

Teaching of Chemical Equilibrium at Further Education and Training Band: Problems and Prospects

Godfrey Pisirai Marumure

University of South Africa, Pretoria, South Africa

Chemical equilibrium, a school topic, where learners manifest many misconceptions. The manifestation of misconceptions is considered as a reason for exploring problems and prospects of teaching chemical equilibrium. An exploratory survey, descriptive in nature was conducted in the Thohoyandou cluster of schools in the Vhembe district of the Limpopo province. Forty educators responded to questionnaires while five "well experienced" educators and two subject advisors were interviewed. The study showed educators' deficiency in subject content knowledge and pedagogical skills to address abstract concepts. Conceptually incorrect, inappropriate, or irrelevant practical experiments, demonstrations, and analogies are used in teaching chemical equilibrium concepts formed part of the findings. Systematic professional development on subject content matter and pedagogical skills are recommended.

Keywords: misconceptions, chemical equilibrium, dynamic equilibrium, pedagogical knowledge, subject content knowledge

Background

During examinations, many learners show misconceptions on chemical equilibrium. For instance, using the following chemical equation of a chemical reaction at chemical equilibrium in a closed container:

$$3H_{2(g)} + N_{2(g)} \leftrightarrows 2NH_{3(g)}\Delta H < 0 \tag{1}$$

When a system is at chemical equilibrium, many learners are quick to say:

- 1. The rate of the forward and reverse reactions is constant (Department of Basic Education [DBE], 2012);
- 2. Apply more pressure to the reactants and equilibrium will shift (DBE, 2014);
- 3. At equilibrium, the concentration of reactants is equal to the concentration of products (DBE, 2012).

Similar learners' misconceptions were reported by Hinton and Nakhleh(1999), Johnstone (2000), Chiu, Chou, and Liu (2002), Van Driel (2002), and Doymus (2008). The misconceptions show learners' lack of conceptual understanding of chemistry concepts. Prevalence of such misconceptions prompts investigating the teaching of chemical equilibrium concepts. The existence of such learners' misconceptions affects the learning of related chemistry concepts as prior knowledge can facilitate, retard, or hinder the learning process (M. Hewson & P. Hewson, 1983; Kilbane & Milman, 2014; Yuksel, 2012).

The Aim of the Study

The study aimed to investigate the problems and prospects of teaching the concepts of chemical equilibrium at the further education and training (FET) band.

Godfrey Pisirai Marumure, Ph.D. candidate, Institute for Science and Technology Education, University of South Africa.

Specifically, it was to:

- (a) identify problems of teaching the topic of chemical equilibrium at the FET band;
- (b) explore why these problems exist;
- (c) identify prospects of teaching concepts of chemical equilibrium to improve the quality of teaching.

The Scope and Delimitation of the Study

The study is limited to educators' problems in teaching concepts of chemical equilibrium and prospects of teaching concepts at the FET band outlined in the Curriculum and Assessment Policy Statement (CAPS) document (DBE, 2011).

Relevant concepts are divided into key terms and basic concepts for easy identification of relationships. Key terms are in everyday life used in a different context than the specific meaning in chemistry. Examples of such key terms are concentration, constant, disturbance, state of balance, system, equilibrium, and shift among others. Basic concepts are defined as concepts that characterise chemical equilibrium, for instance, reversible reactions, dynamics of chemical equilibrium, equilibrium constant, and incompleteness of reaction (Quilez, 2007).

Theoretical Framework and Related Literature Review

The theoretical framework that underpins this study is Novak's Theory of Education which emphasises meaningful learning. Meaningful learning is guided by a framework of elements in education, which are educator, learner, content, context, and evaluation. According to Novak (2011), constructive integration of these elements result in meaningful learning and the role of the educator is to critically facilitate the learning process which requires the dominance of subject content knowledge and a high level of pedagogical skills (Hume, 2010; Rollinick & Mavhunga, 2015).

Teaching chemical equilibrium concepts considers the nature of chemistry as a subject. Chemistry is said to exist at three operational levels: the macroscopic, microscopic, and the symbolic representation (Johnstone, 2000; Taber, 2013; Talanquer, 2011). Effective teaching strategies that assist learners to switch between operational levels are considered very necessary in chemistry (Ghirardi, Marchetti, Pettinari, Regis, & Roletto, 2014; Johnstone, 2000; Talanquer, 2011).

Practical experiments/demonstrations, models, and modeling are considered central in chemistry teaching as theyform part of chemistry epistemology and philosophy (Erduran & Mugaloglu, 2014). Furthermore, practical experiments/demonstrations serve one or more of the purpose of proving a theory, principle, or natural law, ascertain some claims made or introduce a new concept to learners (Harman, Cokelez, Dal, & Alper, 2016). Therefore, selection criteria for practical experiments, demonstrations, models, and/or modeling remains critical for many chemistryconcepts. This makes the "when," "what," and "how" questions fundamental in ensuring more learning is achieved from the activities. The significance of teaching strategies depends on the emphasis placedon its strength, for instance, when, where, and how to use prediction-observation-experiment (POE) in-class demonstration (Dudu & Vhurumuku, 2012).

The abstract nature of chemistry concepts makes it of the utmost importance to assist learners in generating mental models of the scientific concept(s). Facilitation in teaching chemistry remains contentious while emanating from the general problems of chemistry that range from the philosophy of chemistry, supervenience, and chemistry as a language (Erduran & Mugaloglu, 2014).

Osamwonyi (2016) and Wilson and Peterson (2006) argued that lack of in-service training of educators and educators' resistance to change from the old style of teaching and application of appropriate educational theories are among major problems in teaching. However, Vamvakeros, Pavlatou, and Spyrellis (2010) reported that educators' participation in the designing and implementation of professional development that incorporates educator beliefs on conceptual understanding and change has been more successful.

Methodology

A sequential mixed-method approach was used on this exploratory survey in the Thohoyandou cluster of schools in the Vhembe District of South Africa among physical science (chemistry) educators. A random sampling method was adopted in selecting 40 participants who responded to questionnaires for the study. In addition, five well-experienced educators and two subject advisors selected through purposive sampling were interviewed. The statistical data were analysed using Statistic Package for Social Science (SPSS) and qualitative data analysed through content analysis.

Data Presentation and Analysis

Research results presented in the form of text, tables, and graphs.

Correlation of Ed	ducators' Confidence in Te	eaching Basic Con	cepts of Chemic	al Equilibrium	
		Reaction incompleteness	Reversibility	Chemical dynamics	Equilibrium Constant (K _c)
Reaction incompleteness	Correlation coefficient	1.000	0.777^{*}	0.688^*	0.513*
	Ν	37	37	37	37
Reversibility	Correlation coefficient	0.777^*	1.000	0.708^{*}	0.446^{*}
	Ν	37	40	40	40
Chemical dynamics	Correlation coefficient	0.688^{*}	0.708^{*}	1.000	0.752^{*}
	Ν	37	40	40	40
Equilibrium constant (K _c)	Correlation coefficient	0.513^{*}	0.446^{*}	0.752^{*}	1.000
	Ν	37	40	40	40

 Table 1

 Correlation of Educators' Confidence in Teaching Basic Concepts of Chemical Equilibrium

Note. * Spearman's rho correlation is significant at the 0.05 level (2-tailed).

The correlation coefficients of educators' confidence in teaching basic concepts of chemical equilibrium are statistically significant. All variables have a positive correlation at p < 0.05 significance level. The strongest correlation is between reaction incompleteness and reversibility of reaction at 0.777. The weakest correlation is between reaction reversibility and equilibrium constant at 0.446, the only correlation coefficient below 0.500. The results show a high degree of association of the confidence of educators to teach the basic concepts of chemical equilibrium although only 37 educators indicated their level of confidence to teach incompleteness of reaction.

Participants cited practical experiments/ demonstrations and analogies used on basic concepts of chemical equilibrium. These were classified according to the concept addressed (see Table 2).

A: Reversible reaction for NH₄Cl when heated and cooled. B: Elevator demonstration of reversible Reaction. C: Effects of concentration on chemical equilibrium CoCl₄. D: Water-steam for a reversible reaction. E: Effects of pressure $N_2O_{4(g)}/2NO_{2(g)}$. Observing colour change. F: Effect of temperature NO_2/N_2O_4 . G: Reversible reaction $CoCl_4^{2-}/Co(H_2O)_6^{2+}$. H: MnO₄⁻ with OH⁻ and H⁺. I: Place HNO_{3 (conc)} in clear, in an amber

bottle outside in sunlight/ dark. J: $Cr_2O_7^{2-} + H_2S \rightleftharpoons 2Cr^{3+} 3S + H_2O$. K: $HCl + H_2O \leftrightarrows H_3O^+ + Cl^-$. L: Changes in colour of acid/base indicator. M: Acid-base titration. N: Burning magnesium in air. O: Use a scale balance to explain equilibrium. P: Precipitation of Ag^+ with halides. Q: Water in container allowed settling. R: Water poured in a container until equilibrium is reached. S: Disturbing reaction equilibrium (use of HCl, NaOH, and $K_2Cr_2O_7$). T: Reaction of water and copper sulphate. U: $Na^+ + Cl^- \rightarrow NaCl_{(aq)}$. V: Tug of war. W: HCl and Zn. X: Sugar + H₂O. Y: Potassium Permanganate + Glycerine

Frequency (%) =
$$\frac{Number of times for all experiments for each concept}{Total number of all experiments , demonstrations cited} x 100$$
 (2)

Two other categories emerged from the classifications, experiments/demonstrations, and analogies related to chemical equilibrium (53.7%) and those not related to chemical equilibrium (solubility and static equilibrium) (43.3%). Solubility and static equilibrium facilitate learners to view chemical equilibrium as static rather than dynamic.

Table 2

Classification of Experiment/Demonstration to Concept Applied

Concept		Experiment/Demonstration	Frequency (%)
Reaction reversibility		A, B, D, G	18.75
	Effect of concentration	C, H, J, L, M	22.92
Chemical dynamics factors	Effect of temperature	F, I	6.28
on equinorium position	Effect of pressure	E	8.33
Solubility equilibrium		K, P, T, U, W, X	22.92
Static equilibrium		N, O, Q, R, S, V, W, Y	20.83

Participants identified sources of problems of teaching chemical equilibrium. These were classified into either learner-centred or educator-centred category (see Table 3).

Table 3

Category	of Sources	of problem	ıs
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Learner-centred	Educator-centred	
A: Learners have problems in Mathematics, problems in doing calculations.	D: Educator following steps up to the end of a K_c problem.	
B: Learners unable to apply Le Chatelier's principle.	F: To come up with practical examples in this section which	
C: Most learners have a haze understanding of English.	learners will be able to observe and imagine.	
E: Most learners cannot write and balance simple equations.	H: Most reactions not followed by observable changes as colour and temperature.	
G: Learners visualize equilibrium as static.	L: Teaching concepts as separate entities.	
J: Lack of background knowledge on basic concepts of chemical reactions and energetics.		
K: Learners' inadequate and inaccurate prior knowledge of equilibrium.		
M: Lack of logical thinking by learners		

The educator-centred sources of problems category were sub-divided into subject matter knowledge and pedagogical skills knowledge. The subject matter knowledge deficiency was highlighted. On pedagogical skills, sources of problems category included the inability to interrelate and contextualise concepts. On learner-centred sources of problems category, there was low numeracy and literacy level, inadequate and inaccurate conceptual prior knowledge on chemical equilibrium, and haze understanding of English used as a

medium of instruction.

Participants indicated the prospects of teaching concepts of the teaching of chemical equilibrium. These were summarised in Figure 1.



Figure 1. Prospects of improving the quality of teaching chemical equilibrium.

Provision of in-service training emerged most, cited by 45.62% of participants. Educators realised their shortcomings in teaching and resulted in advocating for in-service training. Educator isolation was viewed as detrimental to improved teaching as there is no opportunity to discuss challenges encountered in the subject area and learn from colleagues (Gore, Llyod, Smith, Bowe, Ellis, & Lubans, 2017).Networking and improved human resource support enhance the chances of minimising the challenges encountered.

Topic content knowledge dominance and pedagogical skills remain vital in the teaching of any concept. Conceptual errors are prevalent in educators' conceptual knowledge framework for chemical equilibrium. Participants' responses show a degree of overconfidence as reflected by the high correlations coefficient in confidence to teach basic concepts of chemical equilibrium. Overconfidence of educators hurt teaching as demonstrated by interviewees, Educator 1 (T_1), T_2 , and T_3 . Considering that the basic concepts are well connected, manifesting misconceptions in one has a replica negative effect on other concepts.

Participants had problems in explaining the incompleteness of a reversible reaction. For instance, T1

.... the incompleteness of a reversible reaction can be due to factors which affect the rate of reaction, for example, little concentration can lead to the incompleteness of reaction but if we put more concentration of the reactant, then we can have some completeness

According to the educator, concentration determines whether the reaction should get to completion or not. Reference made to a reversible reaction as complete yet there is a continuous movement of particles at the microscopic level even when at macroscopic level there seems to be nothing happening when the reaction has reached chemical equilibrium.

Participants struggled to connect key terms and basic principles while explaining the basic concepts. For instance, T_3 on reversibility,

... dynamic equilibrium means the forward and reverse reaction are equal, therefore that is why it is reversible. It

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means the reverse reaction will go in the forward direction and thereafter it could reverse again

There is a manifestation of limited understanding of the behaviour of particles at the microscopic level of representation in a reversible reaction. Scientifically, dynamic equilibrium is when the rate of the forward reaction equals the rate of the backward reaction.

There is a general view that chemistry is a practical subject resulting in practical work viewed as "modus operandi" for teaching chemistry concepts without asking whylearners get engaged in these practicals (Abrahams & Reiss, 2012; Lewthwaite, 2014). In facilitating learning, a mishmash of instructional models proposed to assist learners to increase conceptual understanding (Ainsworth, 2006). Although the selection and use of models and modeling need contextualisation to allow learners re-connect, they should be fit for purpose. Class demonstrations, laboratory practicals, and computer simulations, have been considered to improve learner interest in the work at hand although the level of learning success achieved is not ascertained (National Research Council, 2011; Taber, 2014; Toplis, 2012).

A high level of pedagogical skills entails capitalising on existing learner-centred problems that were cited, convert them into baseline knowledge for learning chemical equilibrium concept, yet these we reviewed as obstacles or hindrances to teaching and learning. Educator-centered problems show lack of flexibility in manipulating prevailing conditions to meaningful teaching of concepts. Participants admitted lack of skills through requesting for In-Service Education and Training (INSET). Experienced educators suggested uniformity on educators' approach on a particular topic (T_1 and T_2) to allow narrowing the performance gap between learners from different schools in national examinations.

Rates of reaction were viewed by participants (T_1 and T_2) as necessary conceptual prior knowledge that enhances the learning of chemical equilibrium. Learners' textbooks (Jones, Davies, & Mgoqi, 2007; Kelder, D. Govender & J. Govender, 2007) use the following statement to represent a chemical reaction at equilibrium:

$$aA + bB \leftrightarrows cC + dD$$
 (3)

They deduce equilibrium constant (K_c) as:

$$Kc = [C]^{c} [D]^{d} / [A]^{a} [B]^{b}$$
 (4)

Most learners incorrectly write the K_c expression for specific reactions, they retain the example as the K_c expression. T_1 referred to A, B, C, and D as variables that only represent reactants and products that depend on each particular reaction. Several examples of chemical reactions are given to learners to come up with K_c expression applying the variables. Educators T_2 , T_3 , T_4 , and T_5 made no mention of how to address the problem although the problem has always persisted (Kousathana & Tsaparlis, 2002).

The problem of teaching concepts as isolated entities resulted in learners' lack of scientific logical thinking, having inadequate and unstructured knowledge framework with knowledge gaps. A consistent systematic approach in teaching concepts could be adapted for instance the "anarchistic" model of problem-solving that involves several steps covered under the four-cycle: understanding the problem, devising a plan, carrying out the plan, and looking back (Bodner, 2015). This kind of approach discourages lateral thinking but a holistic approach that responds to what, when, how, and why as not only to surface knowledge dealt with but conceptual knowledge as well.

Frequently conducting in-service training of educators on basic practical experiments and demonstrations on teaching particular concepts of chemical equilibrium is critically important (Gore et al., 2017; Kriek & Grayson, 2009). POE can be a more positive approach to use on experimental work (Chiu, Chou, & Liu, 2002;

Lewthwaite, 2014), especially when using experiment activities that are "simple and clearly show elements" of chemical equilibrium.

Practical experiments/demonstrations and analogies reduce communication breakdown between learners and subject language. Educators used analogies to demonstrate concepts, for example, "the tug of war or filling a cup with water" and say equilibrium is reached. The analogies are meaningless without further explication and analysis. Johnstone (2000) suggested the use of three-dimensional analogical modelsthat show all three chemistry operational levels. The use of analogies with clear parameters of observation that do not contradict with characteristics of the scientific concept is considered vital when demonstrating concepts. In this case, chemical equilibrium is viewed as static rather than dynamic. To negotiate the conceptual outcome Ainsworth (2006) and Harrison and De Jong (2005), suggested providing clarification where the analogy breaks down. This entails providing learners with the opportunity to suggest their analogical models show their understanding of the concept which facilitates the negotiation of a clear and explicit explanation of where the analogy links with the concept.

Participants were conscious of their incompetence in both subject matter knowledge and pedagogical skills, as a result, emphasized requesting for in-service training.

Conclusions and Recommendations

The major findings of the study are deficiencies in topic content knowledge and pedagogical skills of educators. Educators showed a glimpse of declarative knowledge with minimum conceptual and procedural knowledge on chemical equilibrium. The existence of incomplete and unstructured conceptual knowledge framework resulted in teaching concepts as isolated entities. Educators consider chemistry a practical subject, therefore practical experiments/demonstrations and analogies are prescriptive although the majority fails to serve their purpose, as they are inappropriate and irrelevant.

Prospects of teaching chemical equilibrium are educators-centred on addressing problems of subject matter knowledge, pedagogical skills, and pedagogical content knowledge. The following recommendations are made:

Table 4

Basic concept		Experiment	
Reaction reversibility		Boiling water in a closed container	
		Warming NH ₄ Cl in a closed test tube and use wet red and blue litmus paper	
		CoCl ₄ ²⁻ /Co(H ₂ O) ₆ ²⁺	
Reaction incompleteness		Warming NH ₄ Cl in a closed test tube and use wet red and blue litmus paper	
		Boiling water in a closed container	
Chemical dynamics	Effect of concentration	$Cr_{2}O_{7}/CrO_{4}^{2}$	
	Effect of concentration	CoCl ₄ ²⁻ /Co(H ₂ O) ₆ ²⁺	
	Effect of temperature	NO_2/N_2O_4	
		$CoCl_4^{2-}/Co(H_2O)_6^{2+}$	
	Effect of pressure	NO ₂ /N ₂ O ₄	

Proposed Experiments to Demonstrate Basic Concepts

Systematic implementation of recommendations in a "sequential" order. Professional development on content matter of chemical equilibrium is primary before emphasis on pedagogical skills. The subject matter knowledge includes addressing the key terms and designing criteria for identifying suitable practical

experiments for demonstrating basic concepts. As an example, the following set of experiments selected based on simplicity, relevance, and accessibility of parameters for demonstrating basic concepts of chemical equilibrium (see Table 4).

Pedagogical knowledge and skills professional development focusing on using class experiments or demonstrations for inductive or deductive purposes be a priority. Emphasis on the integration of practical experiments/demonstrations, models, and modeling into active teaching strategies. Emphasise facilitation skills rather than content knowledge transfer. Institutionalise reflective approach through learners comparing key terms' everyday use and under chemical equilibrium, even for other chemistry topics. Consistency in applying the three operational levels allow learners to see the interconnection.

Professional development on pedagogical skills on employing active teaching strategies, such as problem-solving, scientific augmentation, inquiry-based teaching, process-oriented instruction (POI), and POE that requires "mastery of topic content matter" on chemical equilibrium recommended. Professional development for educators is a process rather than an event.

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