts were frequent from ancient to contemporary times reflecting the immeasurable value of water. There are many idioms in the English language referring to water like a fish out of water, in deep water, test the waters, and keep one's head above water. They reflect the critical role of 'water' in history [8,16].

The images of water representing dreams, desires, love, and fears play a prominent role in many novels and other literary works. There are several quotes related to water such as "water is the driving force in nature," "life in us is like water in a river," "you can't cross the sea merely by standing and staring at the water," "pure water is the world's first, and foremost medicine," "in one drop of water are found all the secrets of the oceans." The proverbs "water is the only drink for a wise" and "water seeks its level" illustrate a practical precept. Water is of central importance in all world religions and is considered an ultimate natural fluid with multiple benefits. Water is considered one of the five fundamental elements of life as a symbol of life and cleansing in ancient philosophy and as one of the basic alchemical symbols. It has been an enormous source of inspiration for poets in different continents and countries as it touches different aspects of life and is essential for human existence on earth.

Water is a powerful metaphor in the expression of poets as it is a force of nature. Many thought-provoking and visually stimulating artworks depict different aspects related to water, conveying meaningful messages. One can enjoy some spectacular digital images on different websites on various themes related to water and wastewater processes [17]. There are several movies involving water in their title or those set in or around water [18-19]. Exposure to the literature would certainly help people develop a sharing and caring mindset regarding water usage and develop nature-friendly behavior and use of eco-friendly technologies. Water is characterized by distinct physical and chemical properties, theoretical and mathematical models, multiple applications in various fields of activity, and unique structure and bonding features.

PHYSICAL CHARACTERISTICS

Water is a chemical with the molecular formula H_2O, and it consists of one oxygen atom bonded by two hydrogen atoms. When hydrogen burns in the air, it combines with oxygen to form water. Its enthalpy of formation is -285.8 kJ/mol, and energy is required to break the stable bonds. It has a bent or V-shaped structure with an H-O-H bond angle of 104.5^o and an O-H bond length of 0.096 nm. There are two pairs of non-bonding electrons (lone pairs) on the oxygen atom and two bonding pairs in the water molecule's electronic structure. It belongs to the C_{2v} point group with two mirror planes and only one rotational axis C_2. According to the valence shell electron pair theory, the two lone pairs strongly repel each other, resulting in the decreased bond angle from that of a regular tetrahedron, 109.5°. The bonding in water can be considered as an sp^3 hybridization of orbitals on the oxygen atoms. Two hybrid orbitals overlap with the 1s orbital of the hydrogen atom to form two covalent bonds, while the other two contain lone pairs of electrons.

It is the most abundant compound in the Earth's biosphere, with a molar mass of 18 g/mol. There are three normal modes of vibrations, symmetric stretching and bending, and symmetric stretching. It is in a liquid form at room temperature without odor, taste, or color, and it can readily transform from liquid to solid and gaseous states. Its chemical name is dihydrogen monoxide. It is a polar molecule with a significant electric dipole moment (μ) of 1.84 D and a dielectric constant of 78.39. The oxygen atom has a partial negative charge, and the hydrogen atoms have a partial positive charge. The bond dipoles, though equal in magnitude, do not cancel each other, because of a bent structure and because the water molecules have an overall dipole moment.

It is an excellent solvent due to its strong solvation power, the solute-solvent (ion-dipole) attractions and because of the highest dielectric constant of all common liquids, which decreases the interionic attractions. The energy of separation between two dipoles or two ions is inversely proportional to the dielectric constant of the solvent. It can dissolve a wide range of ionic and polar covalent molecules. The table salt readily dissolves in water because of strong ion-dipole forces between the ions (cations and anions) and the polar water molecules that overcome the lattice energy of solid sodium chloride. It can form hydrogen bonds with other polar species that play a significant role in forming the solution. Compounds such as ethanol, acetone, tetrahydrofuran, and sugar dissolve in water and are completely miscible because of H-bonded interaction with the solvent. When a covalent molecule dissolves in water, the solution consists of discrete molecules dispersed throughout the medium. A few molecules such as hydrogen chloride gas, when it dissolves in a water medium contain H^+ and Cl^- ions.

Water dissolves a wide range of ionic and polar-covalent substances and is the most readily available liquid on Earth. It is interesting to note that water-soluble vitamins like vitamin C are polar, while fat-soluble vitamins like vitamin A are non-polar. Commercial products like sodium chloride, bromine, and magnesium are obtained from seawater. Water in a chemical compound could exist as coordinated water, interstitial water, hydrogen-bonded water, clathrate water, adsorbed water, occluded water, absorbed water, lattice water, and zeolitic water. They differ in the degree of association between water molecules and the other components of the crystal, and several compounds may have more than one type of bonding.

Water has a melting point of 0 ^oC and a standard boiling point of 100 ^oC at atmospheric pressure. An exciting feature in the phase diagram of water is that the melting point of water decreases as the external pressure increases. The triple point of water is at 0.01 ^oC and 0.006 atm, at which all three phases (ice, water, and vapor) are in equilibrium. The abnormally high boiling point is due to the more considerable energy required to break the hydrogen bonds that hold the water molecules together. The boiling point is essential for many processes that involve thermal energy input, including cooking. The high pressure inside pressure cookers causes water to boil at a higher temperature (~120 ^{o}C), and the time required to cook food is reduced to half the usual time. It takes longer to cook food at higher altitudes, as the water boils at a lower temperature (~ 71^{o}C on top of the Himalayas).

The density of water at 20 ^{o}C is 0.998 g/mL, and at 25 ^{o}C, it is 1.00 g/mL. It has a maximum density at 4 ^{o}C and expands upon freezing because of open framework formation, and these properties cause seasonal lake stratification. From 0 ^{o}C to 4 ^{o}C, the trapping of water molecules in the cavities of the three-dimensional ice structure continues to make water progressively denser. Beyond 4 ^{o}C, the density of water decreases with increasing temperature because of the higher contribution of the thermal expansion process. It has the second-highest specific heat capacity of 4.186 Joule/gram°C. This helps in moderating the temperature by preventing extremes in the geographical regions and stabilizing the temperatures of organisms by absorbing the heat formed in the cells and transporting it to the skin where it can be lost. Thus, water keeps the temperatures of the oceans constant and maintains our normal body temperature.

Similarly, the efficiency of water heating systems in the house depends on this high specific heat of the water. Water can absorb much heat to enhance the average kinetic energy by breaking many intermolecular hydrogen bonds, with only a slight increase in temperature. It can give off a substantial amount of heat while its temperature decreases only slightly. Large water bodies absorb heat in the summer season while they release heat in the winter season, to effectively moderate the local ecosystem’s climate. Energy used in the evaporation of water over land and sea each year is estimated to be 1.25 x 10^{21} KJ and thereby tends to decrease the temperature of the atmosphere. When water vapor condenses to raindrops over the land each year, 0.31 x 10^{21} KJ energy is released, leading to an increase in the temperature of the atmosphere [20-22].

It has a large heat capacity of 75.3 J/mol K, caused by hydrogen bonding between water molecules, and this results in oceans cooling more slowly than the land. It has the highest thermal conductivity of all molecular liquids, i.e., 0.6 J/s m ^{o}C, and this helps in the transfer of thermal energy within living organisms. It has a very large enthalpy of vaporization (2250 J/g), which affects our ability to regulate our body temperature by evaporation of sweat. It is essential for heat transfer in the atmosphere and oceans. Condensation of water vapor in the atmosphere releases a large amount of heat, triggering storms. The higher heat of evaporation determines the transfer of heat and water molecules between the atmosphere and water bodies.

The critical temperature of the water is 374 ^{o}C, and the critical pressure at this temperature to bring about liquefaction is 217.7 atm. Supercritical water (SCW) is formed at a temperature and pressure above its critical point. At the critical point, the hydrogen bonds holding water molecules break entirely, and this phase can dissolve substances that were previously insoluble in ordinary water in the liquid phase. Supercritical water can behave both as a polar and a non-polar solvent, making it a powerful medium to dissolve a variety of substances and carry out chemical reactions. The practical value of this beautiful property lies in its application in the eco-friendly destruction of industrial wastes. Water is transparent to visible and longer-wavelength ultraviolet light, and this enables the light required for photosynthesis to reach considerable depths in water bodies and control atmospheric temperature. The high latent heat of fusion of water than any standard liquid helps in stabilizing temperature at the freezing point of water. The surface tension of water is 72 dynes/cm at 25 ^{o}C, and this high surface tension is essential in regulating drop formation in clouds and rain.

The property of wetting is due to its ability to adhere firmly to different materials. The freezing point of pure water at atmospheric pressure is 0 ^{o}C, and this value has been fixed at zero on the temperature scale as a convenient standard temperature point. Water has a relatively low viscosity of 0.890 centipoises at 25 ^{o}C and can make a significant impact on the rate at which blood is pumped around our bodies. The ionic product of water (Kw) = $[H_3O^+][OH^-]$ is 1.00×10^{-14} mol^2 dm^{-6} at 25 ^{o}C, and water is an inferior conductor of electricity. The ionic product of water has to be constant, and human plasma has to be electrically neutral. This mechanism protects plasma pH from severe deviations. The refractive index of water is 1.333 at 25 ^{o}C, and it has the least bending effect of light, among other liquids. Its dependence on temperature and wavelength has several applications in biomedical optics and optics of tissues, as it is the most crucial component of intercellular fluid and blood plasma.

The human baby at birth contains nearly 80 % water, while the healthy adult human body contains about 70 % water by weight. It carries nutrients to the cells and takes away waste products as a major component of blood. The three principal categories of water in the human body include intracellular fluid (ICF ~ 55 %), extracellular fluid (ECF ~ 37.5 %), and plasma (`7.5 %). Water deficiency will result in dehydration, and excess body water can cause water intoxication. Its distribution and availability vary widely over the surface of the earth, and over 70 % of the Earth's surface is covered by water. The total amount of freshwater on Earth is 2.5 % of the total water present, making it one of the most precious resources. The world's water consumption data provided by the United Nations in different categories involves agricultural 70 %, domestic 10 %, and industrial 20 %. The purification of water is necessary to get rid of contaminants that can affect our health, and it is now a significant industry with many plants operating at a water processing capacity of the megaton-per-day scale. The transformation of seawater to produce potable water through a large-scale desalination process is of enormous importance to meet the needs of the increasing world population.

Apart from making the easy availability of water, it is essential to introduce other changes to meet the growing consumer demands of a changing world, including an active policy approach to enhance and strengthen the green infrastructure. The most commonly used small-scale methods to obtain freshwater include ultrafiltration, distillation, ion-exchange techniques, ultraviolet sterilization, and multistage reverse osmosis processes. The selection of a particular treatment method or a combination of techniques depends on the source of the water, the end-use envisaged, and the quantity required. The infrastructure required for optimal utilization of available water must be constructed to meet future sustainable development challenges on the path. Globally, the response of people to practical green solutions will be a crucial indicator of the future.

There are three hydrogen isotopes (^{1}H, ^{2}D, ^{3}T) and three oxygen isotopes (^{16}O, ^{17}O, ^{18}O), and in principle, 18 different types of water are possible with slightly different properties. These are also known as isotopologues. The three common types of water are natural water (H_2O), heavy water (D_2O), and tritium water (T_2O). Heavy water (D_2O) is used as a coolant and a neutron moderator in nuclear research reactors. It reacts more slowly than ordinary hydrogen because of its extra mass. THO, HDO, and D_2O occur naturally in ordinary water in deficient concentrations.

he existence of tunneling behavior of water is unprecedented, and in this new state, the water molecules are delocalized around a ring, assuming an unusual double-top-like shape [23]. This discovery provides an opportunity for researchers to take a different approach to water-related phenomena. Hard water contains low percentages of $Fe^{2+,}$ Ca^{2+}, Mg^{2+} or Mn^{2+} ions in dissolved form, usually present as bicarbonates, chlorides, sulfates, and nitrates, due to contact of rainwater with soils and rocky substances on its way to the oceans. It does not give lather with soap, a qualitative indicator of the hardness of the water. The total hardness of water can be quantitatively estimated by complexometric titration using EDTA. Temporary hardness caused by carbonates and bicarbonates can be removed by boiling, while permanent hardness caused by sulfates and chlorides can be removed by treating zeolites.

Drinking water purification is the single most effective way required to prevent waterborne diseases such as cholera, typhoid, and dysentery. Water disinfection is an essential step in water treatment to make it fit for human consumption, in addition to other physical, chemical, or biological processes. Conventional surface water treatment includes coagulation, flocculation, sedimentation, filtration, and disinfection steps to obtain clean water. The buildup of boiler scales in hot water heating systems clogs the pipes and reduces the efficiency of heat transfer as well as the flow of water through the pipes. Hard water is responsible for the boiler scale, which may result in a boiler explosion, in extreme cases.

Wastewater corrosion can result in a loss of water carrying capacity of pipes, structural failures, and degradation in the quality of water transported. Water conditioning and wastewater treatment include removing particulate matter, organics and inorganics, hardness and other scale-forming substances, corrosive contaminants, pathogenic bacteria, viruses, and protozoans. Hard water can be softened on a large-scale by the lime-soda process and small-scale by ion-exchange methods. The lime-soda process involves treating water with lime, CaO, and soda ash, Na_2CO_3, precipitating Ca^{2+}, and Mg^{2+} into $CaCO_3$ and $Mg(OH)_2$. The ion exchange procedure involves passing the hard water through a bed of ion-exchange resin. The Na^+ ions available on the resin are exchanged with Ca^{2+} ions, and the resin is regenerated by flushing it with a concentrated solution of NaCl. Zeolite water softening process, using Zeolite bed, operates on alternate cycles of softening run and regeneration run, where calcium and magnesium ions are removed from the water, and the exhausted Zeolite bed is regenerated for reuse.

CHEMICAL PROPERTIES

It is of interest to note that water participates in making and breaking bonds in different types of reactions including, simple dissolution, acid-base reactions, redox reactions, hydration and dehydration reactions, ionic dissociation, solvolysis, and ligand chemistry [24-28]. Water is amphoteric and it has the unique ability to act as either an acid or a base and can participate in acid-base reactions [Proton donor: $NH_3(aq) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$; Proton acceptor: $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$]. The autoionization reaction of water can be written as $H_2O(l) \rightarrow H^+(aq) + OH^-(aq)$. At room temperature, this ionization process is extremely rapid in both directions, and at any given instant, a tiny fraction of molecules undergo ionization. Moreover, the H^+ ion in water interacts strongly with the non-bonding electron pairs of liquid water molecules to form hydronium ions [$H^+(aq) + H_2O(l) \rightarrow H_3O^+(aq)$]. The electrolysis of water by electrical energy input decomposes it into hydrogen and oxygen as per the overall electrochemical reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$. In this electrolytic production, hydrogen is produced at the cathode and oxygen at the anode, and this is the basis of the fuel cells used in hydrogen-powered vehicles [Anodic oxidation: $2H_2O(l) \rightarrow O_2(g) + 4H+(aq) + 4e^-$ Cathodic reduction: $4H^+(aq) + 4\,e^- \rightarrow 2H_2(g)$].

Limestone caves are formed by the dissolving action of underground water containing CO_2 that is slightly acidic on $CaCO_3$ in the limestone [$CaCO_3(s) + H_2O(l) + CO_2(aq) \rightarrow Ca(HCO_3)_2(aq)$]. Calcium oxide (lime) reacts with water to produce calcium hydroxide (slaked lime) [$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$]. Chlorine reacts with water to form aqueous solutions of hypochlorous acid, an active oxidizing agent and hydrochloric acid [$H_2O(l) + Cl_2(g) \rightarrow HOCl(aq) + HCl(aq)$]. The usefulness of chlorine water lies in its antibacterial action due to hypochlorous acid and its use as a bleach. Most metal oxides that dissolve in water react to form metal hydroxides, i.e., Metal oxide + water → Metal hydroxide [$BaO(s) + H_2O(l) \rightarrow Ba(OH)_2(aq)$]. The basicity of metal oxides is due to the reaction of the oxide ion with water [$O^{2-}(aq) + H_2O(l) \rightarrow 2OH^-(aq)$]. The alkali metals react vigorously with water, forming hydrogen gas and alkali metal hydroxides [$2M(s) + 2H_2O(l) \rightarrow 2MOH(aq) + H_2(g)$]. Among the alkaline earth metals, Magnesium reacts with steam to form magnesium oxide and hydrogen [$Mg(s) + H_2O(l) \rightarrow MgO(s) + H_2(g)$]. Calcium and other elements down the group react with water at room temperature to form respective hydroxides [$Ca(s) + 2H_2O \rightarrow Ca(OH)_2(aq) + H_2(g)$]. The transition metal, iron reacts with steam to give iron oxide and hydrogen gas [$3Fe(s) + 4H_2O(l) \rightarrow Fe_3O_4(s) + 4H_2(g)$].

Steam reacts with red-hot coke to produce the product water gas [$H_2O(g) + C(s) \rightarrow H_2(g) + CO(g)$]. Non-metal oxides react with water to form acids containing oxygen [$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$]. Another non-metal compound, ammonia dissolves in water to form ammonium and hydroxide ions [$NH_3(aq) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$]. This ammonia solution acts as a weak base. Non-metal chlorides react with water forming acidic solutions [$SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq)$]. The electrochemical corrosion reaction involves the reaction of water and oxygen to give hydroxide ions at the cathode: [$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$]. Water reacts with certain metal salts to form hydrates [$CuSO_4 + 5H_2O \rightarrow CuSO_4{\cdot}5H_2O$]. Plaster of Paris forms a paste on mixing with water and then hardens into a solid mass, used in making casts and sculptures. [$(CaSO_4)_2 \cdot H_2O$ + $3H_2O$ → $2CaSO_4 \cdot 2H_2O$]. Some hydrates lose their water of crystallization spontaneously at room temperature on exposure to air in a process called 'efflorescence' [$Na_2CO_3 \cdot 10H_2O(s)$ → $10H_2O(g)$ + $Na_2CO_3(s)$]. Deliquescence is the process in which a substance absorbs water from the air to form a solution [$NaOH(s)$ → $Na^+(aq)$ + $OH^-(aq)$]. Deliquescent substances are used as drying agents; for instance, anhydrous calcium chloride is used in desiccators for storing materials that pick-up moisture.

Water decomposes into hydrogen and oxygen in the ratio of 2:1 by volume when electrolyzed by direct current [$2H_2O(l)$ → $2H_2(g)$ + $O_2(g)$]. Some practical applications of this chemistry include the use of ***cold or hot packs*** as an immediate ***first aid*** product as they will help to reduce inflammation, and they function by dissolving salt into the water. Commercial instant cold packs often use either ammonium nitrate or urea as their salt component, while hot packs use either magnesium sulfate or calcium chloride. When these chemical ingredients dissolve in water, heat is either released in an exothermic reaction or absorbed in an endothermic reaction [An endothermic process: $NH_4Cl(s)$ → $NH_4^+(aq)$ + $Cl^-(aq)$; An exothermic process: $MgSO_4(s)$ → $Mg^{2+}(aq)$ + $SO_4^{2-}(aq)$]. The double replacement reaction of water with calcium dicarbide produces acetylene gas and calcium hydroxide solid, i.e. $CaC_2(s)$ + $2H_2O(l)$ → $C_2H_2(g)$ + $Ca(OH)_2(s)$. Iron(III) salts react with water to form hexaaqua iron(III) complex, i.e., $FeCl_3(s)$ + $6H_2O(l)$ → $[Fe(H_2O)_6]^{3+}$ + $3Cl^-(aq)$]. Hydrolytic cleavage takes place when phosphorous oxide, P_4O_{10} reacts with water [$P_4O_{10}(s)$ + xH_2O

→ $4H_3PO_4(aq)$]. Similarly, aluminum chloride undergoes hydrolysis when it reacts with water [$AlCl_3(s) + 6H_2O(l) \rightarrow [Al(H_2O)_6]^{3+}(aq) + 3Cl^-(aq)$]. The solution of aluminum chloride is very acidic. This property is because of a small but highly charged Al^{3+} ion that draws electrons in the O-H bonds of water towards itself to enable them to become proton donors. The following equilibrium is established. [$[Al(H_2O)_6]^{3+}(aq) + H_2O \rightarrow [Al(H_2O)_5(OH)]^{2+} + H_3O^+$].

Water reacts with some organic compounds to form different products. Water reacts with butyl chloride, producing butyl alcohol and hydrochloric acid [$C_4H_9Cl(aq) + H_2O \rightarrow C_4H_9OH(aq) + HCl(aq)$]. The direct hydration of alkenes produces alcohol, and ethanol is manufactured by reacting ethene with steam [$CH_2{=}CH_2(g) + H_2O(g) \rightarrow CH_3CH_2OH(g)$]. The reaction involves breaking the π bond in the alkene and an O-H bond in water, as well as the formation of a C-H bond and a C-OH bond. Carbon dioxide dissolves in water to an extent, forming carbonic acid that lowers the pH of the water, and this is responsible for the popping sensation of carbonated soft drinks [$H_2O(l) + CO_2(g) \rightarrow H_2CO_3(aq)$]. Industrial manufacture of sulfuric acid by the contact process involves the reaction of water with oleum to form concentrated sulfuric acid in the final step [$H_2S_2O_7(l) + H_2O(l) \rightarrow 2H_2SO_4(l)$]. The production of sulfuric acid is an indicator of the industrial strength of a nation. Concentrated sulfuric acid removes water of crystallization from copper(II) sulfate pentahydrate [$CuSO_4.5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(l)$]. Common dehydrating agents used in organic syntheses include concentrated sulfuric acid, concentrated phosphoric acid, and hot aluminum oxide. Acid anhydrides react with water to give the carboxylic acid [$(CH_3CO)_2O(l) + H_2O(l) \rightarrow$

$2CH_3COOH(aq)$]. Acyl halides undergo nucleophilic substitution readily with nucleophiles such as water [$CH_3COOCl(l) + H_2O(l) \rightarrow CH_3COOH(aq) + HCl(g)$].

The carbon dioxide in the atmosphere reacts with water in the raindrops to produce H^+ ions [$H_2O(l) + CO_2(g) \rightarrow H^+(aq) + HCO_3^-(aq)$]. Nitrogen dioxide reacts with water to give a mixture of nitrous acid and nitric acid [$H_2O(l) + NO_2(g) \rightarrow HNO_2(aq) + HNO_3(aq)$]. Water reacts with sulfur trioxide, formed by oxidation of sulfur dioxide, to form sulfuric acid [$H_2O(l) + SO_3(g) \rightarrow H_2SO_4(aq)$]. This acid rain produced by polluted air present in the atmosphere damages marble structures, architectural monuments, and statues all over the world. It can leach minerals as the rain percolates through soil and rocks [29-31]. In agriculture-intensive areas of the world, water contains significant quantities of sulfate and nitrate ions, partly due to the widespread use of nitrogenous fertilizers containing these ions. Water vapor is the most important greenhouse gas in Earth's atmosphere that trap heat, which makes the Earth warmer and vibrates in response to the absorption of infrared radiation (3756, 3657, & 1595 cm^{-1}). Water plays an important role in the rusting of iron, and it is an electrochemical process that requires the presence of oxygen, water, and an electrolyte. Water-line corrosion is a special type of corrosion when water is stagnant in a steel tank for a long time. This corrosion results from differential aeration leading to the formation of oxygen concentration cells and corrosion take place just below the water level.

Hydration, hydrolysis, dehydration, redox, and acid-base reactions occur during the breakdown and the reassimilation process to transform foodstuffs into specific metabolites in living systems. All the body's critical functions, including the reactions of metabolism and the transfer of chemical energy, depend on the presence of a proper amount of water. Proper intake of water per day varies depending on the climate, dietary habits, body structure, and physical activities, and we need to drink about three liters of water every day. Water containing traces of dissolved salts of Ca, Na, Mg, and Fe are essential for good health, and water is the medium for the transport of nutrients. The surface-active properties of soaps and detergents are attributed to their structure, having both hydrophilic and hydrophobic parts. The water-soluble polymers such as cellulose, polyoxyethylene, polyvinyl alcohol, polyvinyl pyrrolidone, polymethacrylic acid, polyphosphoric acid, and polysilicic acid have a significant commercial impact, and they are used as food sources, blood plasma substitutes, cosmetics, and as diluents in certain medicines.

The role of water in human life, its contributions to humankind, and the research opportunities available for discoveries have a profound positive impact on consumers of different categories, and water shortage can have severe economic consequences. The world of water chemistry would require more rigorous experimental investigations and precise calculations based on different models to discover new phenomena that occur in water mediums and to have a better understanding of the impact of climate change or global warming on natural water resources. Acidification of water supplies due to the dissolution of toxic metals such as Cd, Al, Pb, and Hg from the soil, sediments, metal pipes, and soldering materials is a potential public health hazard. The functions crucial to producing pure water include hazardous waste reduction, breakdown of pollutants, developing adequate sewage water treatment systems, the cycling of nutrients, recharging catchment systems, and re-establishing natural ecosystem services. Further, understanding water variability, conducting laboratory and field studies of water, establishing aqueous reaction mechanisms, performing real-time estimates of ice pack thickness in the Arctic, and implementing long-term water supply measures to help prevent drought-induced migration of people or drought-caused failure of agriculture.

THE PLACE OF WATER IN NATURE

Water is present as solid ice in polar icecaps and glaciers in the Arctic and Antarctic zones and as liquid water in other places on the earth, in rivers and lakes [32-34]. Water vapor is always present in the atmosphere to different extents. About 71 % of the Earth's surface is covered with water, and the oceans contain about 96.5 % of the total water content of the Earth. The conversion of carbon dioxide and water into carbohydrates takes place by the process of photosynthesis.

$$6CO_2(g) + 6\,H_2O(l) \xrightarrow{h\nu} C_6H_{12}O_6(aq) + 6O_2(g)$$

It is the most important reaction in the world, and the energy released in the reverse reaction called respiration is essential to keep us alive. We depend on plant photosynthesis to supply the bulk of our energy needs, as we do not have the capacity for using solar energy directly. Glucose dissolves as a molecule due to its ability to form hydrogen bonds with water molecules. Water is a liquid at room temperature because of hydrogen bonding, and it plays a prominent role in our daily lives. The properties and functions of biological molecules materialize in a water medium. Oceans, rivers, lakes, and ponds would exist, and it would rain as an integral part of the water cycle in nature. Water is the most abundant and widespread solvent on Earth and an aqueous solution that occurs in nature, such as biological fluids and seawater, contains many solutes in different concentrations [35-42].

Water would rise through the capillary tubes in the roots and stems of plants because of high surface tension, and they can obtain salts required for their growth as water can dissolve ionic substances. Ponds and lakes freeze from the surface downwards as solid ice is less dense than liquid water, making a layer of ice on the top in the winter. This phenomenon helps the aquatic plants, fish, and other water-living organisms to survive in the warmer water below the ice in winter. In the solid state, hydrogen bonds have directional nature with specific orientations in the rigid ice crystal lattice, whereas, in the liquid state, they are continuously formed and broken. Water expands as it freezes into ice, and in the ice, the strong hydrogen bonds hold the molecules in a relatively open tetrahedral network structure. Water, with weak bonds between its particles, clings to the walls of the container and curves upwards.

Essential ionic compounds are absorbed into the bloodstream from the aqueous solution in the intestines of animals. Cells in the human body require water to regulate their volume and osmotic pressure to enable biological structures to perform bodily tasks such as transporting nutrients and waste and serving as physical barriers. Small fluctuations in different body systems can build up and cause profound changes over time. Fish and other lake-dwelling organisms obtain nutrients and oxygen dissolved in water. The amount of dissolved oxygen in water is about 9 ppm when it is completely saturated with air at 1 atm and 20 ^{o}C.

Water vapor consists of discrete water molecules, and intermolecular H-bonding chances are small due to the mobility of molecules at high temperatures. It is continuously generated by evaporation in the atmosphere and moves upwards, leading to cloud formation by condensation. The amount of water vapor in the air is known as humidity, and it is measured by hygrometers. The local climate is influenced by evaporative cooling and enhanced relative humidity due to the transpiration process. Unfavorable micro-climatic conditions, unseasonal rains, hot weather, or high humidity can affect certain crops and shake people’s confidence. Water vapor is effective at absorbing the thermal radiation from the Earth's surface, and it is known to be present outside the solar system in small quantities. Extraterrestrial liquid water is a topic of wide interest as it is one of the prerequisites for extraterrestrial life. In the solar system, the asteroid Ceres has large amounts of ice on its surface and also an atmosphere. Thus, water is a precious, life-sustaining resource for the community required for drinking, livestock, irrigation, and industries. As water is crucial for our survival, and to fulfill the needs of the plant and animal kingdoms, pollution of local water sources, development of water-intensive industries, climate change, and lack of legislation can lead to threatening consequences. While adapting modern water treatment techniques, judicious use of water and proper water policies can lead to water as a path to growth. The procedures for obtaining necessary approvals and the regulatory framework need to be streamlined to have an enabling policy framework.

WATER FOR HUMANITY AND OBSERVATIONS

There is a need to recognize the biological, environmental, and industrial importance of water in the real world around us and to make reasoned choices on water consumption [43-48]. The amount of freshwater available to meet our industrial, domestic, and agricultural purposes is relatively limited. Of the 2.5 % freshwater, less than 1 % is available as surface water or groundwater, and the remaining portion of this freshwater is locked in glaciers and polar ice caps. The remaining part of the total volume of water on earth (96.5 %) is found in the oceans. Further, water must be treated to obtain the quality of water suitable for drinking purposes. The total hardness should be less than 400 mg/L, and chloride ion concentration should be less than 250 mg/L. As part of the water purification system, chlorination produces a group of by-products called trihalomethanes (THMs) that are suspected carcinogens.

The WHO has prescribed a concentration limit of 100-200 μg/L on the total quantity in potable water. A study on the health effects of arsenic in drinking water in some parts of the world indicates a lung and bladder cancer risk. The environmental protection agency (EPA) of the USA issued the standard for arsenic in public water supplies to less than 10 μg/L. Today, the water of several rivers is polluted by industrial and domestic wastes and even dead bodies. The types of water pollution could include physical (suspended matter, thermal, solid waste) chemical (nutrients, toxic inorganic materials, persistent organic pollutants), microbiological (oxygen demanding, pathogens).

Water pollution is a major global problem and one of the main problems of ecology [49-64]. This issue must be tackled by local bodies and the government by implementing preventive measures, corrective steps, and promoting local recycling of water at all levels. Ten people out of a hundred lack access to clean and safe drinking water and accessing it through local social enterprises via a network of subscribers for a nominal charge in a locality would make a difference in people's lives. Physical water scarcity arises as a result of inadequate natural water resources to meet the requirement of a geographical location. In contrast, economic water scarcity is a result of poor management of water resources. It is the latter type to be addressed in several countries facing a clean water crisis, and the limited availability of water impacts business. The joint effects of such a water crisis include reduced agricultural production, cost escalation of commodities, and economic pressures or political stresses.

Climate change and water scarcity could adversely impact forest biodiversity and multiple forest products, which in turn would severely impact local communities dependent on forests for their livelihoods and as a source of raw material for a wide range of domestic and commercial applications. The change in a forest ecosystem can serve as a kind of early warning system for environmental problems and could have unpredictable consequences. Water acts as a vital social lubricant in the economic chain through its use in the industrial sector, agriculture, and tourism industry. It is essential to recognize the economic value of water in addition to its ecosystem service, and all human beings should have access to clean water at an affordable price. Importantly, the goal of water for humanity will be achieved within the broad framework of science, technology, and product, and how we apply science practices more broadly.

The human population explosion on a global scale and increased human activities and development have resulted in multiple applications of the three typical phases of water [65-74]. Water is becoming an increasingly scarce resource, and the overexploitation of groundwater resources in the recent past has resulted in the drying of water tables, leading to several emerging water-related science, technology, and management issues. Increased depletion of groundwater, declining surface water sources, decreased replenishment, and excess evaporation due to global warming have caused many water-related issues and concerns [75-76]. The shortage of water harms ordinary citizens' lives, and the potential of distributing fresh water of good quality to all will positively impact societies. Snow measurements from Cryostat show that the Antarctic ice layer is losing 159 billion tons of ice each year, and more than a billion people depend on mountain snowflakes for their water needs. As the climate changes, snowfall may decrease in the future. Water conservation, harvesting, recycling, and the clean water act are essential parts of positive activities to restore the required amount of water for different domestic, industrial, and agricultural purposes.

There is a need to create awareness among the general public on rainwater harvesting, green belt development, and water conservation techniques. Conducting training, awareness, and sensitization programs for people will help maintain the sustainability of water resources. The right combination of recharging water bodies and reliable, responsible, and socially useful water delivery models are expected to make the desired positive impact on the ground. It is essential to improve water quality by regulating domestic sewage, runoff from agricultural lands and livestock areas, and industrial wastewaters from food-processing plants and paper mills. The service-specific regulations governing water use must specify the requirements relating to storage, packaging, transport, delivery, recycling, optimized utilization, distribution network, and regulated water tariff structure. Regulatory requirements are essential to have control over the introduction of toxic wastes from domestic, agricultural, and industrial sectors. Integrated wastewater management, large-scale public water transport systems, waste management legislation, and proper implementation aspects will inspire the next generation for a shared future.

Adaptation of global water quality standards involves significant technological development challenges as well as several management changes. Conflict resolution regarding water disputes involves negotiations seeking a fair and reasonable settlement, which is acceptable to all and causes minimum damage to the environment. In the broader context, it is more important to strike a balance between water conservation and social development goals and arrive at river water-sharing agreements with neighboring countries. Water supplies must be affordable to all as it is the basic need of every human being.

Further, progress in equipment, technology, and purification methods will stand the next generation in good stead. Funding for not-for-profit water-related research activities and application-oriented research programs should be encouraged by the government. The research outcome will help us better understand the benefits of water and social issues associated with its supply to enable us to make intelligent decisions in the future. An association of the government with non-profit organizations for constructing and maintaining water purification plants and managing water supply projects in different areas can make a substantial socio-economic impact. Building a state-of-the-art water treatment plant based on reverse osmosis technology in different locations can save millions of people from waterborne diseases in the world. Progressive and eco-friendly policies and practices in implementing effective water management to achieve tangible results will allow the government to fulfill its commitment to a greener tomorrow gradually.

Advanced wastewater treatment, disposal and analysis, water processing and distribution systems, and recycling and reuse of wastewater from various industries are necessary due to the contamination of water by hazardous wastes. The industries that require large quantities of water include tanneries, breweries, distilleries, refineries, aluminum, copper and zinc smelting, thermal power plants, and units engaged in the production of fertilizers, textiles, paper, sugar, cement, iron and steel, pesticides, petrochemicals, pulp and paper, dyes and dye intermediates, aerated drinks and packaged drinking water. Engineering systems for water purification include physical and chemical processes such as volatilization, dissolution, precipitation, hydrolysis, complexation, redox reaction, and photochemical reactions.

Evaluation of water for public distribution involves a battery of determinations such as dissolved oxygen content, biological oxygen demand, determination of dissolved constituents, and testing for the presence of various forms of harmful microorganisms. A few general principles may be observed in water conditioning and industrial wastewater treatment: increasing industrial reuse, pollution control, recovery of by-products, and the use of green chemistry and engineering principles in the manufacture of pulp and paper, petroleum, and chemical and allied products. The discovery, development, and commercialization of low-polluting processes, green manufacturing methods, and additional research efforts in environmental protection should be encouraged by funds and grant programs by the governments. The green movement has lit the spark for water struggle in several places, and water harvesting, and environmental conservation efforts directed towards meeting the challenge of water shortage have improved the situation dramatically.

The millennium development goal of safe drinking water has reached the international target. Setting up a drought and flood monitoring and management cell (DFMMC) to recommend dynamic short-term and long-term plans, and concrete steps to encourage massive afforestation, protecting natural forests, lakes and other catchments, preventing the destruction of existing forests, preventing soil erosion, recharging the tanks, rivers, and groundwater, and environmental norms to conserve, manage and reuse of water for the benefit of all is essential.

Local water management committees (WMC) can promote water conservation by documenting local water resources, developing guidelines for the extraction of water, conducting discussions and awareness sessions, and removing invasive species from waterbodies. It is crucial to have intricate water purification systems that remove harmful viruses, bacteria, hardness, turbidity, pesticides, harmful metal ions, organic compounds, lead, and other impurities for domestic purposes. The adherence to waste disposal rules, efficient effluent handling, and decreasing pollution levels in lakes and groundwater sources is a collective responsibility of both government and industry. Establishing an efficient effluent treatment plant in specific industries to ensure that either less amount or no residual harmful water is released helps them to achieve minimum liquid discharge (MLD) or zero liquid discharge (ZLD) status.

There is a threefold increase in fresh water withdrawals in the past fifty years. Development at the cost of forests, rivers, and other water bodies will result in desertification and agricultural land shrinkage. Heatwave conditions can lead to exhaustion, cramps, and sunstroke, killing many people across the world every year, and they harm the ecology. With extreme heatwave conditions and acute water shortage in several parts of the planet due to global warming, the heat-related mortality rate has increased substantially. Action plans include public awareness programs, early warning systems, drinking more water, and immediate medical attention. Ecological restoration measures have to be taken on a massive scale to reduce the impacts of heatwaves sustainably. Climate change will increase the evapotranspiration rate, leading to more demand for water. This shortage will result in water conflicts between industry and communities.

It is essential to implement a comprehensive water policy, making all industries, particularly water-intensive ones, recycle and reuse their wastewater back into integrated operations and install necessary pollution control equipment. Recycled wastewater in many industries can be used for maintaining gardens, washing, landscaping, and cooling towers. Saline water for the industry can be used after sedimentation, filtration, reverse osmosis, chlorination, chemical oxidation, carbon adsorption, electro-dialysis, solar desalination, multi-stage flash distillation, or other treatments. The quality and quantity of water available and the effect of impurities such as arsenic, pesticides, and fluorides on the process have to be considered while selecting a suitable location for constructing a factory. Breakthrough research outputs in energy conversion technologies or desalination technologies would make water available in large quantities at the location of industries and open prospects for further industrial development.

Conservation of water through the recycling of wastewaters and their use in the agricultural sector may help prevent severe ecological degradation and prevent environmental contamination. The protection of the environment requires strict laws related to water pollution control, reasonable water quality standards, standards for hazardous water pollutants, implementation aspects, and evaluation methods for both private and public water treatment plants globally. The laws, rules, and regulations will have a direct bearing on the water usage by the contemporary aspirational society. It is better to adapt the required international regulatory standards and have an institutional mechanism to implement the law's intent. The legislative framework should also include the option of enforcing penal action against defaulters as an essential component. We have to establish water testing laboratories to check the quality of water and set up pure drinking water units to ensure the supply of potable water to millions of residents across developing countries in the world by 2025. Water quality parameters to be checked include dissolved oxygen, specific conductivity, pH, alkalinity, major ions, temperature, suspended solids, and turbidity. The principal impurities in Municipal Corporation water include suspended matter and organic substances (sediment, microorganisms), dissolved mineral matter (bicarbonates, sulfate, chlorides of Ca, Mg & Na), and dissolved gases (O_2, N_2 & CO_2). Primary water treating operations include sedimentation, coagulation, filtration, chlorination, taste, and odor removal. The optional treating operations involve the hardness removal, zeolite process, lime-soda process, fluoridation/fluoride removal, demineralization, and removal of dissolved gases.

Water is a finite resource, and water usage needs to be carefully managed to prevent its rapid depletion. A combination of physical, psychological, environmental, and social factors leads to water pressures. Several concrete steps need to be taken to prevent the future water crisis and developing a sound long-term water supply strategy would certainly have some effect on reducing water pressures. The first step is to collect high-quality data about water resources. We have to learn lessons from hard-core environmental facts and figures of major development projects and carry out in-depth research that helps us to make a well-informed choice to avoid drought. The second step is to prevent water pollution as it means less need for purification. The third step is to ensure a clean potable water supply and better sanitation through better management practices.

A global surveillance network is required to monitor the quality of water used in different parts of the world. It is important to share best practices in reliable tools and technologies to replicate the model across the world. Fourth, a public campaign to promote awareness about the dangers of waterborne diseases and the need to have public interest safeguards to promote socioeconomic development. This awareness can bring about a big change. There is a need to increase awareness about the importance of water as a marketable commodity. Creating responsible water consumption patterns by the citizens could help in avoiding water-based conflicts between states or nations. Fifth, encouraging the use of existing water and wastewater technologies as well as developing new environment-friendly technologies. We need a multipronged approach that involves collaboration among neighboring nations and states and improves system efficiency, including distribution and delivery planning, adequate infrastructure, and specific training requirements.

Funding for research and development, innovative water treatment process marketing, and encouragement for creating brand equity would go a long way in establishing water conservation, management, and optimal use. Adopting water-efficient practices, technological innovations, and mandatory reuse in water-intensive industries have a major impact on the socio-economic life of local areas. Attracting private sector investments and participation in eco-friendly water purification plants, research and development efforts on water-related issues are necessary to help contribute towards sustainable development. Sixth, frame future policies on the continuous water supply and distribution systems for domestic, industrial, and irrigation purposes. It is becoming increasingly clear that manufacturing industries should follow environmentally sustainable business practices in their production activities with a focus on energy, water, and nature conservation. Geographic Information Systems (GIS) can be applied in developing water distribution system hydraulic models. Environmental impact assessment (EIA) of large water resources projects, drought assessment, and forecasting, estimating the area and intensity of rainfall, water quality management, corrective, preventive, and scheduled maintenance of water systems, reuse of water, rainwater harvesting, forest regrowth, artificial recharging of groundwater and analyses of other technical aspects play an important role in sustainable water management. Construction of modern rainwater harvesting systems such as dams, injection wells, percolation ponds/tanks, stepwells, open wells, and subsurface barriers serve as effective alternatives to rejuvenate depleted groundwater aquifers.

The key to managing water issues is to initiate local water conservation and management practices, and water sharing through dams and canals and the interlinking of rivers to enable water transfer from surplus to deficit regions. Periodical data collection on water pollution levels in different nations will equip the world to initiate and accelerate global level actions required to keep the pollution level minimum and increase the availability of pure water, under the concept of water for all. A transparent reporting mechanism will enable us to understand the actions implemented to promote a robust and meaningful water distribution system with optimum water efficiency and reuse of water, the impact of these actions on the degree of pollution, and the long-term prospects of sustainable water resources management. The beginning of change lies in each individual's mind, and we need to cultivate the habit of not wasting precious resources like water and causing pollution. Political will and delivery of services and synthetic engineering systems for drinking water are two of the numerous steps to deliver optimal results. Pricing of water should be determined based on working expenses, including the cost of operation and maintenance. Print and electronic media should present a positive and realistic image to the general public, and governments should encourage interdisciplinary research to meet the emerging challenges of the global water crisis.

Global climate change has attracted considerable attention from interdisciplinary researchers around the world in the last decade. The research on essential aspects of water-related topics is expected to reveal new insights on the scale of the impact and its environmental effects. The surface temperature of the earth is increased by 0.74 ^{o}C in the last hundred years. Global warming may lead to extreme hydrological events such as flash floods and severe droughts, driving many creatures to extinction. This warming will further affect the regional ecology and the life of local people, and in extreme cases, it may lead to ecological catastrophes and large-scale social disruptions. The problems of water quality, quantity, reuse, and pollution are complex. They may vary significantly from one location to another and depend on the prospective use, whether for power generation, heating/cooling, agriculture, domestic applications, or as a solvent.

A broad-based approach involving sustainable agriculture, water efficiency in agriculture, sustainable tropical forestry, sustainable development, technical and commercial efficiency of water supply systems, and a sustainable business model will facilitate the sharing of water. Creating ecological awareness, change in the mindset regarding development, better water use policies, responsible consumption of natural water resources, and the use of new techniques to sustainably use water is expected to have positive impacts on the sustainable use of H_2O for humanity. It is essential to take the application and usefulness of water harvesting and conservation ideas, and nature-friendly practices to the common man through the commercialization of products. Managing water harvesting on a large-scale is crucial for consideration in terms of the added load because of high demand due to increased human activities, which will lead to a substantial increase in water level.

The web of issues and concerns associated with effective water management affecting the stakeholders must be addressed through a pragmatic approach, social activism, and empowerment of people to achieve a long-term solution. We must cultivate a greater sense of universal responsibility and put it into practice for the good of humanity. Each should have the right to equal access to natural water resources and the responsibility of protecting the environment for future generations by performing all activities within existing resource constraints. There is an urgent need for intense goal-oriented action by the governmental system and all the stakeholders to foster community water management practices through a societal transformation as water is one of the most abundant, yet depleting, a chemical in nature and essential for life on Earth. Besides, preventing water loss due to leakage and illegal drawing of both surface and groundwater in some areas should become an integral part of sustainability services to preserve this precious commodity. The bottom line is that we have to increase groundwater levels, conserve water, reduce and reuse, plant trees, and fine-tune farming practices through participative ecosystem management and have integrated and sustainable water resources management for more equitable distribution as water is the fundamental substance of life.

The first observation is the rapid loss of forest cover in the recent past in various parts of the world. It is essential to carry out forest area evaluation and detect green cover changes based on satellite data. This survey helps us better understand the relationships between human activities and the change in natural ecosystems. Afforestation on a massive scale plays an essential part in preventing an accelerated reduction of forest cover and enhancing water holding capacity. New forest areas should be added each year to sensitive landscapes to decrease soil erosion and enhance transpiration. We have to protect them from forest fires, grazing, encroachment, and illegal cutting of trees. The second observation is that coal-based power plants are responsible for much of the world's greenhouse gas emissions. It is essential to develop novel technologies and use alternative power generation technologies such as solar, nuclear, and hydropower. The third observation is that the policymakers are focusing their attention on consumption rather than savings. The government should move the focus toward spreading awareness about the judicious use of this multi-use substance and popularizing water harvesting techniques to reduce the global water footprint. The structure and operational details of water treatment and distribution systems should be comprehensive, including supplying water, infrastructure development, exceptions, and administrative matters. The fourth observation is that the determination of the water prices is ad hoc and needs some structured approach and reforms. The fifth observation is that water conflicts arise because of vested interests, and we need to emphasize the importance of developing collective responsibility, primary national interests, and long-term sustainability goals.

There is a need for creating more online educational platforms to spread the message about water conservation and to disseminate articles, news, images, and videos about water. It is essential to provide mental, graphical, computational, or physical models to enhance understanding of key water chemistry concepts, acquire domain-specific knowledge, and use models to explain a specific observation or analyze new experimental outcomes. It is crucial to research issues connected with water consumption and development, to lead the people in the right direction. The social commitment of agriculture departments, civil society organizations, and corporate companies, coupled with positive initiatives can change the entire landscape and help holistic and balanced development of humanity’s well-being.

The integrated organ and printing system uses water-based ink to hold cells and micro-channels to form tissues that can safely integrate into our bodies [77]. Developments in 3D bioprinters could make organs and human tissue good enough for transplant. The future of water purification could involve its treatment with ultraviolet light-emitting diode devices (UV-LED) at the point of use rather than conventional mercury lamps [78]. The recent advances in the water-based printing process involve the use of liquid, waterborne printing inks with negligible volatile organic compound content [79-83]. A significant advance in water-based batteries includes water-in-salt lithium-ion battery technology that could change the use of battery-powered electric vehicles in the future [84]. Smart underwater micro-drones could be used to monitor or map large areas of the oceans [85]. Further advancements in air-to-water generators or advanced versions of wastewater treatment plants, and the adoption of new technologies, help expand access to clean drinking water to new consumers.

CONCLUSIONS

In this paper, we have described the essential uses and different properties of water and emphasized the need to confirm, correct, apply, extend and improve water science and engineering concepts, principles and applications while solving problems related to water. Water is the critical substance for the survival of all civilizations and cultures. It has an essential role in continuing plant and animal life. It would serve to fortify people on the journey of their lives and their businesses.

The businesses can be grouped into verticals like municipal water supply and wastewater treatment, industrial water, and wastewater treatment, seawater desalination, pollution control, and green power generation. The water demand grows as populations increase, placing more significant stress on finding adequate supplies to meet the demand. A focused approach by governments on implementing strategies on the ground will have a significant impact on achieving the national population stabilization target within a short period. Liquid water, a collection of water molecules, is a powerful symbol of hope and literary imagination. It is supporting the whole ecosystem and is crucial for our existence in the laboratory of life. It is a common substance and a unique solvent, essential for living systems. We have to learn to respect nature because of the life-giving care of the water bodies like rivers and streams. We have to invest heavily in quality education and public health, such as clean water, sanitation, and disease control. The growth of an innovative healthcare delivery model depends on the incorporation of waterborne disease prevention through better sanitation and water purification processes in its ecosystem. Funds for developing comprehensive solar power infrastructures such as solar parks and solar farms will help achieve global energy generation targets, enhancing the solar energy capacity manifold.

Water can act either as an acid or as a base. All the chemistry that makes life possible takes place in water media, and different tests involve chemical reactions in water, including the analysis of blood and other body fluids. There are some chemical reactions in water with metals, non-metals, and compounds. Water plays a pivotal role in the metabolism of foodstuffs in the stomach or oxygen transport within the body system.

When raindrops come in contact with carbon dioxide in the atmosphere, water becomes acidic due to the formation of carbonic acid. Water pollution control methods and water treatment techniques used to soften hard water play an essential part in the supply of water required for domestic purposes and industrial processes. The challenges include mindset change, building better systems, achieving water security, maintaining high purity standards, reduction in water pollution levels, improvement in the quality of services, changes in technology, and fair price and transparency. The focus on innovative ideas, a proper plan, established processes, a business model, organizational structure, a strong network of mentors, better water management, access to risk capital, and a forward-looking workforce would pave the way toward sustainable global growth.

Further research and development efforts to improve the water purification and distribution system are warranted. Another direction for future research in this area is the exploration of the technical improvements in monitoring systems and the effective delivery of water fulfilling the regulations. It will be fascinating to see if the development of advanced and hybrid water technologies would significantly reduce the incidence of waterborne diseases. It is an enduring water link in the entire ecosystem that becomes important to the process of climate change. An analysis of specific geospatial data could help in overcoming the water crisis in the future by reconstructing concepts critical to the future of our society. ‘Save water-save the earth’ is a powerful message that would transform the world for the better. It is essential to realize that ‘just do it’ is not enough, but ‘do it right’ is the way to go, as many small expeditious steps in the right direction can make a great leap forward. It remains to be seen if the prospect depends on how water management plans reflect our close observation of images from contemporary situations, history, and life.

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