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EDITORIAL

FINAL CALL FOR ACRICE-2

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Dear AJCE Communities,

The African Conference on Research in Chemistry Education (ACRICE) is FASC’s official conference on chemistry education. ACRICE conference is intended as a platform for understanding and enriching education for preparation of African citizens who are able to deal with local and global challenges. To that end, educators and researchers at all levels are invited to share vital knowledge and strategies for teaching and learning in culturally responsive ways.

ACRICE-1 was held in Addis Ababa/Ethiopia in collaboration with the Department of Chemistry of the Addis Ababa University from 5-7 December 2013. The presentations at the Conference were reviewed and published as special issues of AJCE under volume 4, numbers 2 and 3 (http://faschem.org/node/5).

ACRICE-2 is planned to take place at the University of Venda (South Africa) from 22-27 November 2015. As Prof. Liliana Mammino (Chairperson of the Organizing Committee of ACRICE-2) indicated (http://www.ec2e2n.info/news/2014/1506_201412) the conference will consider a wide range of themes crucial for chemical education, spanning through all instruction levels: pre-university (from younger levels to secondary school) and university (from undergraduate courses to the educational components inherent in mentoring post-graduate students). While inviting you to participate in ACRICE-2, we hope you will enjoy reading the 1st issue of AJCE 2015 on various topics in Chemistry Education in Africa.

SJIF IMPACT FACTOR EVALUATION [SJIF 2012 = 3.963]
CATALYSIS OF CHEMICAL PROCESSES: PARTicular teaching aspects

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ABSTRACT

The paper is devoted to two main issues of catalysis from the viewpoint of teaching and learning activities. The first part deals with positive catalysis which treats the general features of catalytic processes and textbook imperfections. The second part focuses on decelerating or stopping-down chemical processes. It is shown that contrary to the “positive” catalysis, i.e. enhancement of the rate of chemical reactions, which is a regular part of chemical education at secondary/high schools and universities, the inhibition of the chemical reactions is frequently missing in educational curricula. The importance of inhibition is explained, its mechanism presented and examples offered. [African Journal of Chemical Education—AJCE 5(2), July 2015]
INTRODUCTION

The word “catalysis” was introduced into chemistry by the Swedish chemist Jöns Jacob Berzelius in 1835 [1] who realized that there are substances which increase the rate of a reaction without being themselves consumed.

A catalyst which enhances the rate of a reaction by providing an alternative, less energy demanding pathway is called a “positive catalyst” and the process “positive catalysis” or usually simply “catalysis”. A substance which retards the rate of a reaction is called a “negative catalyst” or “inhibitor” and the process “negative catalysis” or “inhibition”.

It is estimated that more than 90% of the production of chemical industry is based on catalysis [1] and in living organisms the proportion of enzymes-catalyzed processes is even higher [2-5]. According to a study from The Freedonia Group, a Cleveland-based market research firm, world demand for catalysts will rise 5.8 percent per year to $19.5 billion in 2016 [6]. As a result, the lesson catalysis is frequently included in chemistry education curricula at secondary/high schools and university levels indicating that catalysis is very important. The field of catalysis is included in the majority of textbooks covering, in particular, general chemistry, industrial processes and technologies, biochemistry and biotechnology [7-16].

Catalysis understood as an acceleration of a chemical reaction in approaching the equilibrium state is extremely important at the stage of obtaining the final product. However, once the product is prepared, there is a requirement to preserve its utility properties or, in other words, to suppress any changes leading to the product deterioration [17, 18]. Cosmetics, foodstuffs, beverages, medicinal drugs, textiles and plastic materials can be used as illustrative examples where such stability is required. To prevent undesirable processes from occurring, substances known as antioxidants, preservers, stabilizers or conserving agents are applied [18-
Their function can be, in a broader sense, described as negative catalysis or inhibition. Surprisingly, the phenomenon of inhibition and its essence is usually not mentioned or correctly, from the viewpoints of kinetics, explained in educational materials and activities. This statement can be exemplified by textbooks [8, 11-14].

The progress of a reaction with time progress starting with reactants R, continuing to their transformation to final product(s) P and subsequently undesired change of P to degradation product(s) D may be illustrated as follows:

\[
\begin{array}{cccc}
\text{R} & \rightarrow & \text{P} & \rightarrow \text{D} \\
\text{desired acceleration at preparing final product(s) using a positive catalyst - positive catalysis} & \text{usable product} & \text{unwanted process(es) deceleration to suppress P degradation applying inhibitors - negative catalysis} & \text{time}
\end{array}
\]

This contribution is aimed at

i) introducing catalysis in a general mode;

ii) providing examples of the most common textbook imperfections in this field, and,

iii) explaining and exemplifying the importance of decelerating or stopping down chemical processes.

POSITIVE CATALYSIS

Introduction

It is worth beginning with catalysis in its usual meaning, \textit{i.e.} a process of acceleration in the rate of a reaction caused by the presence of a substance – catalyst – that does not appear in the chemical equation among the reactants and products, does not change thermodynamics of the overall process, and acts also when being in substoichiometric amount in the reaction system. A catalyst thus does not change the energetic characteristics of the reactants, products and the
reaction ($\Delta_r U, \Delta_r H, \Delta_r G$) and the barriers between them ($E^{\neq}, \Delta H^{\neq}, \Delta G^{\neq}$)[7, 15]. It instead finds an alternative reaction pathway (with a faster reaction rate) that bridges reactants and products with lower energy barriers. It implies that in a reversible reaction the catalyst accelerates the forward and reverse reaction equally. Therefore, although it shortens the time required to approach the equilibrium, a catalyst does not affect the final position of equilibrium and, consequently, percentage yield of the products[21].

In spite of its involvement in the reaction mechanism, the catalyst is not consumed in the overall reaction process, however, it is a constituent of some intermediates[7, 15, 21].

Contrary to the stoichiometric equation not involving the catalyst, it may be included in the rate law with a partial order greater than zero[7]. The rate law for a general reaction of the reactants A and B in a system containing a catalyst C consists of two terms expressing the rate of uncatalyzed and catalyzed reaction and may be written generally in the form [7]

$$v = k_{uncat}[A]^a[B]^b + k_{cat}[A]^x[B]^y[C]^z$$

where $k$ are the corresponding rate constants, $a, b, x, y, z$ are the partial orders. When the catalyst is a solid (heterogeneous catalysis), its concentration is constant and it does not appear as an independent term in the rate law. Its effect is included in the value of $k_{cat}$.

The best kind of catalysts are enzymes. They produce rate enhancement (expressed as $k_{cat}/k_{uncat}$) ranging from $10^7$ to $10^{19}$[21]. In addition to their efficiency, enzymes are usually specific (one enzyme catalyses one reaction) and stereospecific.

**Misinterpretations in teaching and perception of catalysis**

In the area of positive catalysis, three main kinds of imperfections appearing in textbooks may be identified. A first one lies in the claiming that “the catalyst decreases the activation
energy of the reaction”. Reality is that the activation energy of the original reaction is not changed by the catalyst[22, 23]. Suppose, you have a mountain between two valleys so that the only way for people to get from one valley to the other is over the mountain. The tunnel (analogy with catalytic pathway) does not change the original mountain pass, it just represents a new route. The effect of catalysts arises from the fact that in their presence a pathway with lower activation energy becomes available to the reactants and it does not lower the activation energy of the original reaction [22, 23].

A second imperfection relates to the expression of the activation energy for uncatalyzed and catalyzed process. An effort to be as simple as possible may alter a simplification to an incorrectness. Also in otherwise excellent textbooks [8-11] the potential energy curves for catalyzed and uncatalyzed reactions are depicted with the same number of transition states (usually a single state) without documenting the action of the catalyst and its involvement in the reaction mechanism, i.e. without intermediates (Fig. 1a).

The involvement of a catalyst should be illustrated both by a higher number of intermediates and a higher number of transition states (with the activation energy lower than that of uncatalyzed process) [12-16]. A very simple and illustrative example (Fig. 1b) is the oxidation of CO to CO$_2$ occurring in the gas phase by oxygen O$_2$. The mechanism of both uncatalyzed reaction and that catalyzed by metal (Pt) surface was proposed by the Nobel-prize winner, Gerhard Ertl [24].

In the absence of a catalyst, the activation energy is given by bond energy in molecular O$_2$. In the presence of Pt-catalyst, both reactants, CO and O$_2$ are chemisorbed on the metal surface and molecules of O$_2$ dissociate to O atoms. Within these three processes the energy is released (−259kJ·mol$^{-1}$). In order the adsorbed CO molecules to react with adsorbed O atoms,
the activation energy of 105 kJ-mol$^{-1}$ should be overcome, their conversion to adsorbed CO$_2$ molecules is an energy-releasing ($-45$ kJ-mol$^{-1}$) process. The final step of the process, desorption of CO$_2$ molecules is an energy-consuming process (21kJ-mol$^{-1}$). The enthalpy change for the both uncatalyzed and catalyzed overall reaction of CO oxidation is, of course, equal ($-283$ kJ-mol$^{-1}$).

![Image](image_url)

Fig. 1a: Over-simplified energy profile of a general catalyzed and uncatalyzed reaction not involving the role of catalyst in the reaction mechanism [8, 10, 11].

Fig. 1b: Energy profile for the uncatalyzed ($E^* = 249$kJ-mol$^{-1}$) and Pt-catalyzed oxidation of CO by O$_2$. Symbols “ad” and “≠” denote adsorbed molecules and transition states, respectively. All the values are extracted from [24, 25] and expressed in kJ-mol$^{-1}$.

While the energy profile in Fig. 1a might suffice at high school level where the students do not deal with reaction mechanisms, university students of chemistry having the fair
knowledge of physical chemistry and reaction mechanisms should work only with the profiles as depicted in Fig. 1b.

A third imperfection lies in the confusing use of energy quantities in graphical illustration (energy profile) of both catalytic and uncatalytic route of the transformation of the reactants to the products and should be corrected at least at university-level education. Frequently the energy profile is shown as a dependence of energy on reaction progress, without specifying what kind of energy (internal energy, potential energy, total energy, Gibbs energy?) is in question, and what is the meaning of “reaction progress”. Thermodynamics of the overall reaction is usually expressed as enthalpy change while kinetics as potential energy[11, 26].

In any case, only one quantity should be used. Also, it should be clear that the “reaction progress” does not represent time evolution. It is in fact “reaction coordinate“.

It is customary to use activation enthalpy and activation energy interchangeably[13, 26], but there is, in fact, a difference between them from the viewpoint of both physical meaning and value. Activation energy \( E^a \) is an empirical parameter in Arrhenius equation in collision theory of chemical reactions[21]. Activation enthalpy \( \Delta H^a \) (as well as activation Gibbs energy \( \Delta G^a \) and activation entropy \( \Delta S^a \)) are parameters of Eyring relationship[21], originating from transition state theory. As for values, \( E^a \) is lower by a few kJ\-mol\(^{-1}\) than \( \Delta H^a \)[21]. As for the quantity used, preferable might be Gibbs energy (including activation Gibbs energy) due to its direct relation to equilibrium constant or enthalpy due to direct connection to the heat effect of reaction and the temperature dependence of equilibrium constant. The use of Gibbs energy was correctly documented in [27].
NEGATIVE CATALYSIS

The concept of negative catalysis was evaluated in scientific literature back in 1920s[28, 29]. Negative catalysis is useful to slow down or completely stop an unwanted reaction[22, 30]. The student may ask whether any chemical reaction can be inhibited. The answer is “no“. Generally speaking, only catalyzed, photochemical and unbranched chain radical processes may be effectively decelerated[22]. In more detail, inhibition can thus be applied in processes involving substances able to chemically transform (poison) the catalyst, to trap or scavenge intermediates in unbranched chain radical reactions, or to deactivate reactive molecules in electronically excited states. A chemical process may be stopped also due to deposition of substances on the catalyst preventing thus its participation in the catalytic process. It is important to stress within teaching the matter that, contrary to the positive catalyst, the inhibitor does not introduce a new reaction route with a higher activation energy. Due to its action just the reaction continues to occur by the non-catalyzed route.

In the next part the mechanism of negative catalysis will be documented and selected examples presented.

Poisoning a catalyst

A negative catalysis may be a consequence of irreversibly poisoning the catalyst present in the reaction mixture. For example, the traces of transition metal cations released from the container catalyze decomposition of hydrogen peroxide, H₂O₂. But the addition of a complex-forming compound (e.g., derivatives of phosphoric acid, phosphonic acid, various organic acids [31, 32]) to solutions of H₂O₂ would bind the metal cations acting as catalysts into complexes and thus prevent decomposition. Aqueous solutions of H₂O₂ containing H₃PO₄ are called “stabilized“.
In case of transition metal containing enzymes, hydrogen sulphide and/or sulphide anions act as catalytic poisons forming metal sulphides[33]. A consequence for the involved chemical process is transition from a fast catalytic route to a slow uncatalytic one.

A huge amount of knowledge has been accumulated and rationalized in the field of enzyme catalysis and inhibition. Enzyme inhibitors cause a decrease in the reaction rate of an enzyme-catalyzed reaction by binding to a specific portion of an enzyme[4]. One of the oldest and most widely used commercial enzyme inhibitors is aspirin (acetylsalicylic acid), which selectively inhibits an enzyme involved in the synthesis of molecules that trigger inflammation[34].

**Breaking an unbranched chain reaction**

Unbranched chain reaction is a process in which the number of chain carriers is equal (usually 1) in each propagation step[35]. In some cases, negative catalysts are believed to operate by breaking the chain of reactions. For example, the combustion of H₂ and Cl₂ which is a chain reaction is inhibited by oxygen, O₂[36]. The mechanism of the reaction can be expressed by three elementary reactions:

\[
\begin{align*}
\text{Cl}_2 & \rightarrow hvy(\text{UV}) \rightarrow \text{Cl}^- + \text{Cl}^+ (\text{photochemical initiation}) \\
\text{H}_2 + \text{Cl}^- & \rightarrow \text{HCl} + \text{H}^+ (\text{propagation}) \\
\text{H}^+ + \text{Cl}_2 & \rightarrow \text{HCl} + \text{Cl}^- (\text{propagation})
\end{align*}
\]

O₂ breaks the chain of reactions (decreases their rate) interacting with atom H⁺ forming the unreactive radical HO₂⁺:

\[
\text{O}_2 + \text{H}^+ \rightarrow \text{HO}_2^+
\]
It should be pointed out that branched chain reactions (chain reactions in which the number of chain carriers increases in each propagation step, e.g., explosions) cannot be effectively inhibited by this mode[35].

**Deactivating excited states**

The absorption of ultraviolet (UV), visible or near-infrared radiation by a compound may be a cause of its destruction[17]. Undesirable photochemical processes may be inhibited via deactivation of excited molecules. The substances playing the role of inhibitors are called photostabilizers. The mode of their actions depends on the nature and properties of the excited molecules[17].

One of the deactivating modes is energy transfer, applied, e.g. in transforming (quenching) reactive excited singlet oxygen $^1\text{O}_2$ to unreactive ground-state triplet oxygen $^3\text{O}_2$. The process can be exemplified by the quenching of singlet oxygen with the photostabilizer bis($N$-phenyl-dithiocarbamato)nickel(II), abbreviated as [Ni(PDC)$_2$] in its ground singlet state[37, 38]

$$^1\text{O}_2 + ^1[\text{Ni(PDC)}]_2 \rightarrow ^3\text{O}_2 + ^3[\text{Ni(PDC)}]_2$$

The rate constant of the reaction is $1.1 \times 10^{10}$ L·mol$^{-1}$·s$^{-1}$. In general, photostabilizers must comply with at least two conditions: the rate constant of their reactions with excited molecules must be as high as possible, and the excited reaction product (in the above example $^3[\text{Ni(PDC)}]_2$ in its excited triplet state) must be deactivated solely by a photophysical mode and its excitation energy converted to heat[17].

Photodegradation of polymers is decelerated also by using UV absorbers which are compounds absorbing UV radiation with a very high molar absorption coefficient
(\varepsilon_{UV}>10^4 \text{L} \cdot \text{mol}^{-1} \cdot \text{cm}^{-1}) \) and thus preventing the absorption of UV radiation by the polymer or its components[17, 39].

**Scavenging reactive radicals**

To inhibit undesirable radical decomposition reactions from occurring, radical scavengers are used. Among the radicals initiated such processes, hydroxyl radical \('\text{OH}'\) may be mentioned[40, 41]. Radical scavengers are added, \textit{e.g.}, to foodstuff, beverages, polymers, textiles etc. Many of them form integral part of living organisms and inhibit reactions of radicals by reacting with them. Well-known example represents enzymes superoxide dismutases, SOD, inhibiting redox processes of the radical \(\text{O}_2^-\) through its dismutation into dioxygen and hydrogen peroxide molecules (the mechanism is not so simple)

\[
2 \text{O}_2^- + 2 \text{H}^+ \xrightarrow{\text{SOD}} \text{H}_2\text{O}_2 + \text{O}_2
\]

Sorbic acid, benzoic acid and their derivatives are foodstuff and beverages preservatives inhibiting usually redox processes of reactive oxygen species such as \(\text{'OH}, \text{O}_2^-, \text{RO}_2^-\) by their bonding to a double bond or their reduction[20,41]. In polymer chemistry highly effective radical scavengers are 2,2,6,6-tetramethyl piperidine derivatives, known as hindered amine light stabilizers (HALS)[39]. It is worth pointing out that scavengers are consumed in the process without their regeneration, and do not return chemically unchanged to the system. In spite of this fact, they are very useful in protecting and preserving original, required properties of products.

**Depositing substances on the catalyst surface**

When a liquid or solid substance is deposited, or a gas adsorbed on the solid catalyst, it prevents contact of reacting species with the catalyst and the process becomes slower[42]. Such
a situation may happen in the heterogeneous catalysis in which at least one of the reactants or products is a highly viscous or solid substance. As example, residue hydrocracking process of naphta pitch using the catalyst composed of activated alumina, Ni and Mo is inhibited by deactivation of the catalyst due to deposition of coke and high-molecular hydrocarbons (so called coking or fouling effect) on its surface[40].

In heterogeneous gas-phase catalysis one of the reactants may be adsorbed (chemisorbed) on the solid catalyst surface in such an extent that it prevents contact of the catalyst with another gas reactant reducing or destroying thus the catalyst’s efficiency. Together with economical factors, this is why the course of such reactions is governed in a definite pressure and temperature range, e.g. ammonia is industrially synthesized at 400-450 °C and 200 bar.

CONCLUSIONS

Catalysis of one of the most important issues in chemical education, industry and life-relating processes. This is why the correct teaching at all levels of chemical education should result in correct understanding the matter. The most frequently misinterpretations appearing in textbooks and scientific literature are presented and modes of their correction suggested. In the literature and education curricula the issues of catalytic acceleration and deceleration of chemical processes is not sufficiently balanced. Inhibition of chemical processes understood as their deceleration or even totally bring to a stop is of importance equivalent to that of positive catalysis. It deserves a due attention at secondary/high school and university levels. Its significance should be demonstrated by examples from real industrial, environmental and biological systems. When dealing with catalysis, the teacher and textbooks should be careful not to oversimplify the matter.
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ABSTRACT

Research into left-handedness concurs that generally, left-handed people experience difficulties manipulating right handed tools. Specifically, left-handers face challenges associated with right handed instructional resources because of their inherent peculiarities due to their hand orientation in science classrooms. There is evidence for a general cognitive disadvantage for left-handers compared to right-handers according to recent research. Studies have explicitly shown that left-handed learners are disadvantaged when using mismatched instructional resources that are generally ‘ungraspable’, and more so during chemistry laboratory timed tasks. Whereas the importance of practical work in science cannot be ignored based on its significance to learning school science, adaptations left-handers have to make so as to fit with right handed instructional resources gets in the way of their learning. A persistent failure to effectively interact with the resources fluidly lowers learners’ self-efficacy thereby causing them to harbor negative attitudes and interest towards chemistry. This comparative case study assuming a mixed methods concurrent triangulation design sought to find out the relationship between left-handers’ use of right handed instructional resources and their attitudes towards high school chemistry. Participants were drawn from a cross-section of secondary schools in Kenya. Left-handedness was determined using the Torque test for handedness. Quantitative data was collected by use of questionnaires. Qualitative data was collected through focus group discussions. Qualitative data was analyzed thematically while quantitative data was analyzed using SPSS. The final report had contextual description and direct quotations from the research participants, a statistical significance of findings, correlations, and comparisons of means. Suggestions to instruction designers to generate instruction designs that encourage low cognitive load were made. Practical suggestions to instructors on the best practices when instructing left-handed learners during chemistry practical sessions were also highlighted. The findings served to contribute to existing literature on special learning needs, enlightening education stakeholders to embrace the unique needs of left-handed learners. [African Journal of Chemical Education—AJCE 5(2), July 2015]
BACKGROUND INFORMATION

Attitudes have been defined in a variety of ways. For example, Smith, Walker and Hamidova [1] define attitudes as containing feelings and emotions associated with objects and are assumed to result from one’s prior experience with the object. Sarnoff [2] sees an attitude as a disposition to respond favorably or unfavorably to an object. Apparently, these definitions are aligned with behaviorist perspectives that explain the behavior of individuals based on their previous undertakings in their surroundings in general. Therefore attitudes are not innate but learned, suggesting some past experience with the object [3]. Attitudes towards science have been defined by Gardner [4] as a learned tendency to appraise in definite ways objects, people, actions, situations or propositions involved in the learning of science. These attitudes are known to involve attitude objects such as “science” or “science lessons,” “laboratory work” and so on [5]. When the response to either of these objects is favorable, students are said to have positive attitudes and when the response is unfavorable, students are said to exhibit negative attitudes. It has been postulated by Hofstein and Mamlok-Naaman [6] that in order to help learners develop positive attitudes towards and interest in science in general and learning science in particular is one of the key goals for teaching and learning school sciences. This study adopts attitudes as learned predispositions to respond in a consistently favorable or unfavorable manner to a given subject as is consistent with Gardner’s [4] definition of attitudes.

Students develop attitudes toward science, for example, by openly seeking information to respond to an immediate need. An individual student holding a favorable attitude toward science could be expected to do well in science tasks, look forward to science lessons and laboratory sessions, or even choose to pursue science related careers. Once individual’s predisposition or attitudes have been established, it is expected that they will (or will not) perform the associated
behavior [1,7]. That means positive experiences tend to build self-efficacy in carrying out a task. However, the contrary also holds.

Research on psychological effects has found that students’ self-efficacy of ability to perform in science positively correlates with achievement [6]. It has been observed that many students fear chemistry, a fear characterized by mass disenchantment among students towards the subject. The end product has been the declining popularity of chemistry over the years. According to Keeves and Morgenstern [8], students’ anxiety towards the learning of science makes them lose interest in the subject. On the other hand, Deboer [9] points out that students’ achievement is influenced by favorable attitudes towards oneself (positive self-efficacy) as well as the subject. A student with positive self-efficacy of ability in a subject has a higher probability of developing favorable attitudes towards that subject, and as a result spends more time and energy in the subject thus gaining mastery of the subject which results in improved achievement. Deboer [9] further argues that as a result of this success, the student is reinforced further to continue performing well in the subject possibly developing stronger favorable attitudes towards the subject.

A number of factors have been found to influence attitudes in general. For example, Giallo and Little [7] carried out a study in Australia with graduate and student teachers in order to assess the differences in self-efficacy in behavior management between training. Attitudes were found to not only be influenced by the belief that a particular action will lead to desirable outcomes but also by the belief that one has the ability to perform that action. According to Mwamwenda [10], a person’s self-efficacy is a guide to their personality in terms of their own feelings, attitudes, psychological health and the way they are likely to interact with other individuals in their environment. Therefore students with a positive self-efficacy are better
inclined to improve their performance compared to students’ with a negative self-efficacy of ability. It follows that the enhancement of positive self-efficacy of ability of students’ in science will possibly enhance their performance by fostering development of favorable attitudes towards the subject.

Teacher support has also been shown to influence students’ attitudes toward a subject. When students feel that their teachers are supportive, enthusiastic about the subject and content and are willing to help them, they tend to devote more time studying the subject [1]. This is in tandem with Fraser’s [11] assertion that students’ positive attitudes are correlated to teachers’ support, interest, innovative pedagogical approaches and the opportunity to involve students in their learning. A study by Malusi [12] established that left-handed students appreciate teachers’ support more compared to support from their peers, especially during laboratory sessions when they get help in order to cope with instructional resources in these laboratories.

**Learners’ Attitude towards Chemistry**

The interest of earlier studies has been focused on the intervening factors between subject grade level and performance in science-related attitudes [13]. The world over, there has been an interest in the development of positive attitudes among students towards learning school science [14] and the objective of any science curriculum would include fostering favorable feelings towards learning of science as well as imparting cognitive knowledge. This is because attitudes associated with science appear to affect students’ participation in science subjects as well as impacts in science [15]. Across the years of secondary schooling when science is a compulsory subject, research studies from a range of countries show a decline in students’ positive attitudes towards school science [see 16, 17, 18, 12]. It has been established that the prevailing factor that affects students’ willingness to study further chemistry is a negative attitude towards it [19].
Interest has long been recognized as an important motivator of learning [20]. In the recent past, research has however reported a trend of declining interest in science among young students across grades, suggesting that school science has not effectively fostered student interest [21]. For example, Belge-Can [19] in his study that investigated the effect of grade level on high school students’ attitudes toward chemistry across grades in Turkey found that student’ attitudes change across grade levels in terms of both “enjoyment of chemistry” and “importance of chemistry” constructs. This finding suggests that if students are given an opportunity to connect the importance of chemistry to their future lives then, even those with low expectations can still perform in chemistry. This is in agreement with Schwartz-Bloom, Halpin and Reiter [22] claim that “… when students with relatively low expectations for success in science are asked to connect the relevance of their science topics in class to their lives, they display more interest and perform better in science” (p. 744).

Teaching and learning of science involves laboratory sessions. Here, students undertake practical work in order to obtain laboratory skills such as the manipulation of equipment for the collection and interpretation of experimental data. Attitudes are inevitably formed during such laboratory sessions. The relationship between laboratory work and attitudes was scrutinized by Kurbanoglu and Akin [21] in a study that examined the relationships between chemistry laboratory anxiety, chemistry attitudes and self-efficacy among Turkish university students. There were three hundred and ninety five students (236 females and 159 males; m=20.9 years) in the study. Findings revealed that self-efficacy directly affects chemistry laboratory anxiety and attitudes and students low in self-efficacy are more vulnerable to chemistry laboratory anxiety and negative chemistry attitudes. This means that learners may effectively belief that they can undertake a task according to the specifications laid down in the given time frame. But according
to Millar [23], a persistent failure to meet expectation despite learners’ capability to do a task leads to low self-esteem and eventually a negative attitude towards the subject is developed.

The significance of gender and learning school science has also elicited interest in earlier studies. In a study by Barmao [14] that sought to determine the differences in performance between boys and girls in secondary school science subjects, participants included 300 form three boys and girls from a cross-section of schools in Kenya. Findings showed that fewer girls compared to boys excel in science while majority of them underachieve. It was also shown by Karanja [24] that fewer girls than boys continue with the study of science and related courses at higher levels of education and that girls are underrepresented in areas requiring certain qualification in sciences in Kenya. In their study, Inzahuli, Elizabeth and Lazarus [25] sought to determine the gender disparities in self-efficacy, attitude and perception in Physics and Chemistry among high school boys and girls. Findings revealed that boys reflected better academic achievement compared to girls in both Physics and Chemistry. The boys and girls had comparable self-efficacy in Physics but girls had a higher self-efficacy in Chemistry than the boys. This may suggest that self-efficacy does not influence performance in Chemistry since boys outshone girls in spite of the girls’ higher self-efficacy.

Further afield, studies that have investigated gender differences in students’ attitudes toward chemistry courses have shown similar trends. A quantitative study by Cheung [26] examined the interaction effect between grade level and gender with respect to students' attitudes toward chemistry lessons in secondary school. There were 954 students of chemistry (ages 16 to 19 years) from a wide spectrum of socio-economic backgrounds with a large diversity in intellectual ability in Hong Kong. Findings indicated that the interaction effect between grade level and gender on students' attitudes toward chemistry lessons was statistically significant.
Male students in the study liked chemistry theory lessons more than their female counterparts, a liking that declined when the students progressed across the grades. Overall, all participants were just marginally positive about chemistry lessons during the years of secondary schooling.

High school chemistry is a highly interactive subject that requires the manipulation of apparatus in the laboratory. A cross-section of researchers have established that learners across all ages have negative attitudes towards chemistry. For example, a study on gender differences in secondary school in Israel by Hofstein et al., [16] on 11th and 12th graders revealed that girls had a more favorable attitude towards studying chemistry than did boys. In Australia Shannon, Sleet and Stem [27] reported that girls found chemistry more enjoyable than did boys. Contrary to these studies, Menis [28] in USA, Harvy and Stable [29] in the UK and Barnes, McInernery and Mash [30] in Australia revealed that boys’ attitudes towards chemistry was more positive than that of girls. Elsewhere, learners from other countries for example, Turkey [17, 21], Nigeria [18] and Greece [13] all yielded similar results, that is, boys possess more positive attitudes towards chemistry compared to girls. Kurbanoglu and Akin [21] further established that there is a positive relationship between chemistry laboratory anxiety, attitudes towards chemistry and self-efficacy. The inconsistencies seen in their studies are related to the type of measure used by the researchers, the nature of the content and the chemistry curriculum, the instructional techniques often used in the chemistry classrooms, and the students’ grade-level [31].

**How Students Learn Chemistry**

Chemistry learning is a highly interactive activity. Students not only interact with the subject content cognitively (minds-on) but also through practical work (hands-on) during laboratory experiments. The cognitive information processing (CIP) theory opines that learners can only process a few pieces of information at any one given time [32, 33]. Depending on the
level of processing and the attention paid to it, information proceeds to the sensory memory, working memory (WM), short-term memory (STM) and long-term memory (LTM) [34]. For information to be registered in these memory stores it must be attended to and any information that is not paid attention to is lost [34].

The STM store receives information from the environment for processing. It also receives the retrieved information from the LTM to facilitate the execution of a function. However, the STM store has a limited information storage capacity of 7±2 items without rehearsal [33] implying that an individual must chunk information that contains more than 7 items to avoid losing it. The problem is that chunking ought to be done according to some kind of logic to facilitate effective storage yet during learning the learner may not have the luxury of time to devise the logic for chunking.

When the quantity of information is large, cognitive overload arises. As outlined by Sweller’s [32] cognitive load theory (CLT), learning content comes with different types of cognitive loads vis a vis intrinsic, germane and extrinsic loads [32]. Intrinsic load constitutes intended information for processing, germane load constitutes the instructions that accompany the information such as the objective for processing it and how it should be processed while extrinsic load constitutes the noise in the information (Sweller, 1988). In other words, extrinsic load tends to create unnecessary competition for the cognitive resources during information processing.

In most cases, information is first processed by the STM in order to be stored in long-term storage [34]. Yet with the STM’s limited capacity [33], the unnecessary cognitive load such as the extrinsic load may become a hindrance to the effective processing of the intended information [32]. Any information overload will therefore most likely lead to loss of information.
or difficulties at processing it for storage in the LTM. Failure to store such information in the long-term store (the permanent storage of information) means that the learner will most likely have limited resources for retrieval [32].

This overload will also influence the retrieval of whatever information is stored in the LTM because the WM which is largely useful with regard to retrieval functions also has a limited capacity similar to that of the STM [35]. This means that information from the LTM is briefly held there as the STM processes the incoming information in the central processing unit which is the link between incoming information from the environment and that from the LTM. In case the WM and STM are both overloaded, there is a high likelihood for the processor to get a wrong interpretation of the stimulus due to limited information.

To avoid overloading the memory and hence hindering proper information processing, the mind has adopted the process of automating procedural knowledge. Once automated, this knowledge is simply processed unconsciously while attention is focused on processing information in the incoming stimulus for storage and accurate interpretation [36]. This might not be the case where the STM is overloaded by processing information that ought to have been automated and therefore unconsciously processed. In order to effectively process the large amounts of information that are associated with practical work, it is necessary that some of the knowledge and skill is automated [37, 38]. This automatization frees cognitive resources from being overloaded [see 37] and the learner can then handle information that requires conscious efforts effectively.

Needless to say, during teaching and learning, all individual differences need to be understood and factored in because in most classrooms, they not only exist, they affect learning. In tandem with the Education For All (EFA) goals and the Convention for the Rights of the
Child Article 3 (1) [39] which reads in part “… the best interests of the child shall be a primary consideration” (p. 2), it is the right of every child to be treated fairly in educational settings despite their unique needs. This includes paying particular attention to left-handed students who have to handle instructional resources meant for right-handed learners and at the same time reach their threshold.

The Chemistry laboratory: A unique learning environment

Laboratory activities have long played a distinctive and central role in the science curriculum and science educators have suggested that many benefits accrue from engaging students in science laboratory activities [40-44]. More specifically, they suggested that when properly developed, designed, and structured, laboratory-centered science curricula have the potential to enhance students’ meaningful learning, conceptual understanding and their understanding of the nature of science.

Literature has shown a clear correlation between students’ attitudes towards learning science and various modes of instruction in the science laboratory [6]. In a literature review by Hofstein and Lunetta [40, 43], it was reported that students enjoy laboratory work in some courses and that laboratory experiences result in positive and improved attitudes and interest in science. It was also reported that chemistry students found personal laboratory work (hands-on) as the most effective instructional method that they experienced for promoting their interest in learning chemistry when contrasted with group discussion, teacher’s demonstrations, filmed experiments, and teacher’s whole-class frontal lectures [45]. Further, a greater degree of participation in laboratory work may produce more positive attitudes towards the laboratory work [46]. On the other hand, Milner, Hofstein and Ben-Zvi [47] found that students’ enrollment in post-compulsory courses in high-school chemistry was due to students’ ability to participate in
practical activities in the chemistry laboratory thereby gaining valuable experiences. Therefore the decision to study (or not study) optional subjects e.g., chemistry is a partial attitudinal indication [6].

**How Left-Handed Students Learn in the School Laboratory**

The aspect of handedness is very important to the manipulation of instructional resources during timed tasks. To find out the effect of handedness in carrying out a bimanual coordination test, Ruecker and Brinkman [48] sampled 13 left-handers (8 women and 5 men, mean age = 27.8 years) and 15 right-handers (9 women and 6 men, mean age = 28.7 years) for their study. Participants were required to draw lines at various angles on an Etch-a-line by simultaneously manipulating two knobs, one on the left, which moved the cursor horizontally, and another on the right that moved it vertically. The angle at which they were to draw the line was indicated by parallel guidelines drawn on a transparency overlaid on the Etch-a-sketch.

The task involved turning the left and right knobs at an equal rate while drawing $45^0$ and $135^0$ lines. For $22.5^0$ and $157.5^0$ angles, participants had to turn the left hand twice as fast as the right. For $67.5^0$ and $112.5^0$ angles, participants were to turn the right hand faster than the left. For the leftward oriented lines ($x > 90^0$), the left hand was to be turned counter-clockwise and the right hand clockwise. For the rightward oriented lines ($x < 90^0$) both hands were to be turned clockwise. Each participant was allowed two trials for each angle. For one trial, they could see the line as it was drawn while for the other, a barrier was placed over the screen after half the line had been drawn. Participants were required to continue drawing without seeing the line. In-sight trials always preceded out-of-sight trials.

Results indicated a main effect of handedness; for lines not within the guidelines, left-handers made more errors than right-handers (left-handers’ mean =0.86 inches, right-handers’
There was a main effect of angle that was modified by handedness by angle interaction. Left-handers were slower than right-handers for lines oriented at 22.5°, 45° and 67.5°. These were the lines which required clockwise turning by both hands. The 67.5° line also required that the right hand turns faster than the left.

The conclusion was that left-handers have trouble coordinating the movement of the right and left hands. The researchers suggested that the anterior callosum found in left-handers may reflect the additional processing load required in some left-handers when motor programming does not take place in the hemisphere controlling the movement. Due to this predisposition of left-handers, the struggle with teaching/learning instructional resources during manipulation of the same in timed task settings may result in frustrations and a probable negative attitude towards the task and/or the subject.

In another study whose aim was to determine the categorical differences inherent between right and left-handed individuals and how they affect the way they learn, Parish [49] sought to ascertain whether left-and right-handers can learn a skill effectively when seeing a demonstration from an opposite handed instructor. The task involved demonstrating a lacrosse\(^1\) shot to the participants (69 college-aged students), equally split between male and female, left- and right-handed. Half of each group saw a left-handed demonstration and the other half saw a right-handed demonstration. Participants were assessed on target accuracy and four components of shot form. Left-handers performed significantly better compared to right-handers on target accuracy (F (3, 68) =4.38, p=.007), shot form (F (3, 68) =2.87, p=.043) and body positioning (F (3, 68) =4.51, p=.006). Parish concluded that left-handed college students appeared better able

\(^1\)Goal game in which players use a triangular-headed long-handled stick with a mesh pouch for catching, carrying, and throwing the ball.
to collect important information from an opposite-handed demonstration, an attribute that lacked in right-handers.

Demonstration as a teaching methodology and as it applies to the acquisition of gross motor skills has become a central teaching template for instruction [49]. In as far as watching an opposite handed demonstration in the school laboratory is concerned, a study by Malusi [12] established that left-handed high school students (17-19 years) preferred watching a demonstration from the same side as their right-handed teacher. This, the learners argued, made them ‘understand and follow demonstrations with ease’.

This far it appears that paying the desirable attention by younger left-handers during a right handed demonstration may not be enough. This is because most of the time is spend reversing instructions and observing procedures [50]. As a consequence therefore, the effective creation of mental images and motor learning may not occur due to increased information processing required. Essentially, this leads to failure to store the required information in the memory stores effectively. Mental imaging and continuity for future attempts to reproduce and perform the observed skill does not happen as well because most of the incoming information is lost. The additional processing load has been taken to be responsible for the increased cognitive load (CL) that left-handed learners have to deal with during learning [48].

A theoretical case was advanced by Rouet [51] that given a specific task and specific materials, CL is obviously subject to variations as a function of learner characteristics, such as their memory capacity and the interacting elements. For example during learning, students are sometimes faced with the task of understanding some intellectually difficult material that requires considerable time, effort and thought. The learner has to engage certain mental processes and instructional procedures and designs that would best facilitate the learning which,
according to Pollock, Chandler and Sweller [52] in order to facilitate understanding they tend to incorporate all the information elements required for understanding in the instructions. Frequently, these types of instructions may overwhelm a learner’s limited WM and hinder effective learning.

Why Mismatch of Resources Affects Self-Efficacy Belief in Chemistry Learning

Numerous studies have been carried out in the context of attitudes and mismatches in the learning of science. It has been established that students subsequently develop negative attitudes towards science because there is a mismatch in the learning environment. For example, studies by Dhara, Khaspuri, and Sau [53], Parish [49] and Malusi [12] showed that mismatches experienced in learning environments have a negative effect on learning outcomes. Ruecker and Brinkman [48] found that left-handers have difficulties coordinating the movement of the right and left hands simultaneously, especially in tasks that require clockwise turning by both hands.

More often than not, when left-handed learners handle and manipulate mismatched resources, instead of deploying the cognitive resources to consciously process the information that is supposed to be learned such as the task at hand, the learners’ efforts will be directed to processing extrinsic load generated by consciously processing what ought to be unconsciously executed. As a result, the intended content for learning will not be effectively processed for storage in the LTM for future retrieval in response to new situations [32, 35]. The failure to process and retrieve the required information effectively may lead to the development of negative attitudes about their abilities.

On the other hand, the persistent failure to effectively manipulate instructional resources that front challenges to left-handers because they are mismatched to their physiology can lead to a ripple effect that changes the way in which the learners interact with laboratory apparatus. This
also causes lowered self esteem which may lead to the development of negative attitude toward laboratory tasks and the subject, eventually making the learner to harbour unfavorable attitudes towards chemistry and thereby affecting their academic achievement.

THE KENYAN CHEMISTRY CURRICULUM

The educational system in Kenya includes three years of early childhood, eight years of primary school, four years of secondary school and a minimum of four years of university education, hence the 8-4-4 system of education. Primary school constitutes the cycle of compulsory free education. All learners study chemistry under the combined science discipline, taught everyday for 35 minutes. In secondary school, chemistry is taught for four 40 minute periods per week in junior high school (form one and two) and five 40 minute periods per week in senior high school (form three and four). Students wishing to take up advanced chemistry courses at the university after form four must attain 10 points on a 12-point scale to get admission in the public universities.

In the first year of junior high school, chemistry curriculum follows a macroscopic to microscopic approach. This approach refers to instructional methods that use examples of real-world or demonstrations to introduce chemistry topics followed by microscopic explanations using two-dimensional drawings of dots and circles to represent atoms, ions, and molecules [54, 55]. Chemical symbols are introduced as the language of chemical communication. Students are only asked to recognize the chemical symbols of the first twenty elements of the periodic table. For example, students recognize the symbol “H₂O” and “MgO” as the chemical way of writing “water” and “magnesium oxide” respectively. In the second year of junior school, students are taught how to balance simple chemical equations.
In senior school, chemistry curriculum emphasizes a linear development of chemical concepts with a symbolic approach. This refers to instructional methods that start from subjects that introduce first basic theoretical concepts of atomic theory and bonding on the microscopic level and proceed to subjects focusing on the macroscopic level [54]. Symbolic approach refers to instructional methods that use chemical and mathematical symbols and equations to represent matter [55]. Students use chemical symbols to describe a chemical process as well as to extract the qualitative and quantitative information provided by a chemical formula.

The curriculum in Kenya is centralized in that the government not only determines the national curriculum standards and content, but also centralizes the textbooks, the teaching materials, and the pace of teaching. All schools in Kenya that offer the 8-4-4 system of education must follow the same curriculum and use the same educational materials authorized by the Ministry of Education. Laboratory chemistry courses are also included in the curriculum.

The end of form four chemistry examinations comprises of two paper/pencil theory papers and a practical paper coded 233. Paper 1 (233/1) is a short answer paper/pencil, usually marked out of 80 marks and lasts 2 hours. Paper 2 (233/2) is a long answer paper/pencil, consisting of 8 questions each of 10 marks and lasts 2 hours too. The practical paper (233/3) on the other hand is marked out of 40 and lasts 2 hours, 15 minutes. The 15 minutes provided by the examining body, Kenya National Examination Council (KNEC) is used making sure that the provided requirements are adequate and in perfect working order before the examination starts (KCSE Exam Timetable, Instructions & Guidelines).

During timed laboratory sessions, the practice in Kenya is that the working station is prearranged for task takers. This prior arrangement is done with right-handers who constitute about 90% of any random sample in mind [56]. Therefore, left-handed learners have to
consciously make adjustments during handling and manipulation of some selected instructional resources during such sessions. Sometimes they have to change positions and/or rearrange the resources in order to comfortably take the task. No extra time is allowed for these adjustments yet they eat into task time [12]. This disadvantage increases extrinsic cognitive load for left-handed learners.

In Kenya like in many other parts of the world, left-handedness has never been regarded as a special learning need. In that case, all students are exposed to the same instructional resources despite the fact that 10% of any randomly sampled population is left-handed [56]. It therefore follows that there is a mismatch between instructional resources and learners physiology. Since this mismatch has theoretically been shown to impact attitude elsewhere, it was on this backdrop that this study was premised. The study aimed at investigating attitudes toward chemistry among left-handed high school students in Kenya. By “attitudes toward chemistry” the researcher refers to positive or negative set of beliefs towards chemistry. In particular, the study intended to investigate whether the use of right handed instructional resources influences left-handers’ attitude towards the learning of high school chemistry.

**METHODOLOGY**

This section covers the research design, sample and sampling procedures, instrumentation and data collection procedures. Data analysis procedures, ethical considerations and study limitations are also discussed.

**Research Design**

This was a comparative case study that assumed a mixed methods concurrent triangulation design [57]. This method was preferred because in the recent past there has been an
ongoing debate concerning limitations of educational research due to traditional reliance on a single research paradigm [58]. Mixed methods model generally uses separate quantitative and qualitative methods as a means to offset the weaknesses inherent within one method with the strengths of the other [57]. Benefits associated with the use of mixed methods approach include; triangulation of findings, (enhancing the validity or credibility of findings), facilitation (using results of one method to help develop the instrumentation for another), and complementarity (extending the comprehensiveness of findings) [59, 60]. Generally, one of the two approaches dominates and the other is secondary and supplements it. Integrating social science disciplines with quantitative and qualitative approaches in the research process [57] strengthened the reliability of data, validity of the findings and recommendations, as well as broadening and deepening the understanding of study questions [59].

Comparative case study approach seeks to establish the comparability of two different sets of data over the same dependent variable and therefore the need for control is high just as it may be expected of an experimental procedure. For the current study, comparability of the cases was determined on the basis of the factors that the theory and literature review had been established as being capable of influencing the findings. These include learner’s age, teaching/learning experiences and gender. This ensured that the only attribute that was likely to influence the learners learning outcomes and attitude towards chemistry was their handedness. At the same time, it was assumed that this was the single most attribute that was likely to cause the difference in the results observed about attitudes towards chemistry. Additionally, if case findings indicated that handedness did not necessarily affect attitude, then the researcher had the opportunity to extent her investigation to other variables of comparability.
One of the challenges any researcher will face in applying case study is in the selection of samples. This is because the universe of the cases to be sampled is usually unknown. Therefore, procedures such as random sampling techniques were automatically ruled out. Since the researcher intended to identify participants that differed on handedness, which was the attribute hypothesized to influence the attitudes toward chemistry, it demanded that she had to engage a sample selection procedure that ensured comparable distribution of both left- and right-handed participants.

**Sample and Sampling Procedures**

The target population for this study was fourth form students (ages 17-19 years) enrolled and registered for chemistry in the Kenyan Certificate for Secondary Education (KCSE) examinations. For the purpose of comparability, the students in this population were comparable across parameters such as cognitive ability in chemistry, age, experiences and prior knowledge. This was mainly because the students were selected according to certain criteria to join secondary schools.

The population was stratified according to male/female, left-/right-handed students of chemistry. For purposes of comparability, the sample constituted an equal number of right-handed and left-handed male and female students of chemistry. The number of left-handed, both male and female determined the number of their right-handed counterparts selected for the study. Participant teacher(s) constituted the students’ teachers of chemistry.

All left-handers were purposively sampled. Right-handers for the survey were randomly sampled while the matched random sampling procedure based on students’ performance in chemistry was used to select those who participated in the focus group discussions (FDG). The procedure for matched random sampling was applied where two samples in which the members
are clearly paired and matched according to a known construct in this case performance in chemistry. For the quantitative sample, a multistage sampling was used. In this case left-handers were purposively sampled while right-handers were systematically sampled.

Participants for the qualitative data were drawn from form four only. This was because the FGD questions sought to find out the students' experiences when they were carrying out individual tasks in the chemistry laboratory, an exercise some form three students may not have been exposed to by the time of collecting this data. Quantitative data was collected from the whole sample while qualitative data was collected from participants drawn from the co-educational school. For the qualitative data, the participating school was a co-educational national school conveniently selected for its large population of both male and female students who had already been exposed to the same context and as well taught by the same teacher(s) of chemistry.

Participants for the quantitative data were drawn from form three and four (ages 16-19 years). This was because the survey questions required participants to respond to questions on attitude and the ease of use of some selected instructional resources in the chemistry laboratory. The assumption was that the students had been exposed to those apparatus by the time of data collection. For the quantitative data, a further four schools were sampled and comprised of two girls’ only and two boys’ only schools. There were 4 unisex schools selected in and around Kiambu and Nairobi Counties and 1 co-educational school from Nakuru County and a teacher of chemistry from each school. In total there were 5 teachers and 145 student participants segregated into males (59) and females (86), left-handed (72) and right-handed (73).

\[2\] National co-educational secondary schools are known to have large student populations
INSTRUMENTATION AND DATA COLLECTION PROCEDURES

Both qualitative and quantitative data was collected for this mixed methods study. The quantitative data was collected by use of questionnaires in order to measure amounts of behavior, by assigning numeric values to what was being measured (the quantity). The qualitative data that usually results in descriptive data measured behavior (the quality) and was collected through a focus group discussion (FDG) with participants from the co-educational school. In total there were 12 participants for qualitative data (3 left-handed males, 3 right-handed males, 3 left-handed females and 3 right-handed females). Participants were coded L1, L2… L6 for the left-handed and R1, R2 … R6 for the right-handed.

Questionnaires

This self administered quantitative data tool was based upon validated open- and close-ended items, where rating scales and behavioral responses were collected. The questionnaires were given through hand delivery to the teachers of chemistry in the selected schools. The filled questionnaires were then collected one week later from the schools by the researcher. The participants in the qualitative research school filled the 20-25 minutes long questionnaire before the focus group discussion to avoid biases. The questionnaire was divided into four sections and had both open- and close-ended questions.

- Section one had 30 items each on attitudes and performance in chemistry. Each item was rated on a 5-point Likert type scale {from 1=strongly disagree (SA), 2=agree (A), 3=not sure (NS), 4=disagree (D) and 5=strongly agree (SD)}. Higher scores indicate higher positive attitudes towards chemistry.

- Section two had four items on completing timed tasks, attitudes and interaction with apparatus in the laboratory. Each item was rated on a 4-point Likert type scale (from
always, often, sometimes and rarely). The study participants were required to tick in the provided spaces then qualify their responses.

- Section three had 3 items each on experiences in the chemistry laboratory while section four had a list of commonly used (practiced) apparatus (activities) during practical sessions. The participants were required to rate them in terms of ease of use. The items had a 4-point Likert type scale (from very easy to use to very difficult to use). Participants were required to tick in the spaces provided then qualify their responses.

**Focus Group Discussion Schedules**

A focus group discussion with participants form the co-ed school to fill the gaps and points of concern form the survey was carried out. The researcher necessitated the identification of personal values, assumptions and biases at the outset of the study. The discussion guide included unstructured open-ended questions intended to elicit views and opinions on attitudes towards chemistry and effectiveness of learning institutions in meeting left-handers’ needs, laboratory work. Participants also responded to questions on their experiences when undertaking timed tasks in chemistry. The responses were audio taped and notes taken.

**Data Analysis Procedures**

This procedure involved preparing collected data for analysis, moving deeper and deeper into understanding, representing and making sense of the data [57]. Quantitative and qualitative data were typically merged together in the interpretation stage in order to facilitate integrating them during analysis. The concurrent triangular design convergence model [61] was used to compare, validate, confirm and collaborate quantitative results and qualitative findings so as to end up with valid and well-substantiated conclusions about left-handers’ attitudes towards
chemistry [57]. The rationale for this approach was that it became easier for the researcher to qualify and compare quantitative data themes from the qualitative database [57].

**Ethical Considerations**

Confidentiality and anonymity of participants were offered prior to all data collection. However, teachers may be able to identify one another in the study and in some cases, the identity of the school may be apparent to readers in the local service. Furthermore, individual students who were interviewed were identified by their teachers, possibly introducing biased selection criteria of which the researcher would not be aware. It is difficult to assess whether students were willingly included or excluded in the study. Participating schools were informed of the aim of the research from the outset; investigation of the attitudes toward chemistry among left-handed high school students.

**RESULTS AND DISCUSSION**

This study sought to find out what effect the use of right-handed instructional resources had on left-handers’ attitude towards chemistry learning. There were 145 student participants and five teachers of chemistry from the five study schools.

The sample for this study was derived from a few schools (5), which may not be entirely representative of all schools in Kenya. Secondly, attitudes were not observed directly. Instead they were gathered as self-reports through the survey and the FGD with a small sample, which can lend itself to perceptual bias and possibly threaten, to some extent, the validity of the data. And lastly, the sample was unbalanced in terms of proportionality between sub-samples of left-handers, right-handers, males and females, which may have influenced, at some level, the response data gathered.
All the participants filled a self administered questionnaire that had items on perceptions towards chemistry learning. To triangulate the data further, an FDG was conducted with a mixed gender/handedness group. Collected data was broken into broad categories for analytical purposes. It was then prepared for analysis through coding. Editing and cleaning of collected data preceded analysis. Qualitative data was analyzed using descriptive statistics while quantitative data was analyzed using SPSS.

**Students’ Attitudes towards Chemistry**

All participants in the study were enrolled in chemistry as an examinable subject by KNEC. While some students choose to drop chemistry after junior high school in Kenya, the researcher chose to find out the reasons these participants opted to take chemistry in senior high school. It emerged that subject choices were influenced by participants’ parents/guardians and role models as well as science related future careers. Other students said that their decision to take chemistry was based on the subject being compulsory in their school, an indication that some students take chemistry to satisfy educational requirements.

Enrollment in chemistry is an indication that students were interested in the subject. According to Osborne, Simon and Collins [62], students’ enrollment in the various scientific (non-compulsory) subjects suggested that the subject is a significant indicator of students’ interest at the school level, especially in the post-compulsory phase of schooling. However, they pointed out that it would be erroneous to use enrollment as the sole measure of attitudes and interest in sciences. Regarding studying chemistry for future career and employment in sciences, research has failed to show a clear alignment between students’ attitudes towards sciences and choosing future careers in sciences [63].
On another note, 3 out of 12 (25%) participants chose to pursue chemistry because of their teachers’ influence on them. Participants described their teachers of chemistry as being cheerful, sympathetic, well prepared and passionate about chemistry. These teachers also varied their pedagogical approaches. Since teacher attributes were said to have enhanced students “liking” or “disliking” of chemistry, the teacher is therefore a factor in influencing student’s attitudes towards chemistry. When students view a teacher as being motivated (de-motivated), there is a feeling that the teacher will most probably also motivate (de-motivate) learners in the subject. For example, one female left-handed participant, L3 said;

> I chose to do chemistry and biology because the teacher was very motivated and possessed good teaching skills. The teacher of physics was quite tough so I disliked physics and dropped it after form two.

On varied pedagogical approaches, L5, a male left-handed participant claimed that chemistry practicals are interesting because …;

> … it breaks the monotony of seeing teachers in front of you speaking all the time. It involves activities that make one actively involved in their own learning. It makes me understand better.

Another 25% (3 out of 12) students also came out strongly against the subject. They had varying reasons for their attitudes. They expressed misgivings about some of their teachers. Such teachers were described as boring, rushing through their work and mostly not helping left-handers to cope with ‘unfriendly’ instructional resources. One left-handed male (L4) said;

> Sometimes the teacher does not seem to know what they are talking about let alone knowing that I need help with fixing the burette and operating the three way pipette filler. I ask my friend to help me because he seems to understand me better.
Research has shown that initial teacher training institutions do not train teachers on how to handle left-handed learners effectively in the classroom. This is because left-handedness has not been regarded as a special learning need in Kenya and elsewhere in the world [64]. However, it was established that out of their own volition, some teachers are warming up to the plight of left-handed students and are willing to give the attention and help these students require [12].

While students view teachers as playing pivotal roles in their choosing to take chemistry in senior high school, the aspect of future aspirations appeared to also influence subject choices and combinations. This is despite the curriculum and pedagogical approaches to teaching and learning of chemistry being important. It has been shown that students will choose to continue studying science if their teachers demonstrate personal interest in the students, support them and deliver the lesson with an encouraging attitude [11, 65, 66].

Findings showed a significant relationship between participants’ handedness and their reasons for finding chemistry interesting ($\chi^2 = 20.56, 6, p \leq 0.05$, two tailed). While students appreciate hands-on activities because they authenticate theory lessons [45], left-handers seemed to experience obstacles such as manipulating and handling selected instructional resources during the practical lessons compared to right-handers who comparably showed appreciation for accuracy in practical work. An equal number of left- and right-handers (12 each) said they found chemistry practicals interesting because it gave them an opportunity to be in charge of their own learning. There were more right-handers claiming that a mixture of theory lessons with practical sessions (57% of 23 participants), less obstacles experienced during task taking (59% of 17 participants) and accuracy in carrying out tasks and cognitive intelligence involved in doing mathematical calculations in chemistry was their main reasons for finding chemistry interesting (71% of 21 participants) (Table 1 below).
Findings revealed that most students felt practical work was not only exposing and preparing them for further chemistry but that it also accorded them opportunities to be in control of their learning. L3, a female left-handed participant said;

… chemistry practicals give one a sense of responsibility and maturity because when you are undertaking the task you have nobody else to look up to but yourself

Out of the twelve participants who participated in the FGD, two (2) of them appreciated the importance of Chemistry for their future careers. They said that they liked the subject because of its practical nature. For example L5, a left-handed male participant said;

with practical work comes exposure to chemistry and this gives someone the syke (zeal) to continue further chemistry

Interest in chemistry for future career was an encouraging revelation because Chemistry is increasingly becoming an opening to a number of key careers [67]. According to Fairbrother [68], students will learn only if there is a motivation to learn. When students are motivated by relevance and future careers in chemistry, they will approach the subject context with the right attitude. It has been opined by Simpson and Troost [69] that students would be more committed to science when they want to take more science courses and continue reading about science. Therefore, students who were of the view that chemistry syllabus was more “friendly” compared to other sciences would be more committed to the subject.
Table 1: Participants’ handedness and why chemistry practicals are interesting

<table>
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<tr>
<th>Participant's active hand</th>
<th>Reason why chemistry practical lessons are interesting</th>
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<tr>
<td></td>
<td>Active participation than in theory</td>
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<tr>
<td>Right</td>
<td>Frequency</td>
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<td></td>
<td>% within participant's active hand</td>
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<td>% within reason why chemistry practical lessons are interesting</td>
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Eight of twelve participants (75%) claimed that chemistry syllabus was “friendlier” compared to that of both Biology and Physics. The reasons given ranged from the relationship between chemistry and these other science subjects, the syllabus generally and specifically the way the topics are arranged as well as the relationship between themes in the topics across the subjects. One female left-handed participant (L2) said;

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Chemistry is related to all other sciences (biology, physics, mathematics) hence easy to manage (understand)
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While a left-handed male (L6) claimed;

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…chemistry ni kujirudiarudia (pause)….. The same concepts we started with in form one keep growing in depth and width as one approaches fourth form therefore making it less complex
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L5, a male left-handed participant argued that;

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…..the chemistry syllabus is less and (it is) more manageable because it grows in a repetitive and spiral way. The relationships in the topics are also more pronounced compared to those in (pause) for example biology where one day you are learning something in animals and the other day you are doing something in plants and the whole thing is quite confusing to me
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The chemistry syllabus being repetitive in a spiral way means students are able to easily make connections between the concepts more meaningfully and deeply [6]. As the concepts make more sense, chemistry becomes more relevant and meaningful to the students. When students feel that they are familiar with concepts from their previous studies, and feel confident enough to explain them, it positively affects their motivation and achievements and therefore they develop the right attitudes towards learning the subject.

A significant relationship was found between handedness and chemistry being difficult and time consuming ($\chi^2 = 13.38$, 4, $p \leq 0.05$, two tailed). Out of 145 participants, 27 (19%) of
them strongly agreed that chemistry was difficult and time consuming. Twenty two (82%) of these participants were right handed and the rest (5) were left-handed (Table 2). An almost equal number (49% right-handed and 51% left-handed) of participants disagreed that chemistry was difficult and time consuming while slightly more left-handers than right-handers strongly disagreed that chemistry was difficult and time consuming (59% and 41% respectively).

Table 2: Participants’ handedness and whether chemistry is difficult compared to other sciences

<table>
<thead>
<tr>
<th>Participant's active hand</th>
<th>Frequency</th>
<th>% within participant's active hand</th>
<th>% within chemistry is more difficult &amp; time consuming compared to other sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>SA</td>
<td>A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>22</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>30%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>% within chemistry is more difficult &amp; time consuming compared to other sciences</td>
<td>82%</td>
<td>41%</td>
</tr>
<tr>
<td>Left</td>
<td>Frequency</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>7%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>% within chemistry is more difficult &amp; time consuming compared to other sciences</td>
<td>19%</td>
<td>59%</td>
</tr>
<tr>
<td>Total</td>
<td>Frequency</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>19%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>% within chemistry is more difficult &amp; time consuming compared to other sciences</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

In addition, there was a significant relationship between participants’ sex and the perception of chemistry being difficult and time consuming ($\chi^2 = 9.95$, df4, $p \leq 0.05$, two tailed). Out of 86 female participants in the sample, 27 (31%) of them and 22 (37%) out of 59 male participants in the study sample agreed that chemistry was more difficult and time consuming compared to other science subjects. Forty six out of 86 (53%) females compared to 33 out of 59 (56%) males disagreed that chemistry was difficult and time consuming.
About 68% (8 out of 12) of those participants who were interviewed said they found chemistry interesting to learn. The rest (4 out of 12) felt that it was a difficult and time consuming subject. Chemistry being a difficult and time consuming subject was attributed to the content of the subject, the language used and the structure of questions in the assessment of chemistry. One male participant (L4) on the structure of the questions said;

> Some of the apparatus are not easier to use as well as the mole concept questions after the questions. …., the mole concept,… it gets confusing when the calculations which you think are right end up being wrong

A female participant L3, on the language of chemistry said;

> How the examinations are set, it is too complicated and sometimes I fail not because I did not know but because of not using the language of chemistry in answering the exam questions

While L1, a male participant cited the task context as a challenge by saying;

> Sometimes I find it hard to coordinate with all the apparatus that need to be used. Some questions also need a lot of ……, (pause) …., a lot of ……, there is just too much multitasking like in salts, checking the crystal formation, stopping the stopwatch, reading the thermometer and recording all at the same time??

Findings indicated that the reasons for finding chemistry challenging revolved around the subject and the pedagogical approaches teachers used to present content in the classroom. The language in chemistry played a major role with students complaining that they sometimes failed in their examinations because they did not use the right language.

The language of chemistry is one that needs teachers to explain the meaning of the words as used in a chemistry context as opposed to their use in everyday life. It has been suggested by
Gilbert [70] that teachers could select those parts of ‘chemical language’ that are needed for students to grasp the meaning of the chemistry involved in their learning.

Right-handers compared to left-handers felt that chemistry was difficult and time consuming; 53% and 20% respectively. Females more than males also felt that chemistry was more difficult and time consuming. When chemistry is viewed by learners as difficult to understand and time consuming, this is an indication that there is lack of confidence by the students in the subject. The difficulties experienced in grasping the concepts and feelings that chemistry takes students’ time erodes the confidence that they might have in the subject. Since students fail to make connections between the different facts and concepts presented together with their practical applications, the students miss the ‘big picture’ of science and never develop confidence in its relevance. Clearly, all these have potential to influence attitudes and interests.

It has been postulated by Hofstein and Mamlok-Naaman, [6] that relevance, attitudes and interest in the subject are related, that is, if students find the science (in this case chemistry) content that they learn relevant to their daily life and to the society in which they operate, there is a good chance that they will develop positive attitudes towards the subject.

Students Self-Efficacy in Chemistry

As asked to rate their feelings about chemistry tests, there was a significant relationship between handedness of students in the study and feelings of nervousness during chemistry tests ($\chi^2 = 12.872$, 4, $p \leq 0.05$, two tailed). About 60% of the 145 participants agreed that chemistry tests made them nervous. About 76% (22 out of 29) of those who strongly agreed that chemistry tests made them nervous were right-handed while 61% (14 out of 23) of those who strongly disagreed that chemistry tests made them nervous were left-handed. Further and contrary to the
right-handed students who are mostly made nervous by chemistry tests, 68% (21 out of 31) left-handers disagreed that chemistry tests make them nervous (Table 3).

Table 3: Participants’ handedness and participants’ feelings about chemistry tests

<table>
<thead>
<tr>
<th>Participant’s active hand</th>
<th>Chemistry test makes the student nervous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SA</td>
</tr>
<tr>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>22</td>
</tr>
<tr>
<td>% within participant's active hand</td>
<td>30%</td>
</tr>
<tr>
<td>% within chemistry test makes me nervous</td>
<td>76%</td>
</tr>
<tr>
<td>Left</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>7</td>
</tr>
<tr>
<td>% within participant's active hand</td>
<td>10%</td>
</tr>
<tr>
<td>% within chemistry test makes me nervous</td>
<td>24%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>29</td>
</tr>
<tr>
<td>% within participant's active hand</td>
<td>20%</td>
</tr>
<tr>
<td>% within chemistry test makes me nervous</td>
<td>100%</td>
</tr>
</tbody>
</table>

Nervousness during examinations may have contributed to over 60% of the 145 students who participated in this study either disagreeing or strongly disagreeing that given an opportunity they would refrain from taking chemistry in school signifying that, although majority of the participants in this study find chemistry interesting and as an important science subject, there were challenges that hindered their optimum appreciation and performance in the subject.

During the FGD, participants expressed concern that although chemistry was a more manageable science compared to other elective sciences, left-handers felt that they had to put in more work compared to their right-handed peers. One of them said;

*I strongly feel I have to work harder than my right-handed colleagues because I have to take more time ‘getting around the environment’ yet I have to perform well in my exams. The school does not help to ease the situation in any way (L6)*
In terms of the relationship between handedness and participants’ responses on whether they would take chemistry again given another opportunity, a significant relationship existed ($\chi^2 = 9.82, 4, p \leq 0.05,$ two tailed). Out of the total 18 participants who strongly agreed that they would not take chemistry again given another opportunity, 15 (83%) of them were right-handed (Table 4). This finding signifies that left-handed students, indeed, value their time investment in pursuing chemistry in school.

Table 4: Participants’ handedness and whether they would choose take chemistry again if they were given another opportunity

<table>
<thead>
<tr>
<th>Participant's active hand</th>
<th>Given a choice, I would not choose to do chemistry again</th>
<th>SA</th>
<th>A</th>
<th>NS</th>
<th>D</th>
<th>SD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Frequency</td>
<td>15</td>
<td>9</td>
<td>6</td>
<td>14</td>
<td>29</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>21%</td>
<td>12%</td>
<td>8%</td>
<td>19%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>% within given a choice, I would not take chemistry again</td>
<td>83%</td>
<td>41%</td>
<td>40%</td>
<td>44%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Left</td>
<td>Frequency</td>
<td>3</td>
<td>13</td>
<td>9</td>
<td>18</td>
<td>29</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>4%</td>
<td>18%</td>
<td>13%</td>
<td>25%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>% within given a choice, I would not take chemistry again</td>
<td>17%</td>
<td>59%</td>
<td>60%</td>
<td>56%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Total</td>
<td>Frequency</td>
<td>18</td>
<td>22</td>
<td>15</td>
<td>32</td>
<td>58</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>% within participant's active hand</td>
<td>12%</td>
<td>15%</td>
<td>10%</td>
<td>22%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>% within given a choice, I would not take chemistry again</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

About 91% (78 out of 86) females compared to 83% (49 out of 59) males said they found chemistry practicals interesting while 58% (50 out of 86) females compared to 54% (32 out of 59) males claimed that chemistry tests made them nervous. On whether participants thought chemistry was relevant and useful in their future life, more females than males agreed (59% and 44% respectively) that chemistry would be useful for their future.
Findings seem to suggest that left-handed participants in this study had decided to pursue their decision of taking chemistry as an optional subject in senior high school. Despite the challenges experienced in the laboratory while manipulating right handed instructional resources, left-handers appeared more interested in understanding the scientific concepts, and therefore will exhibited more positive attitudes towards science and science studies despite experiencing learning difficulties in the chemistry laboratory. It can therefore be concluded that the challenges left-handed students experience in the chemistry laboratory do not cause them to harbor negative attitudes towards chemistry learning.

**Aspirations for Further Chemistry**

A significant relationship was found between participants’ handedness and their plans not to continue with chemistry after school ($\chi^2 = 11.70$, 4, $p \leq 0.05$, two tailed). Fewer right-handers 42% (31 out of 73) compared to left-handers 39% (28 out of 74) said they would continue with chemistry after high school. Comparably too, there were fewer left-handers 32% (23 out of 72) compared to 45% (33 out of 73) right-handers who agreed that they would not continue with further chemistry after school. On the contrary 70% of the participants who were not sure of their plans to continue with chemistry after high school were left-handed (Table 5).
Table 5: Participants’ handedness and their uptake on Chemistry after high school

<table>
<thead>
<tr>
<th>Participant's active hand</th>
<th>No plan to continue with chemistry after high school</th>
<th>Frequency</th>
<th>SA</th>
<th>A</th>
<th>NS</th>
<th>D</th>
<th>SD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right</strong></td>
<td>% within participant's active hand</td>
<td></td>
<td>24</td>
<td>7</td>
<td>9</td>
<td>15</td>
<td>18</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>% within no plan to continue with chemistry after high school</td>
<td></td>
<td>33%</td>
<td>10%</td>
<td>12%</td>
<td>21%</td>
<td>25%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>% within no plan to continue with chemistry after high school</td>
<td></td>
<td>62%</td>
<td>35%</td>
<td>30%</td>
<td>68%</td>
<td>53%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td>% within participant's active hand</td>
<td></td>
<td>15</td>
<td>13</td>
<td>21</td>
<td>7</td>
<td>16</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>% within no plan to continue with chemistry after high school</td>
<td></td>
<td>21%</td>
<td>18%</td>
<td>29%</td>
<td>10%</td>
<td>22%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>% within no plan to continue with chemistry after high school</td>
<td></td>
<td>39%</td>
<td>65%</td>
<td>70%</td>
<td>32%</td>
<td>47%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>% within participant's active hand</td>
<td></td>
<td>39</td>
<td>20</td>
<td>30</td>
<td>22</td>
<td>34</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>% within no plan to continue with chemistry after high school</td>
<td></td>
<td>27%</td>
<td>14%</td>
<td>21%</td>
<td>15%</td>
<td>23%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Focus group discussions revealed that some of the reasons that participants were against taking further chemistry indicated that continuing with further chemistry was pegged on whether they would make it in the final examination. One female participant L2 said:

*I can only continue with chemistry depending on my performance after fourth form. If it is favorable then I will*

Although left-handers were facing difficulties manipulating instructional resources in the laboratory, there was a mutual feeling that given more time and a fair operating context, they would do much better in their achievement. This was because the time allocated was not enough to do the adjustments with the apparatus and still manage to meet the task requirements on time. The use of mismatched desks, hooking hands wrongly while writing thereby making left-handers get more tired and coping with ‘ungraspable’ instructional resources are some of the reasons that
made left-handed participants request for extra time during practical examinations. On the time allocated to practical work participants said:

- Too much writing makes me tired and uncomfortable. I prefer we were given more time and our work stations arranged with ‘us’ in mind (L3)

- Examinations that require a lot of writing take up too much time and most of the times I do not complete them. The shifting of apparatus during a practical session eats into the task time (L1)

- I get very tired during exams and more so chemistry 233/2. I do not always finish timed exams because some questions require a lot of writing. However, am okay with short answer questions. I find chemistry paper three (233/3) uncomfortable during the session because some of the apparatus give me a hard time (L5)

- Some exams come out badly because of the confusion that comes with using apparatus that feel wrong to work with (L2)

The most effective factor contributing to students’ decisions to study science is their interest in the subject [47]. Left-handed students in this study would not only choose to take high school chemistry again given another opportunity but they were also determined to continue with chemistry after school. This signifies that they had the right attitude toward the subject because they found it relevant. Compared to their right-handed peers, left-handers experienced challenges while using some selected instructional resources in the laboratory. However, this did not deter them from pursuing their dreams of continuing further chemistry and science related careers. Comparably therefore, left-handers are more interested in chemistry than their right-handed peers. This is because as earlier found, many right-handers had said that they took chemistry because their parents wanted them to pursue science related careers while others said that they took chemistry because it was compulsory in their school.
As has been suggested by Gilbert [70], many students who choose to study chemistry to satisfy requirement experience lack of relevance in it and seem to view it in an instrumental way, rather than because it is worthwhile in itself. Considering that discomfort during chemistry laboratory activities is a state occurring in response to situations concerning chemistry tasks which can often create a negative attitude toward the subject [71], the relationships between discomfort in the chemistry laboratory and chemistry attitudes are easily understandable. That is negative attitudes towards chemistry are promoted while positive attitudes are decreased by discomfort during chemistry laboratory practicals. However, did not seem applicable to the left-handers in this study.

Although left-handers experience more than their share of challenges during chemistry practicals, they seemed positive towards the subject as opposed to right-handers whom majority were categorical that they would not take chemistry after senior school. This assertion is in agreement with Salta and Tzougraki [13] that although students believed that the chemistry course was not useful for their future career, they recognized the importance of chemistry in their life. Chemistry attitudes are important factors highly associated with chemistry success and motivation. Students with positive attitudes towards chemistry are more likely to sustain their efforts and have the desire to be involved in learning tasks [21].

CONCLUSION AND RECOMMENDATIONS

This paper has revealed that left-handers harbor more positive attitudes towards chemistry compared to right-handers. Further, female participants appear to have somewhat more positive attitudes towards chemistry compared to males. Students’ lack of interest in chemistry and low self-efficacy during practical work are contributing factors. From the study, it
was apparent that certain content-related pedagogical approaches are more effective than others. More attention should be drawn to the learning context and more specifically the laboratory environment. Based on the study findings, it is clear that girls (as opposed to boys) prefer a more cooperative learning environment as opposed to whole-class learning [72].

Future development in chemistry teaching and learning should pay more attention to mismatches that arise in the classroom, different students’ gender, motivational patterns, and learning styles [73]. This is in fact a call to vary the chemistry classroom learning environment so that it will cater for all learners [74]. Mismatches in the classroom are some of the reasons left-handed learners are unable to reach their threshold during performance of hands-on, minds-on activities. The researcher suggests that chemistry curriculum developers and instructors to factor in the peculiar physiological differences in the case of left-handers, for example allowing more time to make adjustments that would make them comfortable during timed tasks would go a long way in assisting them achieve their learning goals more effectively.

Here the study has examined several areas that can potentially enhance learning science in general and chemistry in particular for left-handed learners. However, there is not a crystal clear picture that informs teachers on how attitudes influence motivation and how motivation influences the learning of chemistry for this particular group of learners [75]. More research is needed in order to advance knowledge regarding attitudes that may have been accumulated thus far.

REFERENCES


SATLC MODEL LESSON FOR TEACHING AND LEARNING COMPLEX ENVIRONMENTAL ISSUES RELATED TO THE THERMODYNAMICS

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ABSTRACT

Environmental chemistry is one of the disciplines of Science. For the goal of the deep learning of the subject, it is indispensable to present perception and models of chemical behavior explicitly. This can be accomplished by giving careful consideration to the development of concepts such that newer approaches are given contemplation, taking in consideration participation of students. Students, well versed in issues which integrate to enhance vital concepts, are thus able to understand nature and help us to discover means to view the impact of industrialization on the well being of mankind. Understanding environmental chemistry needs quality teaching at undergraduate stage of students learning. In the absence of necessary input of biological sciences, mathematics, statistics, along with the parameters of analytical and physical chemistry, students often find environmental chemistry a difficult subject. It is therefore desirable that the practice of disseminating knowledge related to environmental chemistry must avoid the tradition of presenting the necessary information separated from each other. The lectures should be designed in such a way that they provide the complete description of any issue debated in the class room. The students have not to be encouraged to address the issue in a sphere of limited knowledge. It is suggested that the teachers organize their lectures in such a way that the student get involved in the class. This essential scenario can only develop when the knowledge is transferred through Systemic diagrams. Recently concept based teaching methodology; namely systemic approach to teaching and learning chemistry (SATLC) has been employed to highlight the connectivity between some environmental issues and the disciplines of Physical Chemistry. [African Journal of Chemical Education—AJCE 5(2), July 2015]
INTRODUCTION

Numerous strategies have been introduced through which teaching and learning of scientific subjects in general, and chemistry in particular may be made much easier to understand. Several teaching methodologies continue to be reported in literature to illustrate the basics of chemistry in order to enhance its teaching and learning. Recently an inventive way of teaching and learning through systemic approach (SATL) has been familiarized (1-4) for this end. The basic objective of this method is the use of systemic to help students to understand interrelationships of concepts in a greater context, a point of view, once achieved, that ultimately should prove beneficial to the future citizens of a world that is becoming increasingly globalized (3).

Ausable (5) defined meaningful learning as the formulation of non-arbitrary relationships between ideas in the learners' mind. According to Novak (6) meaningful learning means that learners deal with a learning task by attempting to form relationships between newly and previously learned concepts. Michael (7) stated that meaningful learning occurs when the learner interprets, relates, and incorporates new information with existing knowledge and applies the new information to solve novel problems. Whereas concepts pertaining to teaching of some salient issues in physical chemistry have been published recently (8-10), we undertake to present a model SATL lesson that may help to improve the meaningful understanding of some aspects of environmental chemistry.

Environmental change caused by human influences or natural ecological processes. This change undergoes many complex issues related to the kinetic energy of molecules and various thermodynamic parameters.
Temperature has huge impact on our environment, if temperature goes high we feel warm and when it goes down we feel cold. Warmer temperature can be dangerous causing illness such as heat cramps, heat stokes or even death. It also affects the oceans, weather patterns, snow & ice, plants & animals. The warmer it gets the more severe the impacts on environment will be and it will be effected on entropy. It is an irreversible process which occurs due to irreversible phase changes. Greenhouse-gas-induced temperature increase is one of the main reasons of entropy production. These unpredictable changes in climate have led to an increase rate of entropy. Study of the entropy production of the earth’s climate system requires specific regard of the entropy production associated with the irreversible processes of scattering, absorption and emission of radiation. The exchange of radiation between the earth and space define the exchange of entropy between the system and its surroundings. The essence of this exchange is the low-entropy radiation that enters the earth from the sun, and high-entropy radiation that leaves the earth by virtue of the radioactive processes that occur within it.

The relation between altitude and density is a fairly complex exponential that has been determined by measurements in the atmosphere. The heat content or total heat is increasing over time. The increment in total heat of earth atmosphere is causes by energy from sun (which is constant), greenhouse gases which absorb energy and emits radiation to atmosphere and volcanic activity can also cause climate to go hotter. So there is imbalance in energy and heat accumulates on earth’s climate system which causes global warming. A warming planet thus leads to a change in climate in many ways such as ocean acidification i.e., CO2 in the atmosphere dissolves in to ocean by which water becomes acidic also when water is heated it expands and sea level are expected to rise.
Rising sea level also result as glaciers begins to melt and due to increasing heat it is melting at higher rates, this affect the humanity live near the coast or by major areas.

Energy plays an important role in many aspects of our lives. Climate is influenced by natural changes that affect how much solar energy reaches Earth. These changes include changes within the sun and changes in Earth’s orbit. Changes occurring in the sun itself can affect the intensity of the sunlight that reaches Earth’s surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity). The sun follows a natural 11-year cycle of small ups and downs in intensity, but the effect on Earth’s climate is small. \(11\).

**METHODOLOGY**

Understanding environmental chemistry is easier when scientific approach involving chemical and biochemical information is followed. It provides a systemic description of the environment, based upon the energy sources and the involved chemical reactions. Hence transformation of chemical species in the air, soil and water, and the consequence of human activity on these parameters of significant impact on the quality of environment may be easily gauged. Environmental chemistry is an interdisciplinary science that comprises of a systemic approach to atmospheric, aquatic and soil chemistry.

Being a multidisciplinary science, as pointed out earlier, students face obscurity in appreciating correlation between environment and divergent rules that form the basis of current advances in science and technology. In the present lesson we try to highlight environmental issues through systemic diagrams, developed on thermodynamic concepts. These are being presented for developing a deep insight for understanding the relationship between the energy
and environment. In order to understand their connection, student must realize a number of multidisciplinary aspects of the contemporary science.

Understanding relationship between energy and environment is important in our global society. Energy provides the driving force that influences the production and consumption of material resources that improve the standard of living of modern human beings. The dependence of environmental health on a variety of biological, chemical and physical parameters cannot be disregarded. Energy is one of the variables that cause the environment to alter itself for an optimistic effect or pessimistic fallout.

About 75% of the solar energy falling on the earth is absorbed by the earth’s surface, which boosts its temperature. The rest of the heat radiates back to the atmosphere. Some of the heat is trapped by gases such as carbon dioxide, methane, ozone, chlorofluorocarbon compounds (CFCs) and water vapor in the atmosphere. Energy controls the availability or lack of this in compounds in the respective atmosphere. In particular fine particles and ozone are the most pervasive health damaging pollutants that are let loose from the prevalent abuse of the energy resources.

The relationship among various parameters that influence the environmental changes can be better presented via systemic diagrams according to the Scenario of systemic building strategy of teaching units (10 - 11).

So, any unit to be taught using SATL methods involves the building of a systemic diagram (SD0) that has been determined as the starting point of the unit; SD0 incorporates the prerequisite concepts. The SD0 of unit assures that all students will have the same starting point as they progress through the entire set of systemic diagrams. The unit ends with a final systemic diagram (SDf) in which all the relationships between concepts in the unit that have been taught
to the student are known. From SD0 through SDf we encounter several similar systemic with known and unknown relationships (SD1, SD2, etc.). (4, 10).

According to this scenario we present the unit according to the following steps:

**Step-1:** We start the unit by presenting the linear relationships among various parameters influence the environmental changes as in the following linear diagram Fig.1.

**Figure 1: Linear relationship among various parameters influence by the change in environment**

**Step-2:** Students convert linear diagram Fig. 1 into systemic diagram SD0 by connecting factors as represented in Figure 2. In systemic diagram (SD0) (Figure 2) all the systemic relationships
between environmental changes and parameters (1-11) and between parameters (12-23) are unknown.

Step-3: Systemic approach will be applied to decode the relations in SD0 and the students are able to convert SD0 to another systemic diagram SD1 (Figure 3) in which few of the relations have been clarified by putting a check (✓) on relations (1-5 & 11—15).
Step-4: After clearing up some more environmental relations students are able to convert systemic diagram SD1 into SD2 (Fig.4) in which more environmental relations have been clarified by putting a check (✓) on relations (6-8 & 16—19).
Step-5: After presentation of remaining environmental relations (9-11\&20-23) the students are able to convert systemic diagram SD2 (Figure 4) to attain the final systemic diagram SDf, (Figure 5) in which all the relations are clarified by putting a check (✓) on relations and the unit ends.
Figure 5: Sdf
Figure 6: SDF, showing the connections between molecular kinetic energy and other factors.
CONCLUSION

A model lesson for teaching and learning the concepts underlying environmental chemistry has been developed on the basis of systemic building strategy. We feel that a lecture delivered through this SATL Scenario is going to be a vital route to deep understanding of the complex environmental issues.

This mode of teaching and learning is likely to open new avenues for appreciating the interconnectivity between thermodynamics and environment.
REFERENCES
AVOIDING GENERAL CHEMISTRY TEXTBOOKS’ MISREPRESENTATIONS OF CHEMICAL EQUILIBRIUM CONSTANTS

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ABSTRACT
This paper summarizes the misrepresentation of the equilibrium constants in general chemistry textbooks. It is reported that there is a terminology problem as many authors state that practical equilibrium constants, viz. $K_p$ and $K_c$, are unit-less quantities. Also, in many chemistry textbooks $K_p$ plays the role of the thermodynamic equilibrium constant, $K^\circ$. Thus, after reviewing the proper definition of each of the terms analyzed, one problem is presented in order to exemplify the correct treatment of the quantities involved, which may help in the discussion and clarification of the misleading conventions and assumptions reported in this study. [African Journal of Chemical Education—AJCE 5(2), July 2015]
INTRODUCTION

The equilibrium constants are fundamental quantities in the treatment of chemical equilibrium reactions. This paper aims to exemplify the correct treatment of these quantities in order to avoid current first-year university chemistry textbooks’ misrepresentations.

Equilibrium constants

Discussion concerning the terminology of equilibrium constants has received great attention in different science education journals where contributions of authors from several countries can be found. This issue might seem controversial as in some articles it is stated that the equilibrium constant is dimensionless [1-11], but in others, authors advocate that practical (or experimental) equilibrium constants, viz. $K_p$ and $K_c$, do have units [12-24]. But as it is discussed below, this debate is essentially a terminological problem and can be easily solved from a sound didactic approach.

Textbook misrepresentations

The above referred arguments may have confused general chemistry textbook authors when dealing with those quantities, as many of them state that practical equilibrium constants, $K_p$ and $K_c$, are dimensionless and very often do not explicitly distinguish between the thermodynamic constant, $K^\circ$, and practical equilibrium constants. Moreover, the different ways in which textbooks give information concerned with this topic embody an array of names for the thermodynamic equilibrium constant (e.g., $K$, $K^\circ$, $K_p$, $K_{eq}$, $K_{th}$). Thus, authors seem to be concerned with an accurate thermodynamic presentation, neglecting the proper introduction of practical equilibrium constants ($K_p$ and $K_c$). The statements found in first-year university chemistry textbooks do confuse students because they are always required to pay great attention to units elsewhere and must know and differentiate the proper meaning of these basic terms. A
qualitative list of general chemistry textbooks’ misrepresentations of the equilibrium constants is
the following:

1) Some textbooks do not explain why they omit units when reporting the calculation of
experimental equilibrium constants (i.e., \( K_c \) and \( K_p \)).
2) Textbooks often do not explicitly distinguish between thermodynamic and practical equilibrium
constants.
3) \( K_c \) and \( K_p \) are dimensionless.
   • It is frequently stated that units are not given for equilibrium constants because there are
     more accurate ways of treating these quantities.
   • In a few cases, it is expressed that it is customary to omit the units of the equilibrium
     constant.
   • It is often usual to refer to activities after defining \( K_p/K_c \), stating that the equilibrium
     constant has no units because the values used for \( K_p/K_c \) are identical to those of partial
     pressures/concentrations, but dimensionless.
4) There is usually no explicit distinction between both \( K^\circ \) and \( K_p \), and \( K^\circ \) and \( K_c \).
5) The mathematical relationships between both \( K^\circ \) and \( K_p \), and \( K^\circ \) and \( K_c \) are normally not given.
6) \( K^\circ \) often means \( K_p \).
7) \( \Delta_r G^\circ = -RT \ln K^\circ \) is commonly written as \( \Delta G^\circ = -RT \ln K_p \). In this case, some authors do
   not report why \( K_p \) in this equation must be dimensionless. Moreover, the different ways in
   which textbooks give the information concerned with this equation embody an array of names
   for the thermodynamic equilibrium constant (e.g., \( K_c, K^\circ, K_p, K_{eq}, K_{th} \)).
8) Some textbooks report the equilibrium constant with units when it is calculated from the
    equation \( K = e^{-\Delta G^\circ/RT} \).
9) Most of the textbooks still refer to the value 1 atm as the standard state pressure, thus few of
    them use the current value, \( p^\circ = 1 \) bar.

An initial study on the way equilibrium constants are misrepresented in those textbooks
was reported in a previous article [25]. A recent paper has provided a detailed discussion on this
topic as it has augmented and updated the initial sample and also has included in its analysis a
large sample of Grade-12 chemistry textbooks [26]. First-year chemistry textbooks consisted of
26 well-known textbooks that have gone through several editions, thereby showing their
acceptance by chemistry teachers. Moreover, various studies published in science education
journals have included those textbooks. It included textbooks whose authors are mainly from
USA and Great Britain, covering textbook editions from 1989 to 2011. Grade-12 chemistry
textbooks consisted of 35 textbooks edited throughout the last 30 years.
Most of the misrepresentations found in first-year university chemistry textbooks were also present in this pre-university level. Thus, in 60% of first-year chemistry textbooks $K_p$ and $K_c$ are calculated as unit-less quantities, but in many of the cases analyzed, any explanation is given. Similar results were obtained in the case of Grade-12 chemistry textbooks. Moreover, in 91% of first-year textbooks $K_p$ was presented as the thermodynamic equilibrium constant. In addition, 96% of these textbooks still refer to the value 1 atm as the standard state pressure. Similar values concerning those misrepresentations were obtained in the analysis of pre-university textbooks.

As stated above, the main conclusion from those two previous studies [25, 26] was that the quantities $K^\circ$ and $K_p$ are confused or represented by the same symbol. Thus, the aim of this article is to both differentiate these quantities and establish their relationships. This analysis will be mainly focused on their units.

**Gas-phase equilibrium**

As there is a great confusion in the terminology used by textbooks, it is necessary to review briefly the definition for each term.

Equilibrium constants $K_p$ and $K_c$ are usually defined before thermodynamics is taught. For example, in the case of the following gas-phase equilibrium

$$a \ A(g) + b \ B(g) \rightleftharpoons r \ R(g) + s \ S(g) \quad (1)$$

$K_p$ is defined as an experimental quantity as follows

$$K_p = \left( \frac{\prod_i p_i^t}{\prod_j p_j^s} \right)_{eq} \quad (2)$$
where \( p_i \) is the partial pressure of each of the gases involved. They are usually measured in atm.

Still, a few textbooks have recently changed this case reporting partial pressures of gases in bar [25, 26].

Similarly, \( K_c \) is defined as follows

\[
K_c = \left( \frac{[R]_T[R]_S}{[A]^r[B]^s} \right)_{eq}
\]

(3)

where the concentrations are usually measured in mol L\(^{-1}\).

That is, it seems that the units of \( K_p \) must be \((\text{atm})^{\Delta n(g)}\), whereas those of \( K_c \) must be \((\text{mol L}^{-1})^{\Delta n(g)}\), where \( \Delta n(g) = (r + s) - (a + b) \). Indeed, the IUPAC [27] allows the use of \( K_p \) and \( K_c \) having units. As it has been stated before, it was found [25, 26] that 40% of first-year university chemistry textbooks agreed with those conventions. Consequently, many authors treated both \( K_p \) and \( K_c \) as dimensionless quantities (60 %). Thus, students may get surprised when a great number of authors leave units when reporting the calculation of experimental equilibrium constants. For example, in some textbooks (27%), authors simply omit units in the calculation of \( K_p/K_c \), without explaining why they do this.

In other cases, the explanations provided in some textbooks really may amaze students. For example, three textbook authors [28-30] just claimed that the units of the equilibrium constant can always be figured out from the equilibrium constant expression. In addition, some authors [31-33] stated that it is customary to omit units in expressing the equilibrium constant as there is a more rigorous thermodynamic foundation for the equilibrium constant. Thus, they explained that each partial pressure/concentration in an equilibrium constant expression has been divided by the standard value of pressure/concentration (1 atm for gases, 1 mol L\(^{-1}\) for solutes) to make \( K_p/K_c \) dimensionless.
Indeed, the IUPAC [27] defines a third equilibrium constant term: the thermodynamic constant, $K^o$, which is dimensionless. The thermodynamic equilibrium constant is defined as follows (ideal behaviour)

$$K^o = \left( \frac{p(R)_{eq}}{p^o} \right)^a \left( \frac{p(S)_{eq}}{p^o} \right)^b \left( \frac{p(A)_{eq}}{p^o} \right)^c \left( \frac{p(B)_{eq}}{p^o} \right)^d$$

(4)

Knowing the value of one of these three constants, it is easy to find out the corresponding values of the other two. Then, we are able to state the following relationship

$$K_p = K^o (p^o)^{\Delta n(g)}$$

(5)

As $p^o = 1$ bar, if the units of $K_p$ are (bar)$^{\Delta n(g)}$, its value equals that of $K^o$. But, as (atm)$^{\Delta n(g)}$ are usually the units of $K_p$, then the values of both constants are different.

Other relationships are

$$K_p = K_c (RT)^{\Delta n(g)}$$

(6)

$$K^o = K_c \left( \frac{RT}{p^o} \right)^{\Delta n(g)}$$

(7)

The reader is reminded that the above equations are only valid for homogeneous gas-phase reactions where $K^o$ contains dimensionless ratios of pressure/standard pressure for gaseous species. Rather, the thermodynamic equilibrium constant contains dimensionless ratios of concentration/standard concentration for aqueous species (as it will be examined in a subsequent section). Those mathematical relationships may help students in the differentiation between the practical equilibrium constants and the thermodynamic constant. However, the aforementioned
recent study [26] has reported that equations (5) and (7) are usually not discussed in first-year chemistry textbooks.

A glossary of chemical equilibrium constants is given in Table 1.

**Table 1. Glossary of equilibrium constant terms for a given chemical equilibrium**

represented as: a A(g) + b B(g) ⇌ r R(g) + s S(g).

<table>
<thead>
<tr>
<th>Practical equilibrium constants, $K_p$ and $K_c$:</th>
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<tbody>
<tr>
<td>$K_p = \left( \frac{p_r p_s}{p_a p_b} \right)_{eq}$; its units are (unit of pressure)$^{\Delta n(g)}$</td>
</tr>
<tr>
<td>$K_c = \left( \frac{[R] [S]}{[A]^a [B]^b} \right)_{eq}$; its units are (unit of concentration)$^{\Delta n(g)}$</td>
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<tr>
<th>Thermodynamic equilibrium constant, $K^\circ$ (unitless quantity):</th>
</tr>
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<tbody>
<tr>
<td>$K^\circ = \left( \frac{p(R)<em>{eq}}{p^\circ} \right)^a \left( \frac{p(S)</em>{eq}}{p^\circ} \right)^b p^\circ = 1$ bar</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Mathematical equation relating $K_p$ and $K^\circ$:</th>
</tr>
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<tr>
<td>$K_p = K^\circ (p^\circ)^{\Delta n(eq)}$</td>
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</table>

In Example 1 we outline the calculation of $K^\circ$, $K_p$ and $K_c$ corresponding to a gas-phase equilibrium at a given temperature. In this problem, we calculate the equilibrium constant, $K^\circ$, with the help of the following equation

$$\Delta_G^\circ = -RT \ln K^\circ$$  \hspace{1cm} (8)

where $\Delta_G^\circ$ is the standard free energy of reaction [34]. Equation (8) can be written for our purpose as follows

$$K^\circ = e^{-\Delta_G^\circ RT}$$  \hspace{1cm} (9)
It must be stressed that $K^o$ is dimensionless. However, two university textbooks\textsuperscript{35,36} presented the equilibrium constant with units when it was calculated from the above equation. This finding was also reported concerning some current Grade-12 chemistry textbooks [26]. Other related misrepresentations arise when some authors assume that $K^o = K_p$ [25, 26], and thus they write equation (8) as follows

$$\Delta G^o = -RT \ln K_p$$

(10)

Specifically, 80\% of first-year chemistry textbooks presented the above equation and among those Grade-12 chemistry textbooks that treated this topic, in 80\% of them equation (10) was also introduced. But it must be emphasized that equation (10) embodies two terminological misrepresentations: i) it is assumed that $K_p$ plays the role of $K^o$; ii) $\Delta G^o$ is stated instead of $\Delta G^o$. This last confusion has been reported in two recent articles [34-37]. However, although one of these last papers [37] correctly states that in equation (10) the units on $\Delta G^o$ are not the same as the units on $RT$ because $\Delta G^o$ is an extensive quantity with units of energy, whereas $RT$ is intensive with units of energy mol\textsuperscript{-1}, it still commits the first aforementioned terminological misrepresentation keeping $K_p$, instead of using $K^o$. This case exemplifies how deep the confusion on the equilibrium constant terminology is rooted as not only does it broadly appear in first-year chemistry textbooks, but also it is present in an educational article dealing specifically with the incorrect use and units of thermodynamic related quantities.

Note that $K^o$ is dimensionless, but $K_p$ has the dimensions of pressure raised to the power of $\Delta n(g)$. In Example 1 we have reported one value for $K^o$ ($p^o = 1$ bar), but three different values for $K_p$, depending on the units of pressure used. The value of $K_p$ equals that of $K^o$ only when the partial pressures are reported in bar units. That is, $K^o = 771$ (p$^o = 1$ bar) and $K_p = 771$ bar$^{-1}$; $K_p = 781$ atm$^{-1}$; $K_p = 7.71 \times 10^{-3}$ Pa$^{-1}$. At this point it is worthwhile to note that before 1982 it used to be
that \( p^o = 1 \) atm, and thus both values of \( K^o \) and \( K_p \) were the same when partial pressures were measured in atm units (in our example, \( K^o = 781 \) before 1982, and thus the value of \( K_p \) was equal to that of \( K^o \) when the units of pressure were atm; that is, it used to be that \( K_p = K^o (\text{atm})^{\Delta n(g)} \)). That year, the IUPAC Commission on Thermodynamics recommended use of 1 bar, rather than the traditional 1 atm, as the standard-state pressure for tabulating thermodynamic data [38]. The effect of this modification had a slight variation in the values of thermodynamic equilibrium constants, \( K^o \) [5, 24, 39]. This change did not affect the values of \( K_p \) as they depend on the units of pressure used [21], as it has been exemplified in Example 1.

While these last two statements are true, it is also true that equilibrium calculations are almost never more accurate than about 5% because of deviations from ideal behavior, so the difference in the values of \( K_p \) is not important in practical terms when the units are atm instead of bar. However, this is not the case when other pressure units are used as Pa. Finally, in Example 1 we have also reported the value of \( K_c \). It should be noted that this quantity has the dimensions of concentration raised to the power of \( \Delta n(g) \).
Example 1
Calculate $K^o$, $K_p$, and $K_c$ at 298.15 K for the ammonia synthesis equilibrium:

$$\frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g) \rightleftharpoons \text{NH}_3(g)$$

Thermodynamic data at 298.15 K (p° = 1 bar): $\Delta_r H^o[\text{NH}_3(g)] = -46.1 \text{kJ/mol}$; $S^o[\text{N}_2(g)] = 191.6 \text{ J/mol}\cdot\text{K}$; $S^o[\text{H}_2(g)] = 130.7 \text{ J/mol}\cdot\text{K}$; $S^o[\text{NH}_3(g)] = 192.5 \text{ J/mol}\cdot\text{K}$.

**SOLUTION**
$K^o$ can be calculated using the following equation $K^o = e^{-\Delta_r G^o/RT}$. So, the value of $\Delta_r G^o$ is needed. It can be obtained from the equation $\Delta_r G^o = \Delta_r H^o - T\Delta_r S^o$.

- $\Delta_r H^o = -46.1 \text{kJ/mol}$
- $\Delta_r S^o = S^o[\text{NH}_3(g)] - \frac{1}{2} S^o[\text{N}_2(g)] - \frac{3}{2} S^o[\text{H}_2(g)] = -99.4 \text{ J/K/mol}$
- $\Delta_r G^o = \Delta_r H^o - T\Delta_r S^o = -16.5 \text{kJ/mol}$;

$K^o = e^{-\Delta_r G^o/RT} = 771$.

$K_p$ and $K_c$ are calculated as follows,

$$K_p = K^o (p^o)^{\Delta n(g)} = 771 \text{ bar}^{-1};$$
as 1 atm = 1.01325 bar, it should be noticed that $K_p = 781 \text{ atm}^{-1};$ also, as 1 bar = 10$^5$ Pa, $K_p = 7.71 \times 10^3 \text{ Pa}^{-1}$.

$$K_c = \frac{K_p}{(RT)^{\Delta n(g)}} = \left(781 \text{ atm}^{-1}\right) \cdot \frac{1}{(0.08206 \text{ atm L/mole K}^{-1} \times 298.15 \text{ K})^{-1}} = 1.91 \times 10^4 \text{ (mol/L)}^{-1}$$

<table>
<thead>
<tr>
<th>$K^o$ (p° = 1 bar)</th>
<th>$K_p$</th>
<th>$K_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>771</td>
<td>771 bar$^{-1}$</td>
<td>781 atm$^{-1}$</td>
</tr>
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</table>

Hence, we must remark that only when the values of pressure are measured in bar does $K_p = K^o (\text{bar})^{\Delta n(g)}$. Conversely, if it is not that case, we find that, as far as numerical values are concerned, $K_p \neq K^o$. That is, the thermodynamic equilibrium constant has only one value (of course, the standard state must be stated as each standard state has its corresponding thermodynamic equilibrium constant value; in our example, p° = 1 bar, which corresponds to the IUPAC recommendation), but $K_p$ has many, depending in each case on the pressure units used to measure the partial pressures of the species involved in the gaseous mixture. These facts are usually not examined in general chemistry textbooks [26].
Aqueous equilibrium solutions

Although this paper deals mainly with equilibria involving gaseous mixtures, it may be necessary to make a brief discussion on aqueous equilibrium solutions. In these cases the thermodynamic equilibrium constant is defined analogously, but now the standard-state of an aqueous substance may be either \( c^o = 1 \text{ mol L}^{-1} \) or \( c^o = 1 \text{ mol kg}^{-1} \) [27]. For example, in a weak acid solution, HA(aq),

\[
\text{HA(aq) + H}_2\text{O(l)} \rightleftharpoons \text{A}^-\text{(aq) + H}_3\text{O}^+\text{(aq)}
\] (11)

the thermodynamic equilibrium constant is as follows

\[
K^o = \frac{\left[ \text{A}^-\text{eq} \right]}{\left[ \text{HA}\text{eq} \right]} \times \frac{\left[ \text{H}_3\text{O}^+\text{eq} \right]}{c^0}
\] (12)

Once again, \( K^o \) is a dimensionless quantity, and its value depends on the standard state used. Thus, in aqueous equilibria the standard state must be given when the value of the equilibrium constant is reported.

For equation (11) \( K_c \) is expressed as

\[
K_c = \frac{\left[ \text{A}^-\text{eq} \right] \left[ \text{H}_3\text{O}^+\text{eq} \right]}{\left[ \text{HA}\text{eq} \right]}
\] (13)

and its value must be reported using concentration units. Notice that in aqueous solutions \( K^o \) and \( K_c \) are different quantities although they may have the same values. In our example, \( K_c = K^o c^o \). That is, the values of \( K^o \) and \( K_c \) are the same when there is coincidence in the units of both the concentrations of the substances involved and the concentration standard-state used.

Thus, if \( c^o = 1 \text{ mol L}^{-1} \) and the values of concentration, \( c_o \), are expressed in \( \text{mol L}^{-1} \) units, the values of \( K_c \) and \( K^o \) are the same. But, if there is not such coincidence in the
concentration units, then those quantities have different values. For example, at 25 °C, if we use \( c^0 = 1 \text{ mol L}^{-1} \), we have for the acetic acid: \( K_c = 1.751 \times 10^{-5} \text{ mol L}^{-1} \) and \( K^{o} = 1.751 \times 10^{-5} \), but if the units of concentration used are \( \text{mol kg}^{-1} \), then \( K_c = 1.756 \times 10^{-5} \text{ mol kg}^{-1} \) [13]. Similarly, when \( c^0 = 1 \text{ mol kg}^{-1} \), the values of \( K_c \) and \( K^{o} \) are the same if the values of \( c_i \) are expressed in \( \text{mol kg}^{-1} \) units. This discussion may help to avoid current misrepresentations as in aqueous equilibrium solutions it is normally assumed that \( K_c \) plays the role of \( K^{o} \) [26]. Once again (analogously to the case of gas-phase equilibrium reactions), this confusion is also present in a recent article [37] dealing with the correct use and units of related quantities, which reinforces the view that terminological misrepresentations of the equilibrium constants are firmly anchored in current educational approaches associated to this topic.

CONCLUSIONS

When reporting the value of the thermodynamic equilibrium constant, \( K^{o} \), the standard state must be specified. For gaseous reactions the IUPAC recommends \( p^0 = 1 \text{ bar} \); in addition, for aqueous solution reactions \( c^0 = 1 \text{ mol L}^{-1} \) or \( c^0 = 1 \text{ mol kg}^{-1} \). For each standard state there is only one value of \( K^{o} \). Conversely, \( K_p \) and \( K_c \) have many values depending on the units of pressure/concentration chosen. That is, \( K^{o} \) is a unitless quantity; on the contrary, \( K_p \) has units of pressure (eg. bar, atm, Pa, etc.) and \( K_c \) has units of concentration (eg. mol L\(^{-1}\), mol kg\(^{-1}\)).

Many first-year university chemistry textbooks assume that \( K^{o} = K_p \) (and also \( K^{o} = K_c \)) and confusion on units is also widespread. These misrepresentations are also broadly present in pre-university chemistry textbooks.

The analysis of the example outlined in this article has helped in discussing the differentiation of practical equilibrium constants (ie. \( K_p \) and \( K_c \)) and the thermodynamic constant,
$K^\circ$. Thus, the treatment performed in this study may be useful for both textbook authors and their users (ie. general chemistry teachers and students) in order to avoid current misrepresentations [25, 26]. That is, this examination may help textbook authors when dealing with the proper definition of both the practical equilibrium constants and the thermodynamic equilibrium constant as well as when both performing their calculation and reporting their relationships. Still, given the discussion of the confusion among $K^\circ$, $K_p$, and $K_c$, some teachers would argue to define $K^\circ$ only, which might pose a challenging didactic issue. As this suggestion might seem appropriate, for it would give rise to less confusion, since then $K^\circ$ would be the only relevant parameter, it would need the use of activities of reactant and product species. However, we could presume this concept too difficult as it is both unnecessary and undesirable for an introductory course. Hence, the introduction of concepts such as activities would mean to advance what has traditionally been carefully treated in later years of the undergraduate curriculum and thus to add needless strains to beginners. This argument does also apply to pre-university chemistry textbooks as it seems neither essential nor beneficial to introduce the thermodynamic equilibrium constant at this level. Still, practical equilibrium constants should be defined properly and reported with the corresponding units.

Hence, similar problems to the example discussed in this study can be presented to students when dealing with equilibrium constants in first-year chemistry courses. This examination allows to apply the different equations provided in table 1, which may help in avoiding current terminological misrepresentations. That is, authors must always warn their readers that focusing on reporting quantities with the correct units is a basic activity that should not be overlooked. In addition, each term should be properly defined, allowing students to establish the mathematical relationships among them.
REFERENCES
SYSTEMIC ASSESSMENT AS A NEW TOOL FOR ASSESSING STUDENTS LEARNING IN HETEROCYCLIC CHEMISTRY

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ABSTRACT
Systemic Assessment [SA] has been shown to be a highly effective new tool in raising the level of students' academic achievements, improve their ability to learn by enhancing the process of teaching and learning, and converts students from surface to deep learning. It also allows teachers to monitor students learning throughout the course and gives them the ability to make necessary adjustments to improve learning. SA strategy changes assessment from linear bothering exams to enjoyable puzzle games by dealing with systemic assessment diagrams. The aim of the systemic assessment (SA) of learners in heterocyclic chemistry is to introduce an efficient evaluation of the systemic-oriented objectives of the [SATL-Heterocyclic Chemistry] model & effective tool for assessing students' meaningful understanding of heterocyclic chemistry topics in the tertiary level. Systemic Assessment Questions SAQ,s are the building units of the systemic assessment. It measures the students' ability to correlate between heterocycles and to discover new relations between them. In this issue we use SA as a tool to assess the student achievement in heterocyclic chemistry by choosing five types of systemic assessment questions, namely Systemic Multiple Choice Questions (SMCQ,s), Systemic True False Questions (STFQ,s), Systemic Matching Questions (SMQ,s), Systemic Sequencing Questions (SSQ,s), and Systemic Synthesis Questions (SSynQ,s). [African Journal of Chemical Education—AJCE 5(2), July 2015]
INTRODUCTION

Heterocyclic chemistry appears to be hard to a large number of students due to the versatility and complexity of heterocyclic compounds, enormous amount and variety of information, abstract nature of many heterocyclic chemistry concepts, teaching styles applied in classes, and lack of new teaching aids... For this reasons and others the students find the following difficulties in learning heterocyclic chemistry (1); i) to remember the structural formulas of heterocyclic compounds and understand the chemical properties related to these structures, ii) to understand the reactivity of compounds due to enormous diversity of structures; iii) to understand the systemic effect of heteroatom on the reactivity of both heterocycles and the attached functional groups, iv) to synthesize systemic chemical relations between compounds of the same or different heterocycles, v) to follow up the theoretical bases connected to the complexity of heterocycles, vi) to design Synthesis of new target heterocyclic compounds via RSA..

For these reasons we use SA strategy is to enhance, support and improve both teaching and learning processes in heterocyclic chemistry via; (i) helping teachers to use evidence of student learning to assess student achievement against goals and standards to improve their performance, (ii) enable students to make feedback and feed forward during their study of any heterocyclic course materials, and helping them in making maximum connections between heterocyclic chemistry concepts, compounds, and reactions: iii) enable students to think systemically to solve complexity. Thus the student should be able to think in a systemic way when he is able to analyze a systemic to its fundamental components/subsystems and to synthesize these components into a meaningful whole, namely, to organize a systemic of interest (2-3). The students gain all these skills via solving different types of SAQs which is the
building units of the systemic assessment. By using SA we actually measure the change in cognitive structure of our students after each learning process.

Goals

Our goal of this issue is to make use of different types of SAQs: i) to build a new systemic assessment strategy in heterocyclic chemistry to assess students meaningful understanding, which might lead to a better understanding of the systemic relations between heterocyclic compounds and their reactivity in chemical reactions; ii) to overcome the complexity of heterocyclic compounds structures and working memory limitation (as well as overload) by constructing cognitive schemas “combining simple elements into more complex ones” [4-5]. Cognitive schemas reduce working memory load, because even highly complex schema can be considered as a single element in the working memory [4-5]. Systemics which is the building unites of SAQs can be considered as closed cognitive schemas.

Discussion

Students organize their thinking in dealing with systemic diagrams of systemic assessment. By solving SAQs students use their critical thinking, problem solving and decision making abilities, demonstrate self-management skills, improve their perception by increasing their observation skills, and learn through creation and not through reproduction, therefore, they could increase their creativity (6). Also, SAQ schemes were used as a strategy for capturing students’ systemic thinking skills in organic chemistry (7).

In this issue we will introduce SA of learners as an efficient evaluation of the systemic-oriented objectives of the [SATL-Heterocyclic Chemistry] model and effective tool for assessing students’ meaningful understanding of heterocyclic chemistry topics in the tertiary level. A significant association was observed between students’ performance on SAQs and on objective
items designed for assessing their meaningful understanding. This association reveals that the
students’ systemic thinking level developed in organic chemistry is strongly related to a deeper
understanding of the relevant chemistry concepts (7). In this regards we will illustrate five types
of SAQs in heterocyclic chemistry based on systemics to assess students at synthesis and
analysis learning levels. We experiment some of these questions successfully on our 3rd year
major chemistry students, faculty of science, Ain Shams University, Egypt. On the other hand
the conventional (Linear) assessment questions (LAQ, s) in heterocyclic chemistry were
designed to assess simple recall of knowledge which intensify rote learning and linear thinking.

Linear Assessment VS Systemic Assessment in Heterocyclic Chemistry

A-Linear Assessment in Heterocyclic Chemistry [LAHC]: [eg. Thiopene chemistry]

In the linear (Traditional) Assessment of heterocyclic chemistry [LAHC] we ask our
students to represent the different types of reactions by chemical equations. The student can
write the correct symbolic chemical equations, but, however, he couldn’t correlate between
reactants and resultants or between both and used reagents. So, the student just writes separate
chemical equations without any comprehension or appreciating significance of these
relationships representing the chemical reactions [rote learned materials]. According to Ausuble
[8] rote learned materials are not anchored to existing concepts, it is more easily forgotten and
consequently assesses our students at lower learning outcomes [memorization].

Q: Complete the following equations [1-6]: [eg. Thiopene chemistry]:

\[ \text{(Equation-1)} \]
B-Systemic assessment in heterocyclic chemistry [SAHC] [Thiophene chemistry]

We can ask our students about the same chemical reactions 1-6 by using systemic assessment questions, based on systemic.

E.g.: Systemic Synthesis Question: [Sync]

Draw pentagonal systemic diagram illustrating the chemical relations between thiophene and its related compounds stated in the chemical equations 1-6.

A) In this type of question we assess our students’ knowledge about chemical relations between (thiophene-2-Lithiothiophene-2-Methylthiopene-2-Formylthiophene-2-Carboxythiophene), beside the relations between the six chemical processes [Lithiation-
methylation-reduction [Zn [Hg]/HCl – oxidation-decarboxylation - reduction with Co (OAc) 2] and the used reagents.

The student synthesizes the following systemic pentagonal diagram which is considered as closed cognitive scheme.

In the above question, we assess our student at the synthesis learning level by synthesizing the above pentagonal systemic diagram to show the relations between the five thiophene compounds and the chemical processes in equations 1-6 and. The student discovers another two possible chemical relations between the above thiophene compounds (Carboxylation-7, and formylation-8).

DESIGNING OF SYSTEMIC ASSESSMENT QUESTIONS IN HETEROCYCLIC CHEMISTRY

Systemic diagrams representing different types of systemic assessment questions [SAQ, s] in which the selected heterocyclic compounds of any reaction were located in the given
systemic. SAQs have been designed in accordance with the guidelines stated by: Tzougraki (2), Golemi (6), Fahmy & Lagowski (9-11)

Here we continue our work on systemic assessment to assess student academic achievement in heterocyclic chemistry by using new different types of SAQs, namely, Systemic Multiple Choice Questions [SMCQs], Systemic True False Questions [STFQs], Systemic Matching Questions [SMQs], Systemic Sequencing Questions [SSQs], Systemic Synthesis Questions [SSynQs].

**Type [I]: Systemic multiple choice questions [SMCQs] (9)**

SMCQs are choosing of one systemic from a list of possible systemic. Each systemic represents at least three chemical relations between three heterocyclic compounds. SMCQs are well suited for testing students’ comprehension, synthesis, and analysis.

Put (√) in front of the correct systemic diagram in each of the following questions:

Q1)

<table>
<thead>
<tr>
<th>(a)</th>
<th>(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="" alt="Diagram" /></td>
<td><img src="" alt="Diagram" /></td>
</tr>
</tbody>
</table>

| ( ) | ( ) |
Q2:

(a)  
\[ \text{S} \xrightarrow{\text{CH}_2\text{O/HCl}} \text{S} \xrightarrow{\text{heat in water}} \text{S} \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7/\text{conc. H}_2\text{SO}_4} \text{S} \]

(b)  
\[ \text{S} \xrightarrow{\text{Cu/Quinoline/\Delta}} \text{S} \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7/\text{conc. H}_2\text{SO}_4} \text{S} \]

A: (√)
Q3:

(a) 

\[ \text{Co(OAc)}_2 \quad 9,10\text{-dibromo anthracene} \]

\[ \xrightarrow{\Delta} \]

\[ \text{Bu}^+\text{Li} \]

\[ \xleftarrow{(\text{CH}_3)\text{N/\Delta}} \]

(c) 

\[ \xrightarrow{\text{Cu/Quinoline} \quad \Delta} \]

\[ \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7 \quad \text{conc. H}_2\text{SO}_4} \]

\[ \xleftarrow{(\text{CH}_3)_3\text{N}(\text{NH}_2)_\ell / \text{alco.}} \]

(d) 

\[ \xrightarrow{\text{Cu/Quinoline} \quad \Delta} \]

\[ \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7 \quad \text{conc. H}_2\text{SO}_4} \]

\[ \xrightarrow{\text{aq KOH/heat}} \]
(b) 

\[
\begin{align*}
\text{Bu}^n\text{Li} & \xrightarrow{\Delta} \text{Cu/Quinoline} \\
\text{CO(OAc)}_2 & \xrightarrow{9,10\text{-dibromo anthracene}} \\
\text{Bu}^n\text{Li} & \xrightarrow{\text{B(CH}_3)_3/\text{I}_2} \\
\end{align*}
\]

(c) 

\[
\begin{align*}
\text{Bu}^n\text{Li} & \xrightarrow{\Delta} \\
\text{Cu/Quinoline} & \xrightarrow{\text{N(CH}_3)_3/\text{I}_2} \\
\text{Bu}^n\text{Li} & \xrightarrow{\Delta} \\
\end{align*}
\]

(d) 

\[
\begin{align*}
\text{Bu}^n\text{Li} & \xrightarrow{\text{B(CH}_3)_3/\text{I}_2} \\
\text{Co(NO}_3)_2 & \xrightarrow{\Delta} \\
\end{align*}
\]

b: ( ✓ )
Type [II]: Systemic True False questions (STFQ, s): (6, 10)

STFQs require a student to assess whether a systemic is true or false. This means that the student assess systemic relations between concepts, rather than concepts. STFQ, s are well suited for testing students’ comprehension, synthesis, and analysis.

Q1: Which of the following systemics are true and which are false?

(a)

(b)
(c)\[\begin{array}{c}
\text{S} \\
\text{O} \\
\text{NH}_3 \\
\text{NH}_3 \\
\text{H}_2\text{S}
\end{array}\]

(d)\[\begin{array}{c}
\text{C}_2\text{H}_5 \\
\triangleleft (a) \checkmark, (b) \times, (c) \checkmark, (d) \times
\end{array}\]
Q2)

![Chemical structures and reactions](image)

A)  a: (x), b: (✓), c: (✓), d: (x)

III: Systemic matching Questions (SMQ): (6, 11)

Systemic Matching Questions assess students learning outcomes at synthesis level. The given systemic diagram could be triangular, quadrilateral or Pentagonal.

Q) Choose heterocyclic compounds from column (A) and reaction conditions from column (B) to construct the systemic diagrams in column (C):
<table>
<thead>
<tr>
<th>(A)</th>
<th>(C)</th>
<th>(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
<tr>
<td><img src="A" alt="Chemical Structures" /></td>
<td><img src="C" alt="Chemical Structures" /></td>
<td><img src="B" alt="Reagents" /></td>
</tr>
</tbody>
</table>

CO(OAC)$_2$
AcNO$_3$
BuLi
DMF/POCl$_3$, NaOAc
Cu/Quinoline, $\Delta$
(CH)$_3$B/I$_2$
CH$_2$I/FeCl$_3$
Zn[Hg]/HCl
CH$_2$O/HCl
(CH)$_2$(NH)$_2$/alc.
P$_2$S$_5$
NH$_3$ (hv)
K$_2$Cr$_2$O$_7$/H$_2$SO$_4$
Heat 200°C
HNO$_3$ [conc.]
CH$_3$MgBr, H$_2$O
NaNO$_2$/HCl
NaN$_3$

NH$_3$/Al$_2$O$_3$/450°C
1- Answers in a triangular systemic chemical relations

(a)

\[ \text{NH}_3/\text{Al}_2\text{O}_3 \rightarrow 450^\circ\text{C} \]

(b)

\[ \text{Cu/Quinoline} \]

(i) \text{DMF/POCl}_3  
(ii) \text{NaOAc}  

(c)

(i) \text{DMF/POCl}_3  
(ii) \text{NaOAc}  

(d)

\[ \text{HNO}_3 \]

(ii) \text{Pyridine}  

(i) \text{AcONO}_2
2- Answers in a quadrilateral systemic chemical relations

(a)

(b)
3- Answers in a pentagonal systemic chemical relations

Type [IV]: Systemic Sequencing Questions [SSQ, s] : (9)
SSQs require the student to position molecule, or text or graphic objects in a given systemic sequence and assess the student learning outcomes at synthesis level.

Example:

Q) Arrange the following pyrrole compounds in the right places in the following (SD):

\[
\begin{align*}
\text{NH} & \quad \text{NH} & \quad \text{NH} \\
& \quad \text{CHO} & \quad \text{CH}_3 \\
& \quad \text{COOH} & \quad \text{NO}_2
\end{align*}
\]
Type [V]: Systemic Synthesis Questions [SSynQs]: (6, 11)

Requires the student to synthesize systemic from the given chemicals and assess the student learning outcomes at synthesis level. It measures various kinds of knowledge, including students’ ability to correlate between concepts, formula, or reactions.

Type [V-A]: Synthesis of triangular systemic chemical relations:

Q1) Draw triangular systemic diagram illustrating the systemic chemical relations between the following heterocyclic compounds:
Type [V-B]: Synthesis of quadrilateral systemic chemical relations:

Q2: Draw quadrilateral systemic diagram illustrating the systemic chemical relations between the following compounds:
Q3: Draw quadrilateral systemic diagram illustrating the systemic chemical relations between pyridine and the following related compounds:

A3

\[
\begin{align*}
\text{Cl} & & \text{Li} \\
\text{N} & & \text{N} \\
\text{N} & & \text{N} \\
\text{N} & & \text{N} \\
\end{align*}
\]

BuLi

-40°C

\[
\begin{align*}
\text{Cl}_2 \text{ (2 mole)/ AICl}_3 & \quad \text{CO}_2 \quad \text{H}_2\text{O} \\
\text{N} & \quad \text{Li} \\
\text{N} & \quad \text{N} \\
\text{N} & \quad \text{N} \\
\end{align*}
\]

Cu/Quinoline

\[
\begin{align*}
\Delta & \quad \text{COOH} \\
\text{N} & \quad \text{N} \\
\text{N} & \quad \text{N} \\
\text{N} & \quad \text{N} \\
\end{align*}
\]
**Type [V-C]: Synthesis of pentagonal systemic chemical relations:**

Q4) Draw pentagonal systemic diagram illustrating the systemic chemical relations between Pyrrole and the following related compounds:

```
\[
\begin{align*}
&\text{Pyrrole} & \text{CHO} & \text{CHBr}_2 & \text{COOH} & \text{CH}_3 \\
&\text{N} & \text{N} & \text{N} & \text{N} & \text{N}
\end{align*}
\]
```

A4

Q5: Draw pentagonal systemic diagram illustrating the systemic chemical relations between thiophene and the following related compounds:
Type [V-D]: Synthesis of hexagonal systemic chemical relations:

Q6: Draw hexagonal systemic diagram illustrating the systemic chemical relations between pyrrole and the following related compounds:
A6:

Type [V-E]: Open synthesis of systemic diagrams:

Q7: From your study in Heterocyclic chemistry draw systemic diagrams illustrating the systemic chemical relations between each of the following:

1) Any four compounds.
2) Any five compounds.
3) Any six compounds.

Answer (2):
CONCLUSION

By using Systemic Assessment in heterocyclic chemistry, we expect from our students making maximum connections between different heterocycles, view the pattern of pure and applied heterocyclic chemistry rather than synthesis and reactions of heterocycles, synthesize the given target heterocyclic compound by making use of different synthetic strategies, develop their skills and abilities to recognize problems and to participate in their solution, find systemic solutions for any problems in heterocyclic chemistry (Analytic, Synthetic), become more enthusiastic towards learning of heterocyclic chemistry and enter exams with minimum exam anxiety.

REFERENCES


STUDENTS’ CONCEPTIONS AND MISCONCEPTIONS IN CHEMICAL KINETICS IN PORT HARCOURT METROPOLIS OF NIGERIA

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ABSTRACT
The purpose of the study was to probe the conception and misconception of senior secondary (SS3) and University (US) chemistry students in chemical kinetics in Rivers State, Nigeria. The study sample was made up of 107 SS3 and 93 US students. Two main instruments were used to collect data for the study. They are the chemical kinetic calculation problem and alternative conceptions test in chemical kinetics. Overall results of the study showed that students’ performance in basic chemical kinetics calculation was generally poor with the mean scores less than one point. Item analyses on the conception test revealed that about 10% of the students were able to identify the correct answers while about 90% could not identify the correct answers. The university students were superior in performance than the secondary students in the conception test. These results were discussed in the study. [African Journal of Chemical Education—AJCE 5(2), July 2015]
INTRODUCTION

One striking significance of import in chemical kinetics is that the derivatives can provide a model for evaluating the growth of a science education project through examination entries [1, 2, 3, 3] Although Karl Popper, T. S. Kuhn and other co-workers have argued in their own knowledge what constitutes growth in scientific knowledge, the application of the kinetic model to growth seen to provide a better measuring growth index.

One stage in science curriculum development that is relevant in this discourse is the implementation of an added portion of the curriculum arising from the growth. This is where teaching and learning is done. The impact of teaching is evidenced in the performance of the learner. It is in this vein that it is suspected that, there could be a link between a growth in a science education project and the performance of science students. It is also possible to use the kinetic model to evaluate the growth of a science education project considering the performance of the students after ascertaining their entries.

If this is the case, we expect science educators to be conversant with the principles of chemical kinetics. It becomes worrisome when some chemical educators perceive chemical kinetics and related concepts difficult to teach [4, 5]. Studies have also reported that students perceive chemical kinetics and related concepts difficult to learn [4, 5].

Cakmakci: [6] in a study carried out with upper secondary students, first year and third year university students in Turkey reported that students encounter difficulties in chemical kinetics because they are unable to differentiate reaction rate and reaction time in understanding that the reactions had the highest rate of the beginning of the reaction and the lowest at the end; confuse the chemical kinetic concepts with the thermodynamic concepts to mention a few.
Cunningham [7] also added that the trouble with some first-year college students is their problem of identifying a change that is clearly chemical as to physical in nature.

Chemical kinetics is a vital discipline to grasp in order to comprehend a chemical change in its perspective. It also provides vital skill sought for by physical chemists in particular and hence its comprehension is highly desirable [8]. Chemistry teachers, notwithstanding the difficulties encountered by the students, are making frantic efforts in making chemical kinetics less difficult and interesting to learn.

For the past ten years, chemical educators have been advocating the use of Systematic Approach to Teaching and Learning (SATL) in preparing lesson delivery for chemical concepts including chemical kinetics [9, 10]. In SATLC technique the concepts are positioned in such a way that the relations between a series of ideas and issues are made logical. The basic goal of this approach is the achievement of meaningful (deep) learning by students. In preparing lessons based on this approach and other techniques, reference is made to the previous experience or what the learner already knows.

SATL model seems to suggest that one way of teaching a learner is to use what is in the learners’ memory (construct). A learner’s construct of an idea or concept could be correct or incorrect. Being correct or incorrect depends on the teacher’s standard by way of matching the learner’s response to a task with his (teacher’s) marking scheme. To the learner, the response (answer) given whether adjudged correct or incorrect by the teacher is correct. The teacher’s concern is how to correct the misconception. The educator will be concerned about the significance of misconception in the learning of an individual.

According to White and Gunstone [11] there is nothing wrong with an operational definition of a complex construct like understanding, provided that we recognize that the
definition is not the only possible way of measuring it. Restriction of measurement to one form, or too small a number of forms can distort the construct and lead to neglect of important aspects of it.

White and Gunstone [11] noted further that in physics, tests of understanding in Australia and America are mainly short problems which may be multiple choice objective tests (in this sense students constructs can be cued). Chemistry like physics can be tested in a similar way for understanding.

Therefore using chemical kinetics and considering secondary and university students, questions could be asked, namely,

1. What are the general performances of the students in the basic calculation involving chemical kinetics? Is there any significant difference between the mean score of the senior secondary students (SS3) and that of the university students (US) in chemical kinetics calculation?

2. What proportions of the students possess the correct conception and misconception about the questions on chemical kinetics?

METHODOLOGY

The study is of the descriptive type. A total of 409 SS3 students and 196 third year chemistry students in the University (US) in Port Harcourt Metropolis of Nigeria constituted the population of the study. The sample of the study was made up of 107 SS3 students and 93 US. These students indicated their interest to participate in the study. It was observed that the SS3 students and the year 3 university students were studying chemical kinetics at their various levels in the schools. This was what informed their inclusion in the study.
Instrument

Two main instruments were used in collecting data for the study. They are (1) chemical kinetics calculation problem (CKCP) and (2) Alternative conceptions test in chemical kinetics (ACT).

CKCP is a one-item calculation test based on elementary knowledge of chemical kinetics. Thus: when 0.5g of calcium trioxocarbonate (IV) was added to excess dilute hydrochloric acid, carbon (IV) oxide was evolved. The entire reaction took 5 minutes. What was the rate of reaction?

The stages to the solution of the problem are given as:

(a) \[ \text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + \text{CaCl}(\text{aq}) \]

(b) \[ \text{CO}_3^{2-}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \]

(b) Rate of reaction = \( \frac{\text{mass of reactant}}{\text{time taken for the reaction}} \)

(c) Mass of reactant (\text{CaCO}_3) = 0.5g

Time taken for the completion of reaction = 5 minutes

(d) Find out amount in moles of 0.5g of \text{CaCO}_3, using the molar mass of \text{CaCO}_3, given that

\[ \text{Ca} = 40, \text{C} = 12, \text{O} = 16 \]

Molar mass of \text{CaCO}_3 = 40 + 12 + (16 x 3)

= 40 + 12 + 48 = 100

Amount in moles of 0.5g = \( \frac{\text{mass (m)}}{\text{molar mass (M)}} \) = \( \frac{0.5}{100} = 0.005 \text{ moles} \)

(e) Find out how many seconds in 5 minutes:

60 seconds x 5 minutes = 300 seconds

(1 minute = 60 seconds)
\[
\text{Rate} = \frac{0.005}{200} \text{mols}^{-1} \\
= 0.0000166 \text{mols}^{-1} \\
= 1.66 \times 10^{-5} \text{ mols}^{-1}
\]

From the solution of the problem, students’ expected abilities in chemical kinetics problems were mapped out, these included students’

(i) ability to distinguish between a physical change and a chemical change;
(ii) ability to write balanced chemical equations to represent reactions;
(iii) ability to identify reactants and products of the reaction;
(iv) ability to write rate equation;
(v) ability to carry out simple computation involving mass of substance and time;
(vi) being able to specify the correct unit to all measurements of rate of reaction; and,
(vii) being able to identify factors influencing chemical reactions.

Alternative Conceptions Test in chemical Kinetics (ACT) was drawn up based on the identified expected students’ abilities. The specification table is shown on Table 1.

<table>
<thead>
<tr>
<th>Students’ Abilities</th>
<th>Item No.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td>Ability to distinguish between a physical change and a chemical change</td>
<td>1, 2, 3, 3 items</td>
</tr>
<tr>
<td>ii.</td>
<td>Ability to write balanced chemical equations to represent reactions</td>
<td>13, 14, 23, 32, 34, 5 items</td>
</tr>
<tr>
<td>iii.</td>
<td>Ability to identify reactants and products of a reaction</td>
<td>16, 28, 37 3 items</td>
</tr>
<tr>
<td>iv.</td>
<td>Ability to write rate equation</td>
<td>21, 22, 24, 25, 29, 36 6 items</td>
</tr>
<tr>
<td>v.</td>
<td>Ability to carry out simple computation involving mass of substance and time</td>
<td>30, 31 2 items</td>
</tr>
<tr>
<td>vi.</td>
<td>Ability to specify the correct unit of measurement of rate of reaction</td>
<td>26 1 item</td>
</tr>
<tr>
<td>vii.</td>
<td>Ability to identify factors influencing chemical reactions</td>
<td>4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 17, 18, 19, 20, 27, 33, 35, 38, 39, 40 20 items</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>40 items</strong></td>
<td><strong>40 items</strong></td>
</tr>
</tbody>
</table>
 Altogether there are forty (40) items in ACT. The two instruments were given to three doctoral students in chemical education to check considering the level of the students, content and the answers to the question. The students had this assignment for two weeks to enable them do a thorough job. After this period, the investigators had a discussion with the postgraduate students with respect to the validity of the instruments. Some flaws were pointed out and a way out was suggested.

Scoring techniques were then decided. For the calculation involving chemical kinetics (using CKCP) each relevant statement, equation and computation identified in the written work of a student was scored one (1) point. For the ACT, any option chosen by the student was scored one (1) point.

The tests were then administered on thirty SS3 chemistry students in a school that was not chosen for the main study. There was first administration of the tests followed by a second administration of the tests after two weeks. A comparison of the two sets of scores of the CKCP using Pearson’s Product Movement Correlation Coefficient Formula (PPMCCF) gave an r of 0.61. The scoring of the test was considered fairly reliable to be used in assessing the ability of the students to carry out calculations in chemical kinetics. For the ACT, item analyses were carried out on the first set scores which showed a mean facility value of 58% and mean discrimination index of 0.39. Computation of reliability coefficient (using PPMCCF) for the two sets of scores yielded an r of 0.68. The test was considered reliable in measuring the alternative choices of students’ answers to chemical kinetics problems.

The tests were then administered to the students in their various institutions after permissions were sought from their various authorities. For each of the institutions, testing took place during a normal class period in the classrooms. So the institutions’ programmes/activities
were not affected by the administration of the instruments. Three teachers in the secondary school and two lectures from the university volunteered to assist in the invigilation of the students.

CKCP was administered first. Students were allowed 20 minutes. ACT was administered next after a break of 5 minutes. Students were allowed 40 minutes. It is important to note that students were supplied the answer sheets and question papers marked 001 to 107 for the secondary students and 108 to 200 for the university students. Students brought their writing materials to the examination hall.

RESULTS

These are presented according to the research questions of the study.

Research Question 1

What are the general performances of the students in the basic calculation involving chemical kinetics? Is there any significant difference between the mean score of the senior secondary students (SS3) and that of the university students (US) in chemical kinetics calculation?

Results are presented in table 2

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Sd</th>
<th>df</th>
<th>t-value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS3</td>
<td>107</td>
<td>0.89</td>
<td>0.18</td>
<td>198</td>
<td>Significant at p &lt; .05</td>
</tr>
<tr>
<td>US</td>
<td>93</td>
<td>0.75</td>
<td>0.20</td>
<td>5.19</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Mean Scores (X̄) and standard deviations (sd) of SS3 and US students and t-test

Students’ performance in basic chemical kinetic calculation was generally poor with the mean scores less than 1 point. It is observed in table 2 that SS3 students obtained higher mean score than the US in the basic calculation in chemical kinetics. The difference between their mean scores was significant at P < .05 (t = 5.19, df = 198).
Research Question 2

What proportions of the students possess the correct conception and misconception about the questions on chemical kinetics?

This question was answered by considering the various abilities of the students measured in the study. The results are displayed in Tables 3 to 9.

i. Students ability to distinguish between a physical change and a chemical change:

Items 1, 2, 3, of the test (ACT) measured this ability. The results are shown in table 3.

Table 3: Proportion of conception and alternative conception of SS3 and US students in chemical kinetics questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3(%)</th>
<th>US(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Which is an example of a chemical reaction?</td>
<td>A. Melting of Ice</td>
<td>20.0</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. The grinding of salt crystal to powder</td>
<td>12.5</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C The burning of firewood</td>
<td>29.0</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. The evaporation of water from the puddle</td>
<td>38.5</td>
<td>35.8</td>
</tr>
<tr>
<td>2.</td>
<td>Which is a chemical change?</td>
<td>A. Element 1 is hammered into a thin sheet</td>
<td>25.0</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Element 2 is heated and turned into a liquid</td>
<td>19.0</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C Elements 3 turns a greenish colour as it sits in</td>
<td>32.5</td>
<td>32.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>air</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Element 4 is grinded into a fire, slipping powder</td>
<td>23.5</td>
<td>23.8</td>
</tr>
<tr>
<td>3.</td>
<td>Which is not an example of a chemical change?</td>
<td>*A Boiling water</td>
<td>35.5</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Rusting water</td>
<td>31.5</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Burning wood</td>
<td>15.0</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Baking</td>
<td>18.0</td>
<td>17.9</td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)

Task 3 revealed that over 29% of the students possess the correct conception about physical and chemical changes. About 71% possess misconceptions according to the incorrect
options. Higher percentage of the University Students (US) performed better than the secondary students in distinguishing physical change from the chemical change.

ii. Students’ ability to write balanced chemical equations to represent reactions:

Items 13, 14, 23, 32 and 34 of ACT were used to measure the students’ ability.

The results are shown in Table 4.

Table 4: Proportion of conception and alternative conception of SS3 and US students in chemical kinetics questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td>A mixture of powdered iron and sulphur is heated. What will be formed?</td>
<td>A. A single element</td>
<td>20.5</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Two other elements</td>
<td>12.5</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. A solution</td>
<td>29.0</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*D A compound</td>
<td>38.0</td>
<td>42.3</td>
</tr>
<tr>
<td>14.</td>
<td>CaCO₃(S) + 2HCl (aq) → CaCl₂ (aq) + H₂O(l) + CO₂(g). In the reaction, the rate of reaction may be increased by -- --?</td>
<td>*A Using powdered CaCO₃</td>
<td>12.0</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Using lumps of CaCO₃</td>
<td>6.0</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Applying high pressure</td>
<td>31.0</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Using dilute hydro-chloric acid</td>
<td>51.0</td>
<td>42.5</td>
</tr>
<tr>
<td>23.</td>
<td>Which of the following disciplines studies chemical reaction with respect to reaction rate, rearrangement of atoms, formation of intermediate complex?</td>
<td>*A Chemical kinetics</td>
<td>22.0</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Biogeography</td>
<td>15.0</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Biology</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Physical education</td>
<td>43.0</td>
<td>36.9</td>
</tr>
<tr>
<td>32.</td>
<td>Which of the following correctly represents the balanced chemical reaction between aluminum and sulphur?</td>
<td>*A 16Al+3S₂→ 8Al₃S</td>
<td>47.0</td>
<td>50.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. 12Al + S₆→4Al₃S₂</td>
<td>13.0</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. 8Al + S₆→8AlS</td>
<td>22.5</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. 4Al + S₆→4AlS</td>
<td>17.5</td>
<td>15.5</td>
</tr>
<tr>
<td>34.</td>
<td>If additional calcium phosphate is added to the reaction mixture 2H₃PO₄ + 3Ca(OH)₂ → Ca₃(PO₄)₂ + 6H₂O, what will happen to the overall reaction?</td>
<td>A. There will be no change in the overall reaction.</td>
<td>45.5</td>
<td>45.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. The reaction will occur at a faster rate</td>
<td>18.0</td>
<td>20.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C Less of the reactants will react in order to compensate for the increase in the amount of one of the products of reaction.</td>
<td>9.5</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. More of the reactants will have to react in order to compensate for the increase in the amount of one of the products of the reaction.</td>
<td>27.0</td>
<td>23.3</td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)
Table 4 revealed that students that possess the ability to write balanced equations constitute over 9% of the total sample. About 91% have difficulties in writing balanced equations. It was observed that more university students than the secondary students had right conception about writing balanced equations.

iii. Students ability to identify reactants and products of a reaction

Items 16, 28 and 37 were used to measure the students’ ability. The results are displayed in Table 5.

Table 5: Proportion of conception and Alternative Conception of SS3 and US students in chemical kinetics questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Which statement explains why the speed of some chemical reactions is increased when the surface area of the reactant is increased?</td>
<td>A. This change increases the density of the reactant particles.</td>
<td>52.0</td>
<td>36.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. This change increases the concentration of the reactant particles.</td>
<td>38.5</td>
<td>29.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C This change exposes more reactant particles to a possible collision</td>
<td>5.0</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. This change alters the electrical conductivity of the reactant particles</td>
<td>4.5</td>
<td>21.4</td>
</tr>
<tr>
<td>28</td>
<td>Two ways of reacting food with oxygen are…</td>
<td>A. Burning and respiration</td>
<td>5.0</td>
<td>47.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Burning and eating</td>
<td>12.5</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Energy and respiration</td>
<td>50.0</td>
<td>26.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Water and air</td>
<td>32.5</td>
<td>15.9</td>
</tr>
<tr>
<td>37</td>
<td>For most irreversible reactants …</td>
<td>A. The reaction rate increased with time</td>
<td>53.0</td>
<td>39.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*B. The reaction rate decreases with time</td>
<td>11.0</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. The rate stabilizes with time</td>
<td>23.0</td>
<td>31.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. The rate produces a curve with time</td>
<td>13.0</td>
<td>8.3</td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)

For the students’ ability to identify reactants and products of chemical reactions, Table 5 showed that over 5% of the students could do this, while about 95% of the students had
difficulty. It was shown that more university students than the secondary students could identify reactants and products of chemical reactions.

iv. Students’ ability to write rate equations: Items 21, 22, 24, 25, 29 and 36 were used to assess the students’ ability. The results are shown in Table 6.

Table 6: Proportion of conception and alternative conception of SS3 and US students in chemical kinetics questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Which of the following reactions react rapidly at room temperature?</td>
<td>A. $2H_2 + O_2 \rightarrow 2H_2O$</td>
<td>21.0</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. $H^+ + H^- \rightarrow H_2O$</td>
<td>29.0</td>
<td>29.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. $C_12H22O11 + 11H_2O \rightarrow 12C + 1H_2O$</td>
<td>24.5</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. $H + OH \rightarrow H_2O$</td>
<td>25.5</td>
<td>7.2</td>
</tr>
<tr>
<td>22</td>
<td>Which of the following burns easily?</td>
<td>A. A bar of steel</td>
<td>44.0</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Steel wool</td>
<td>17.5</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Steel sheet</td>
<td>14.0</td>
<td>36.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Steel pipe</td>
<td>24.5</td>
<td>17.0</td>
</tr>
<tr>
<td>24</td>
<td>Which of these methods is not used to determine the rate of the reaction?</td>
<td>A. Change in amount of precipitate formed</td>
<td>31.0</td>
<td>21.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Change in intensity of colour</td>
<td>25.0</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Change in pH value</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Change in total gas pressure</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.0</td>
<td>25.9</td>
</tr>
<tr>
<td>25</td>
<td>The energy difference between the reactants and the transition state is</td>
<td>A. The free-energy</td>
<td>27.5</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>..........?</td>
<td>B. The heat of reaction</td>
<td>36.0</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. The activation energy</td>
<td>21.5</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. The kinetic energy</td>
<td>15.0</td>
<td>22.3</td>
</tr>
<tr>
<td>29</td>
<td>If the temperature of a reaction is increased by the reaction will be 20°C</td>
<td>A. Two times as fast</td>
<td>11.5</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Four times as fast</td>
<td>25.0</td>
<td>19.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Twenty times as fast</td>
<td>32.0</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Unchanged because the reaction rate is not dependent on the</td>
<td>31.5</td>
<td>17.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Minimum or critical amount of energy required before a chemical reaction</td>
<td>A. Reaction energy</td>
<td>17.5</td>
<td>17.8</td>
</tr>
<tr>
<td></td>
<td>could occur is called…?</td>
<td>B. Effective collision</td>
<td>34.5</td>
<td>30.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Activation energy</td>
<td>23.5</td>
<td>32.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Activated complex</td>
<td>24.5</td>
<td>19.2</td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)

The results in Table 6 revealed that over 17% of the students showed that they could write rate equations. About 83% had misconception related to the idea of rate equations. It was
also found that more university students than the secondary students could write rate equations or identify related concepts.

v. Students’ Ability to carry out simple computations involving mass of substance and time: Items 30 and 31 were used to assess the students’ ability. The results are shown in Table 7.

Table 7: Proportion of conception and alternative conception of SS3 and US students in chemical kinetics Questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.</td>
<td>When the following reaction equation: ( \text{C}_3\text{H}_8 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} ) is properly balanced, the amount in moles of ( \text{O}_2 ) will be…?</td>
<td>A. 1.5</td>
<td>27.5</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. 3.5</td>
<td>55.0</td>
<td>33.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. 3.0</td>
<td>7.5</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*D. 5.0</td>
<td>10.0</td>
<td>21.0</td>
</tr>
<tr>
<td>31.</td>
<td>When the equation: ( \text{C}<em>6\text{H}</em>{14} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} ) is properly balanced, the amount in moles of ( \text{O}_2 ) will be…?</td>
<td>A. 1.5</td>
<td>39.5</td>
<td>37.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. 13</td>
<td>11.5</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C. 19</td>
<td>9.5</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. 38</td>
<td>39.5</td>
<td>42.1</td>
</tr>
</tbody>
</table>

Table 7 showed that over 9% of the students had the correct conception as regards computations involving mass and time.

vi. Students’ ability to specify the correct unit of measurement of rate of reaction: Item 26 was used to measure the students’ ability. The result is shown in Table 8.
Table 8: Proportion of conception and alternative conception of SS3 and US students in chemical kinetics questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>The unit of rate of chemical reaction is…?</td>
<td>A. moldm⁻³s⁻¹</td>
<td>7.5</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. mol⁻¹s⁻¹</td>
<td>13.5</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C. mol s⁻¹</td>
<td>18.5</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Smol⁻¹</td>
<td>60.5</td>
<td>23.1</td>
</tr>
<tr>
<td>31</td>
<td>When the equation: C₆H₁₄ + O₂ → CO₂ + H₂O is properly balanced, the amount in moles of O₂ will be</td>
<td>A. 1.5</td>
<td>39.5</td>
<td>37.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. 13</td>
<td>11.5</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C. 19</td>
<td>9.5</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. 38</td>
<td>39.5</td>
<td>42.1</td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)

It is shown in table 8 that over 18% of the students could specify the correct unit in measurement involving reaction rate. About 82% of the students are unable to do this. Higher percentage of the university students than of secondary students is able to state the correct units of reaction rates.

vii. Students’ ability to identify factors influencing chemical reactions: Items 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 17, 18, 19, 20, 27, 33, 35, 38, 39, and 40 were used to assess the students’ ability. The results are shown in Table 9.

Table 9: Proportion of conception and alternative Conception of SS3 and US students in Chemical Kinetics Questions

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Questions</th>
<th>Options</th>
<th>SS3 (%)</th>
<th>US (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Why does a catalyst cause a reaction to proceed faster?</td>
<td>A. They are more collisions per second only.</td>
<td>22.5</td>
<td>22.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. The collisions occur with greater energy only</td>
<td>36.5</td>
<td>33.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*C. The activation is lowered only</td>
<td>24.0</td>
<td>23.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. There are more collisions per second and collisions are of greater energy</td>
<td>17.0</td>
<td>20.7</td>
</tr>
<tr>
<td>5.</td>
<td>What happens to a catalyst in a reaction?</td>
<td>*A. It is unchanged</td>
<td>48.5</td>
<td>48.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. It is incorporated into the products</td>
<td>7.5</td>
<td>12.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. It is incorporated into the</td>
<td>4.0</td>
<td>12.6</td>
</tr>
</tbody>
</table>
6. A catalyst works by...?

<table>
<thead>
<tr>
<th></th>
<th>reactants</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Lowering the activation energy barrier</td>
<td>32.5</td>
<td>31.1</td>
</tr>
<tr>
<td>B.</td>
<td>Shifting the equilibrium position towards the product</td>
<td>27.5</td>
<td>33.5</td>
</tr>
<tr>
<td>C.</td>
<td>Changing the temperature of the reactants</td>
<td>30.0</td>
<td>19.3</td>
</tr>
<tr>
<td>D.</td>
<td>Changing the particle size of the reactants</td>
<td>10.0</td>
<td>16.1</td>
</tr>
</tbody>
</table>

7. When oil is burning the reaction will...?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>*A.</td>
<td>Only release energy</td>
<td>50.0</td>
<td>35.3</td>
</tr>
<tr>
<td>B.</td>
<td>Only absorb energy</td>
<td>11.5</td>
<td>19.7</td>
</tr>
<tr>
<td>C.</td>
<td>Neither absorb nor release energy</td>
<td>5.0</td>
<td>7.6</td>
</tr>
<tr>
<td>D.</td>
<td>Sometimes release and sometimes absorb depending on the oil</td>
<td>33.5</td>
<td>11.5</td>
</tr>
</tbody>
</table>

8. What drives chemical reactions?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>*A.</td>
<td>Energy</td>
<td>27.5</td>
<td>28.0</td>
</tr>
<tr>
<td>B.</td>
<td>Activation energy</td>
<td>31.0</td>
<td>30.8</td>
</tr>
<tr>
<td>C.</td>
<td>Electrons</td>
<td>22.0</td>
<td>19.2</td>
</tr>
<tr>
<td>D.</td>
<td>Physical conditions</td>
<td>19.5</td>
<td>22.0</td>
</tr>
</tbody>
</table>

9. You store food in a fridge to prevent spoilage. What factor are you applying to show the rate of reaction?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Nature of reactant</td>
<td>48.5</td>
<td>48.5</td>
</tr>
<tr>
<td>B.</td>
<td>Isolation of reactant</td>
<td>45.0</td>
<td>26.3</td>
</tr>
<tr>
<td>C.</td>
<td>Avoid catalyst</td>
<td>5.0</td>
<td>11.9</td>
</tr>
<tr>
<td>*D.</td>
<td>Temperature</td>
<td>1.5</td>
<td>13.3</td>
</tr>
</tbody>
</table>

10. The purpose of striking a match against the side of the box to light the match is......

<p>| | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>To supply the activation energy</td>
<td>51.3</td>
<td>49.1</td>
</tr>
<tr>
<td>*B.</td>
<td>To supply the free energy of the reaction</td>
<td>20.0</td>
<td>36.8</td>
</tr>
<tr>
<td>C.</td>
<td>To supply the heat of reaction</td>
<td>15.0</td>
<td>9.1</td>
</tr>
<tr>
<td>D.</td>
<td>To catalyze the reaction</td>
<td>13.7</td>
<td>5.0</td>
</tr>
</tbody>
</table>

11. Rate of chemical reaction depends on the following except...

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>*A.</td>
<td>Rate at which gas is evolved</td>
<td>18.5</td>
<td>25.4</td>
</tr>
<tr>
<td>B.</td>
<td>Rate at which product is formed</td>
<td>31.0</td>
<td>23.2</td>
</tr>
<tr>
<td>C.</td>
<td>Rate at which colour of reaction change</td>
<td>25.0</td>
<td>24.3</td>
</tr>
<tr>
<td>D.</td>
<td>Rate at which reactant diminish</td>
<td>50.0</td>
<td>35.1</td>
</tr>
</tbody>
</table>

12. Reaction rears when the colliding reactant particles.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Have energy less than the energy barrier</td>
<td>23.5</td>
<td>29.0</td>
</tr>
<tr>
<td>B.</td>
<td>Have energy equal or greater than the energy barrier</td>
<td>25.0</td>
<td>24.3</td>
</tr>
<tr>
<td>*C.</td>
<td>Have energy less than effective collision</td>
<td>20.5</td>
<td>23.5</td>
</tr>
</tbody>
</table>
15. Which statement describes characteristics of an endothermic reaction?

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The sign of H is positive and the products have less potential energy than the reactants.</td>
<td>3.5</td>
</tr>
<tr>
<td>B*</td>
<td>The sign of H is positive and the products have more potential energy than the reactant.</td>
<td>19.0</td>
</tr>
<tr>
<td>C</td>
<td>The sign of H is negative and the product have less potential energy than the reactants.</td>
<td>25.0</td>
</tr>
<tr>
<td>D</td>
<td>The sign of H is negative, and the products have more potential energy than the reactants.</td>
<td>24.7</td>
</tr>
</tbody>
</table>

17. Which conditions will increase the rate of a chemical reaction?

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>Decrease temperature and increase concentration of reactants</td>
<td>27.5</td>
</tr>
<tr>
<td>B</td>
<td>Decrease temperature and increase concentration of products</td>
<td>19.5</td>
</tr>
<tr>
<td>C</td>
<td>Increase temperature and decrease concentration of reactants</td>
<td>20.5</td>
</tr>
<tr>
<td>D</td>
<td>Increase temperature and increase concentration of reactants</td>
<td>29.6</td>
</tr>
</tbody>
</table>

18. In a chemical reaction, a catalyst changes the....?

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>Potential energy of the products</td>
<td>32.5</td>
</tr>
<tr>
<td>B</td>
<td>Potential energy of the reactants</td>
<td>15.0</td>
</tr>
<tr>
<td>C</td>
<td>Heat of reaction</td>
<td>27.0</td>
</tr>
<tr>
<td>D</td>
<td>Activation energy</td>
<td>50.0</td>
</tr>
</tbody>
</table>

19. Which procedure will increase the solubility of KCl in water?

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>Stirring the solute and solvent mixture</td>
<td>12.5</td>
</tr>
<tr>
<td>B</td>
<td>Increasing the surface area of the solute</td>
<td>24.0</td>
</tr>
<tr>
<td>C</td>
<td>Raising the temperature of the solvent</td>
<td>32.5</td>
</tr>
<tr>
<td>D</td>
<td>Increasing the pressure on the surface of the solvent.</td>
<td>32.1</td>
</tr>
</tbody>
</table>

20. Reactions are generally faster at high temperature because the ...

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Activation energy increases</td>
<td>31.0</td>
</tr>
<tr>
<td>B*</td>
<td>Energy of the product is lowered</td>
<td>48.5</td>
</tr>
<tr>
<td>C</td>
<td>Energy of the reactant decreases</td>
<td>5.5</td>
</tr>
<tr>
<td>D</td>
<td>Number of effective collision</td>
<td>20.5</td>
</tr>
</tbody>
</table>
27. Why does a catalyst cause a reaction to proceed faster?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>A. There are more collisions per second only</td>
<td>25.5</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>B. The collision occurs with greater energy only</td>
<td>25.0</td>
<td>17.3</td>
</tr>
<tr>
<td>*C. The activation is lowered only</td>
<td>10.0</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D. There are more collisions per second and collisions are of greater energy</td>
<td>35.0</td>
<td>37.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30.0</td>
<td>29.9</td>
</tr>
</tbody>
</table>

33. Which of the following would not increase the rate of reaction?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. Raising the temperature</td>
<td>31.0</td>
<td>35.1</td>
</tr>
<tr>
<td></td>
<td>B. Adding a catalyst</td>
<td>42.0</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td>C. Increasing the surface area of a solid reactant</td>
<td>7.0</td>
<td>11.2</td>
</tr>
<tr>
<td>*D. None of the above</td>
<td></td>
<td>20.0</td>
<td>33.4</td>
</tr>
</tbody>
</table>

35. Which of the following statements about chemical kinetics is not correct?

<p>| | | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>*A. The higher the activation energy, the faster the reaction</td>
<td>10.5</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>B. The lower the activation, the faster the reaction</td>
<td>24.0</td>
<td>24.3</td>
</tr>
<tr>
<td></td>
<td>C. The higher the temperature, the faster the reaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D. The activation of a catalyst lowers the activation energy</td>
<td>15.5</td>
<td>16.0</td>
</tr>
</tbody>
</table>

38. What do we do to increase the surface area of the reactant?

<p>| | | | |</p>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. Breaking them into chips</td>
<td>42.0</td>
<td>37.4</td>
</tr>
<tr>
<td>*B. Subjecting the reactants to higher pressure</td>
<td>10.5</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. Altering the direction of the reaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D. Using reactant to different densities.</td>
<td>15.0</td>
<td>27.1</td>
</tr>
</tbody>
</table>

39. Which of the following does not affect the rate of a chemical reaction between non-gaseous reactants?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. Concentration of reactants.</td>
<td>32.5</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>B. Pressure</td>
<td>24.0</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>C. Temperature</td>
<td>31.5</td>
<td>29.9</td>
</tr>
<tr>
<td></td>
<td>D. Presence of a catalyst</td>
<td>17.0</td>
<td>23.1</td>
</tr>
</tbody>
</table>

40. Temperature affects rate of reaction exception...?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. Increase in frequency of collision.</td>
<td>29.5</td>
<td>35.3</td>
</tr>
<tr>
<td></td>
<td>B. That it burns the reactants with reckless heating.</td>
<td>20.0</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>C. It increases the kinetic energies of the reactant</td>
<td>32.5</td>
<td>24.9</td>
</tr>
<tr>
<td>*D. The number of effective collision of the reaction</td>
<td>18.0</td>
<td>22.2</td>
<td></td>
</tr>
</tbody>
</table>

* - correct answers (conceptions)
Table 9 revealed that apart from item 9 concerning temperature as one of the factors influencing rate of reaction over 10% of the students were able to identify the various factors affecting chemical kinetics. About 90% of the students had misconceptions related to chemical kinetics factors. More university students than the secondary students had correct conceptions about the factors influencing rate of reactions. These findings need to be discussed.

DISCUSSION OF FINDINGS

Generally, students’ performance in basic chemical kinetic calculation was poor with the mean scores less than one point. Cakmakci [6] and Cunningham [7] have reported the difficulties students have in learning concepts and related concepts of chemical kinetics. The nature of chemical reaction in chemical kinetics involving breaking and making of bonds and election transfer is such that the students can hardly conceptualize. This problem is recurrent as the students’ progress from the secondary schools to the tertiary institutions.

Overall analyses (Tables 3-9) of the conception test revealed that about 10% of the students are able to identify the correct answers while about 90% could not identify the correct answers. This further suggests the degree of difficulty encountered by the students in learning chemical kinetics, the importance of this concept notwithstanding.

There is an issue that is noteworthy as to the performance of the secondary students and the university students. Namely, the senior secondary students were significantly better than the university students (Table 2) in carrying out elementary calculations in chemical kinetics. This may not be surprising because the chemistry course in chemical kinetics is more complex than the fundamentals at the senior secondary level. Generally the test items were elementary and at the fundamental level which the university students have studied long time ago and must have
been overtaken by forgetfulness. The senior secondary students had an edge over the university students and so performed better than them. However, item analyses of the conception test showed the superiority was displayed by the university students in their better performance than the secondary students.

It behoves on the chemical educators to query the poor performance of the secondary students considering the fact that they are to pass into the higher institutions to study chemistry and have to come across chemical kinetics. Considering the results of the study, further research will be carried out to determine how the differential in the students’ performance could be used to determine growth in chemical knowledge.

REFERENCES
The African Journal of Chemical Education (AJCE) is a biannual online journal of the Federation of African Societies of Chemistry (FASC). The primary focus of the content of AJCE is chemistry education in Africa. It, however, addresses chemistry education issues from any part of the world that have relevance for Africa. The type of contents may include, but not limited to, the following:

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**REVIEWS** presenting a thorough documentation of subjects of current interest in chemical education.

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**SCIENTIFIC THEORIES** describing the scientific, historical and philosophical foundations of theories and their implications to chemical education.

**ACTIVITIES** describing a hands-on activity that can be done in the classroom or laboratory and/or as a take home project.

**INDIGENOUS KNOWLEDGE AND CHEMISTRY IN AFRICA** as a special feature that addresses the relationship between indigenous knowledge and chemistry in Africa. It could be in the form of an article, a note, an activity, commentary, etc.

**LETTER TO THE EDITOR**: A reader response to an editorial, research report or article that had been published previously. The short piece should contribute to or elicit discussion on the subject without overstepping professional courtesy.

All manuscripts must be written in English and be preferably organized under the following headings: a) **TITLE**, Author(s), Address(es), and **ABSTRACT** in the first page, b) **INTRODUCTION** reviewing literature related to the theme of the manuscript, stating the problem and purpose of the study, c) **METHODOLOGY/EXPERIMENTAL** including the design and procedures of the study, instruments used and issues related to the reliability and/or validity of the instruments, when applicable, d) **RESULTS AND DISCUSSION**, e) **REFERENCES** in which reference numbers appear in the text sequentially in brackets, each reference be given a separate reference number, *et al* and other notations like *Ibid* are avoided, and finally f) **ACKNOWLEDGEMENTS**.

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