ENHANCING TEACHER TRAINEES' UNDERSTANDING ABOUT CHEMICAL REACTIONS AND EQUATIONS

Ruby Hanson
University of Education, Winneba
Ghana
maameruby@yahoo.com

ABSTRACT

Teacher trainees with misconceptions about chemical phenomena tend to pass this on to their students, thereby creating a vicious cycle of misconceptions which are often difficult to break among learners. This article presents the use of micro chemistry activities and worksheet activities in remediating identified alternative conceptions about types of chemical reactions and their diverse representations among 74 chemistry teacher trainees. The design adopted for the study was a case study which followed the pre- test, post-test, delayed test approach in order to assess trainees' retention of desired basic concepts about types of chemical reactions. The study which lasted for four weeks exposed the trainees' weaknesses about the nature of matter, types of chemical reactions and their representations. Remediation was offered to enable the trainees to distinguish between types of chemical reactions, with a success rate of 85%. The tools used in this study were found to have great potential in uncovering, deconstructing, and remediating trainees' misconceptions as well as equipping them with skills, such that authentic conceptions were built at the end of the study period.

Keywords: chemical equation, chemical reaction, conceptions, representational levels.

INTRODUCTION

Chemistry is basically a laboratory science with many abstract concepts and frameworks which must be learned through robust laboratory or hands-on activities. One abstract concept that students have to deal with is chemical reactions, the formation of chemical compounds, and their representations at various levels; yet it is a pre-requisite to understanding the principle of compound formation. Students have been known to struggle with chemical reaction types in first year general chemistry (du Toit, 2016). This is because the abstract nature of chemistry, and imaging events between different representational levels, makes it difficult for them to form mental models of the true events. Representation of chemical reactions could be in word, symbolic, sub microscopic, macroscopic or diagrammatic form. This could be a challenge for students.

Word equation is shorthand used to describe chemical reactions in a vivid and conversational form. It is a descriptive chemical language and a heuristic tool, while symbolic representations require the use of chemical symbols and formulae. The sub microscopic level presents ions, atoms or other particles that engage in bonding to result in another substance. Diagrammatic representations require pictorial models (2- or 3-dimensional models) of species in their elemental (ionic, atomic or molecular) state. Due to this complexity, teachers' lack of content knowledge, pedagogy, and ineptitude in organising concept-based activities could inadvertently cause learners to develop alternative conceptions (ACs). This implies that, chemistry student-teachers (herein called teacher trainees or trainees) who may be prospective classroom and laboratory teachers must master important basic chemical concepts, as well as innovative ways of teaching and representing them so that the vicious cycle of teacher-made and non-scientific misconceptions could be broken with their students. One successful way of forming concepts could come through building linkages between 'hard core science' and real life practices as well as through regular hands on activities so that patterns could be formed from repetitive action.

Science and chemistry in particular, is a practical discipline where activities have to be regularly performed by students for first hand observation, in order to experience refutation, re-organisation, confirmation, and subsequent acquisition of concepts and skills through the formation of patterns by distinction, through repetitive or recurring processes. A chemical reaction equation is a unique feature of chemistry and chemistry education that enables students to appreciate changes in chemical phenomena. Yet, the abstract and condensed formulation of these equations often presents numerous challenges for students. Chemical equations contain an array of descriptive and conceptual details. They display not only the conversion of reactants into products, but also provide the basis for stoichiometric calculations or for deriving reaction mechanisms. This causes a lot of difficulties for learners as they have to grapple with specialised language, problems with the meaning of terms and functions, as well as with the syntax of chemical formulae (Justi, Gilbert, & Ferreira, 2014; Taskin & Bernholt, 2014).

The challenges that students face in representing chemical reactions and distinguish them into their peculiar types have come up at several Departmental and Academic Board meeting at the University where this study was done. Besides, it has featured severally in the report from the chief examiners of the national examining body for secondary schools- the West African Examinations Council (WAEC) (WAEC, 2013-2016). Since no literature was found on the causes of trainees' underperformance in identifying types of chemical reactions and their representations at the three main levels, it was considered expedient to investigate how micro scale chemistry activities (MSC) accompanied by worksheet activities would affect trainees at the University of Education's understanding about chemical reactions.

The main chemical reaction types that students must deal with in pre-tertiary and beginning undergraduate years are replacement, displacement, neutralisation, oxidation, reduction, synthesis and thermal decomposition reactions. It is important that they are able to decipher among these types using basic differentiations, principles, and distinguishing characteristics, so that characterisation becomes easy. Their knowledge of names of elements, radicals, symbols and formulae become useful in such instances.

Students' conceptions about chemical symbols, formulae and equations as well as the link between the macro and microscopic worlds have been extensively researched (Nakhleh, 1996; Kirman Bilgin, Demircioglu Yurukel, & Yigit, 2017). Findings from these studies indicate that teachers do not teach these multiple representations clearly and move among them in an uncoordinated manner, to the neglect of students' challenges (Hanson, 2017). Besides students' inabilities to connect the three levels of representations of matter, they further cannot identify changes that accompany chemical reactions which result in the formation of chemical compounds. The observed changes that primarily occur during chemical reactions include colour change, the evolution of gas, the disappearance of a solid reactant, the evolution or absorption of heat, and the appearance of a precipitate. Yet, it is difficult for most undergraduate students to use these criteria or indicators for determining whether a chemical reaction has occurred in an obvious demonstrable way or not. These obvious observations could help students to develop patterns into which they can classify reaction types so that in cases where no observable reactions may occur, their knowledge about reaction types based on reactants which have been learned in an obvious demonstrable way can enable them to place the unobtrusive reactions correctly. This is easily possible and has been used by some researchers with success. Hanson (2016) used changes in colour (one of the basic factors for identifying a chemical change) to enable students to understand Le Chatelier's summation of some stress factors on equilibrium position. Thus, one's ability to employ such indicators as a key to identifying types or changes in chemical behaviour is important. In Hanson's study, prior to this activity, her students had challenges in understanding or imagining how excesses of species could change equilibrium position and their implications. However, the idea of colour change (visualisation) enabled students to appreciate how systems behaved to relieve stress and thereby affect equilibrium position. The way trainees used change in colour to explain the phenomena of Le Chatelier's summation of stress effects showed that they were able to understand the forms and functions of the stress factors as well as the relationships between the operating concepts within the macro and symbolic levels as they were able to build representational mental models of given events. This reiterates the possibility of using other distinguishing characteristics of changes in chemical phenomena to enhance conception in the identification and expression of chemical reactions and equations as students build mental models that would be useful to solve abstract problems involving chemical reactions.

It is common knowledge that majority of teachers use the lecture method which studies have shown not to be favourable for students in constructing knowledge. This is because students remain largely passive in the teacher-centred environment and accept whatever knowledge that the teacher gives to them, with very little challenge or participation and sometimes none at all. In such situations, students' naive ideas are neither unveiled nor challenged. Thus, in most cases, they also find it difficult to accept new ideas from their teachers- an academic rebellion, if not repulsion of the 'unknown'. If these ideas are accepted at all, they are not retained for long. If new ideas are presented in such an affable manner that challenges their alternative conceptions they are 'forced' to analyse their faulty ones more critically in diverse dimensions, deconstruct, and then re-construct more authentic ones or accept the new idea wholly.

Tertiary students formally encounter chemical reactions in secondary schools and are particularly conversant with synthesis, neutralisation and precipitation reactions, as well as the formation of covalent and ionic compounds. Often, they may not be able to explain what happens at the particulate level when say, a new substance is formed or precipitated or dissolution occurs. This is because they have alternative conceptions about the nature of chemical bonding. Thus, it is important that in teaching about compound formation, bonding is taught with respect to ionic interactions and all other types in relation to how their bonding occurs.

The confusion about atoms, ions, molecules and electrons must be clarified when teaching about the nature of substances (Taber, 2002). Concepts such as the structure of atoms, elements, and their symbols, compounds and their formulas, electronic configurations, chemical bonding, the periodic law, chemical reactions and many more other basic concepts about matter are taught in lower secondary schools (ages 11 to 14) before further reinforcement at senior high schools (ages 14 to 17). From these contents, properties about matter should be easily understood and explained with coherence and comprehension by students. However, this is not the case. Besides, the conservative nature of matter must be a basic principle that learners of chemistry must acquire, if they are to be able to successfully represent and interpret chemical reactions and equations. According to Taskin and Bernholt (2014) and Hanson (2017) misinterpretation of chemical reactions are expected to decline over time of schooling, but have been found to be persistent among university students, who represent a highly selected academic sample. These observed shortcomings among learners of chemistry call for immediate arrest of the situation as some of this crop of selected academics could be the ones to help upcoming young science students to also build scientific concepts about many chemical phenomena.

Generally, one is said to acquire a concept when they are able to elicit examples and distinguish them from non-examples (Demircioglu, Ayas, & Demircioglu, 2005; Taber, 2002). Chemical concepts are always hierarchical, starting with very basic identities and definitions or ideas and distinctions. In this study, in order to enable concept deformation and formation among teacher trainees, micro scale chemistry experiments were developed for them to investigate chemical reaction types from a fundamental base so that they would be able to construct their own unchallenged scientific concepts about types of chemical reactions and their representations at various levels. The theoretical basis of this study would be the constructivist approach that is grounded in the belief that learners have ideas formed from their environments before they receive formal tuition; which determines the outcome of whatever they learn later.

Micro scale activities have been known to provide learners with opportunities to carry out activities to in order to enhance conception (Supasorn, 2015; Zakaria, Latip, & Tantayanon, 2012; Sebuyira, 2001). The advantage of using the micro scale experiments were to enable as many activities as possible to be performed within a relatively short period at a lesser cost but enhanced availability, so that trainees could build their own scientific conceptions from a recurring pattern – distinguishing examples from non-examples. The activities were also designed to enable them to see chemical reactions at first-hand so that peculiar discerning distinctions such as reactions of acids with alkalis, carbonates, nitrates, sulphates and their associated outcomes could be identified and explained with ease, using physical characteristics such as change in colour, formation or dissolution of solids and evolution of characteristic gases, to mention a few. Worksheet activities were employed, in addition to the micro scale activities, as they have also been known to facilitate conceptual understanding through practice (Yildrim, Kurt, & Ayas, 2011; Celikler, 2010). They are effective resources which also fall in line with the principles of constructivism and so were used in this vein as simple diagnostic tools or resources that contain process steps that encourage learners to structure knowledge and allow for full participation in class. Worksheets are also cheap to supply for engaging classroom activities. Besides, they enable free expression of thoughts.

Limited literature was found about the effect of worksheets on students' understanding of the types of chemical reactions and the expression of their accompanying equations, especially in sub-Saharan Africa. Neither was any literature found on how micro chemistry activities could be used to teach types of chemical reactions and their various level-type representations. The only literature closest to the intended intervention for this study was what du Toit (2016) carried out in South Africa. This study therefore sought to research into that.

The objective for the study was that the chosen activities would enable trainees to distinguish between formal (scientific) and personal (naïve) ways of structuring chemical knowledge about types of chemical reactions and their representations. For the purpose of this study the three representational levels relevant to understanding of chemistry concepts were:

1. macroscopic representations that describe bulk properties of visible phenomena in the everyday experiences of learners when observing changes in the properties of matter (such as colour changes, pH of aqueous solutions, and the formation of gases and precipitates in chemical reactions) in diagrammatic form,
2. sub microscopic (or molecular) representations that provide explanations at the particulate level in which matter is described as being composed of atoms, molecules and ions, and
3. symbolic (or ionic) representations that involve the use of chemical symbols, formulas and equations, as well as molecular structure drawings, diagrams, models and computer animations to symbolise matter.

The questions that guided the study were:

1. To what extent would the use of micro chemistry activities and worksheets enable the remediation of teacher trainees' alternative conceptions about chemical reactions?
2. What heuristic and other learning skills would trainees demonstrate as they engage with microchemistry equipment and activity worksheets to show gains in conception?

MATERIAL AND METHODS

This was a case study undertaken to find out some of the possible causes of teacher trainees' inability to distinguish among different types of chemical reactions in their laboratory activities and represent them appropriately so that remediation could be offered. A case study allows a researcher to focus on and gather in-depth information about a specific person, group, community or event. Case studies can provide very detailed information about a particular subject that would not be possible to acquire through other types of experimentation. Besides, it allows for unethical issues to be tested without rigorous redress.
Seventy-four trainees participated in this study. A pre-assessment test on chemical reactions was administered to the trainees to assess their prior conceptions at the entry level of this course, after which they carried out micro chemistry (micro scale) activities involving chemical reactions for 30 minutes per session for four (4) weeks in their lecture rooms. Four chemical reactions were carried out in each 30-minute session, so that in all, 16 activities were carried out. This was easily possible because of the micro scale equipment that was employed. The trainees were expected to use basic logic and knowledge of chemical changes such as that of colour, evolution of gases, formation or dissolution of solids and other such parameters to differentiate among types of reactions in the questions which followed each activity, as the setting was one of a constructive conceptual environment. They were encouraged to use multiple levels of representations in their analytical descriptions of chemical phenomena. Examples of such worksheets are shown as Appendices A 1 to A3. The worksheets were also used to facilitate the guided-inquiry micro activities which aimed to help trainees to identify reaction types by pattern recognition through visualisation and image formation processes. Their effect was assessed in a retention test (Appendix B) two weeks after the 4-week treatment session.
A 10-item 3-point validated observation schedule with a reliability index of 0.74 was used to also assess gains in trainees' learning skills (Appendix C).

RESULTS AND DISCUSSION

Obtained data showed that the trainees in this study had difficulties with writing, (representing in other forms) and balancing of chemical equations as well as identifying chemical reaction types in the pre-assessment exercise. A practical activity that they carried out further exposed their challenges with the interpretation and deduction of types of chemical reactions, making correct observations, and explaining their macroscopic observations on a sub microscopic level, even if their observations were correct. Their mean score for both activities were 4.80 each, out of a total score of 20 marks. This however improved systematically over the 4-week treatment session, as shown in Table 1.

Table 1: Trainees' mean scores for 4-weeks of micro scale and worksheet activities

Activity	Week 1	Week 2	Week 3	Week 4	Overall mean
Micro scale (20 marks)	7	8	13	17	11.25
Worksheet (20 marks)	4	8	15	17	11.00
Mean	5.50	8	12.50	17	10.75/11.13

From Table 1, it is observed that the trainees' interpretations of the given practical and worksheet assignments were mostly incorrect to begin with but improved as their conceptions were enhanced. Unquestionably, they not only had alternative conceptions about matter and the concepts associated with chemical reactions; they were not familiar with the kind of problem sets given to them, which required higher order thinking and justification. Interpretation and deductions of micro scale activities had moved up a cumulative gain of seven mean units at the end of the four-week treatment session while interpretation of worksheets moved up by a cumulative gain of six mean units over the means from Week 1 but 10 and 13 mean units in Week 4 alone, as compared to their Week 1 performance. Likewise, their performance in the MSC activities also moved up by six units. In the retention test, scores from the worksheets and practical sessions showed means of 18.5 and 18 out of a total 20 marks.

Most challenges that the trainees faced in writing equations were because of their poor knowledge of the nature of chemical change and the patterns of common reaction types. For example, they were expected to have performed enough laboratory practice to effectively identify the nature of substances such as metal carbonates or metals and decipher the outcome of their reactions with dilute acids. With the knowledge of such basic concepts, they could have gained and entrenched their knowledge about the principles required in classifying matter into similarities and differences. For example, in the reaction of lead (II) nitrate with sodium iodide, the trainees were to suggest the products that would form, which were lead iodide and sodium nitrate. However, a gradual and stepwise process was required. They first had to identify the ions that constituted each of the reactants and then those that would result from the products. Besides, they were to identify the kind of particles as ions, atoms, or molecules and present them diagrammatically. This activity was geared toward enabling them to build mental models of abstract events or structures of substances. They further had to justify their choice of specific particle. Then came the symbolic representation which tested their knowledge about symbolic or formula representations. After the symbolic representation (or equation), they fitted it into a specific reaction type(s), with reasons. The example cited was a double replacement reaction.

An edge over such basics as discussed, could lead to the identification of more complex chemical reactions like synthesis, displacement, combustion, and reduction-oxidation (redox) reactions. From here, advanced discrimination, as expected at the tertiary level, could have been attained as they learned about how a reactive metal could displace a less reactive metal from its salt. Findings from this study support Taskin and Bernholt's (2014) assertion that misinterpretation of chemical reactions persist even among academically elect and premier university students. Nevertheless, conceptions and academic performance improved after several similar micro activities on reaction types were carried out by the trainees. Activities were deliberately structured so that in each week's session, trainees carried out two activities of a particular type of chemical reaction, which was followed by two discriminatory ones.

Data were analysed both qualitatively and quantitatively for in-depth analysis of outcomes. The success rate of the tools was about 85% in a delayed assessment to test retention of acquired knowledge. The innovative engaging activities provided students with the appropriate mental images that they needed to enable them develop skills for mental visualisation and the ability to draw relationships among macroscopic, sub microscopic and the symbolic levels of matter in chemical reactions. Recognising types of reactions through engaging activities due to personal recognition from recurring patterns can help students to fit reactions into a limited number of classes (du Toit, 2016), which is good for mastering of concepts when building mental models or frameworks. Acquiring and using concepts requires one to recognise similarities and differences among events or presentations. This means that some attributes must be pertinent to desired concepts for appropriate classification. Therefore spotting differences is one way to expose students to relevant attributes (Hanson, 2017). For example, the trainees in the current study found out that the higher halogens could displace the lower ones from their activities with halides. They also found out that lead (II) ions always reacted with iodides, irrespective of the anion in the lead compound and the cation in the iodide, to form a yellow solution of lead iodide, which always precipitated after a while. They also were able to deduce from several activities that the appearance of sodium ions were colourless in solution. Neither did they form precipitates with the common bench reagents that were used at their level. Thus, if a cation had to be identified but was not yielding precipitates of any kind and was not coloured either, then sodium could be deduced. Many such simple and basic but true or authentic deductions were made by the trainees. The presence of colour, and changes in colours of solutions, the formation and dissolution of solids that were observed in the MSC activities helped the trainees to form longer lasting mental models (Supasorn, 2015).

The interesting and yet challenging part of the remediation was the processing of ideas. Reactants and products had to be defined and presented in the macroscopic (diagrammatic), sub microscopic and symbolic forms (Appendix A). Each of these activities was intended as a reinforcement of the other. Thus, if trainees could not relate or connect their answers in a systematic order, then lapses in their thought processes could easily be discerned and interpreted with subsequent remediation. The diagnostic probe was quick and simple to use. It was useful for discussion, revision, and enabled the trainees to see patterns and connections between seemingly similar and dissimilar examples of reactions. If learners engage in learning by investigating, inquiring, collaborating, discussing and forming mental models in multiple representational modes, they will learn more meaningfully and make conceptual gains.

Students should be provided with opportunities to perform chemical reactions themselves and discuss with their peers the observed changes in terms of the particles involved as was done in this study. In chemistry, well-planned lessons that include pertinent, probing, and effective questions, encourage student to come up with new ideas amidst reflection- all geared towards conceptual learning. Success in chemistry involves imagination, organisation, and critical thinking on the part of teachers and students. With this in mind, discussion of the multiple levels of representation associated with the corresponding chemical equation for the reaction was emphasised in this current study. Carrying out additional similar chemical reactions by trainees themselves or as demonstrations by the teacher helped to further consolidate trainees' conceptions. For example, using several metal oxides to react with different dilute acids helped to illustrate the similarities in their chemical reactions and yet, the different salts that were produced. Once trainees became aware of the similarities in the chemical reactions, deducing the ionic equations for the reactions became a more meaningful endeavour, as expected at the tertiary levels, than the common practice of 'cancelling out' the 'spectator ions' from the overall balanced chemical equation which is taught in upper secondary schools to obtain product of reactions.

There is a need to place greater emphasis on the correct use of multiple levels of representation when describing and explaining chemical phenomena during classroom instruction. All too often teachers take it for granted that students are able to switch back and forth between levels of representation with ease. However, this isn't the case as many trainees in this study were found to have challenges with representing what truly happened among particles of matter at the microscopic and sub-microscopic levels. Neither could they present them diagrammatically. A similar observation was made by Hanson (2017) in a recent study. This study has shown that the assertion that students can switch back and forth among the various levels of representation is far from the case, when students are asked to describe and explain chemical reactions. Nevertheless, the exposure to a new and active learning environment could lead to the acquisition of learning skills with significant gains in imagery (Hanson, 2016) and conceptions about chemical reactions as analysed observed data proved in this study. The initial observation was confirmed in trainees' performance in the retention test which was conducted two weeks after treatment and still showed high positive retention of concepts about chemical reactions and their representations among the trainees.

Analysed data from the observation schedule indicated that students gained many learning skills which could have contributed significantly to enhance their performance at the end of the study. Some of these developed skills were, communication skills (as they were able to discuss their observations and reasonably argued out their answers), manipulative skills (which showed in the dexterity with which work materials were handled), collaborative skills (observed through paired and group discussions among trainees) and many more such as imaginative, reflective, analytical, deductive, and reflective skills. In short, their process, concepts and laboratory skills were enhanced. These skills were further confirmed in their high-quality performance in a delayed assessment to test their retention of acquired concepts.

The micro chemistry hands-on activities, coupled with worksheet activities, were effective in enhancing teacher trainees' conceptual understanding about types of chemical reactions and the three scientifically accepted representational levels. The exposure to their naive conceptions and commitment to the exploration of new and authentic ideas led to the accommodation of acceptable scientific concept which they constructed upon sound reasoning. They were able to ascertain and analyse correctly, the various types of reactions on the worksheets that they were presented with and carried out micro chemistry activities to confirm their veracity or otherwise in delayed assessments, attestation of retention of acquired knowledge.

CONCLUSION

Data obtained from this study show that some of the alternative concepts held by these trainees in Ghana could be global as they illustrate similar patterns with findings from related literature about reaction types (du Toit, 2016). The results further indicated that eliciting trainees' conceptions about the types of chemical reactions and their different presentations through an enabling and innovative engaging environment provided them with the opportunity to promote their conceptual understanding about chemical phenomena as it eliminated idiosyncratic ideas which had been learned by rote in irrational ways as observed by Demircioglu et al. (2005) and Kirman Bilgin et al. (2017). Most of the trainees' alternative

concepts which they manifested at the start of the study were replaced by scientific ideas with coherent reasons and constructed accurately as evidenced in a retention test.
Results from the trainees' practical activity sessions proved that the MCE and worksheets were successful tools in promoting learning. The micro activities were performed with dexterity as trainees developed laboratory, process and consequently concept skills. Many of the trainees were observed to be collaborating with each other to learn and develop the proper ways to describe and illustrate observed scientific events. Similar observations were made in studies that required students to use MSC, worksheets and other modelling kits. These observed results are again consistent with researchers who have attempted to use worksheets and models to enhance conceptions among students (2017; Supasorn, 2015; Justi, Gilbert, & Ferreira, 2014; Zakaria, Latip, & Tantayanon, 2012; Yildrim, Kurt, & Ayas, 2011). These observations suggest that the micro scale chemistry activities, coupled with the constructivists-designed worksheets exposed trainees' weakness, enabled them to walk a scaffolded pathway to develop scientific concepts and caused significantly better understanding about types of chemical reactions, as evident from their writing heurestics. They were able to build mental models through these activities as with the passage of time, they were able to predict correctly the outcomes of given reactions, and supported their assertions with criteria such as expected colour, whether a precipitate would be formed or not, whether a gas would evolve, and such basic observations as accompany chemical reactions. Chemical reaction types could now be stated, not by rote, but by fitting expected reactions into built mental models in coherent scientific language (Hanson, 2017) based on patterns, similarities and differences as observed by du Toit (2016). This proves further that the tasks led to higher order thinking and could be implemented in pre-service training of teachers to make them change focus from recall of factual knowledge, which is often acquired wrongly and by rote to higher order analytical, reflective and deductive thinking.

RECOMMENDATION

It is recommended that chemistry teachers should capitalise on the use of micro chemistry activities and worksheets as well as the importance of chemistry in everyday life to engage their students, and then follow through with opportunities for them to actively explore newly introduced concepts. This will bring the study of chemistry closer to students and make them appreciate chemical reactions in everyday life, as observed in the human body, with understanding.
The permanency of the trainees' acquired knowledge was not assessed through a clinical interview in relation to the identified misconceptions, as should have been. Thus, data variety and reliability could be enhanced through interviews with a new sample.

REFERENCES

Celikler, D. (2010). The effect of worksheets developed for the subject of chemical compounds on student achievement and permanent learning. *The International Journal of Research in Teacher Education, 1*(1), 42-51.

Demircioglu, G., Ayas, A., & Demircioglu, H. (2005). Conceptual change achieved through a new teaching program on acids and bases. *Chemistry Education Research and Practice, 6*(1), 36-51.

du Toit, M. H. (2016). The value of small scale chemistry kits to support socio-economic transformation in South-African schools through onsite workshops. *24th IUPAC International Conference for Chemistry Education* (p. 73). Kuching: KIMIA Institut.

Hanson, R. (2016). Using an embedded conceptual strategy to enhance students' understanding of Le Chatelier's summation of some stress factors on equilibrium position. *International Journal for Cross Disciplinary Subjects in Education (IJCDSE), 7*(3), 2889-2899.

Hanson, R. (2017). Assessing the potential of worksheets as a tool for revealing teacher trainees' conceptions about chemical bonds. In C. A. Shoniregun, & G. A. Akmayeva (Ed.), *CICE-2017 Proceedings* (pp. 648-653). Mississauga, Canada: Infonomics Society.

Justi, R., Gilbert, J. K., & Ferreira, P. F. (2014). The application of a 'model of modelling' to illustrate the importance of metavisualisation in respect of the three types of representation. In J. K. Gilbert, & D. F. Treagust (Eds.), *Multiple representations in chemical education* (pp. 285-307). Dordrecht: Springer Netherlands.

Kirman Bilgin, A., Demircioglu Yurukel, F. N., & Yigit, N. (2017). The effect of a developed REACT strategy on the conceptual understanding of students:'particulate nature of matter'. *Journal of Turkish Science Education, 14*(2), 65-81.

Nakhleh, M. B. (1996). Narrowing the gap between concepts and algorithm in freshman chemistry. *Journal of Chemical Education, 73*(1), 758-762.

Sebuyira, M. (2001). *A trial introduction of RADMASTE microchemistry kits in Chemistry 1 practical at the University of the Witwatersrand.* South Africa: University of Witwatersrand, South Africa.

Supasorn, S. (2015). Grade 12 students' conceptual understanding and mental models of galvanic cells before and after learning by using small-scale experiments in conjunction with a model kit. *Chemical Education Research and Practice, 16*, 393-407.

Taber, K. S. (2002). *Chemical misconceptions- Prevention, diagnosis and cure. Volume 1: Theoretical background.* London: Royal Society of Chemistry.

Taskin, V., & Bernholt, S. (2014). Students' understanding of chemical formulae: A review of empirical research. *International Journal of Science Education, 36*(1), 157-185.

WAEC. (2013-2016). *Chief Examiners' Reports for WASSCE: Chemistry.* Accra: West African Examinations Council.

Yildrim, N., Kurt, S., & Ayas, A. (2011). The effect of worksheets on students' achievement in chemical equilibrium. *Turkish Science Education, 8*(3), 44-58.

Zakaria, Z., Latip, L., & Tantayanon, S. (2012). Organic chemistry practices for undergraduates, using a small lab kit. *Procedia-Social and Behavioural Sciences, 59*(1), 508-514.

Appendix A1: Pre-assessment

1. What particles (such as ions, atoms, and molecules) are present in sodium hydroxide and hydrochloric acid?
2. Aqueous sodium hydroxide reacts with aqueous hydrochloric acid to form ......
3. What particles would be present after aqueous sodium hydroxide and hydrochloric acid react?
4. Explain how the particles are bonded to each other. State the numbers of particles in the combinations.
5. Make a sketch of the reactants and products
6. Write out the reaction in word and formula form.

Appendix A2: Worksheet Exercise 3

Consider the chemical reactions below and classify them as precipitation, displacement, redox, neutralisation, synthesis, or thermal decomposition reactions, with reasons as shown in the example.

For example:

$NaOH + HCl \rightarrow NaCl + H_2O$

This is a neutralisation reaction because ……………………………………………

1. $N_2(g) + 3H_2(g) \rightarrow 2NH_3$
2. $NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)$ neutralisation

3. $CuCO_3(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l) + CO_2(g)$
4. $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$ Redox; displacement
5. $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$
6. $CuCO_3(s) \rightarrow CuO(s) + CO_2(g)$ Thermal decomposition
7. $2NaBr(aq) + Cl_2(aq) \rightarrow 2NaCl(aq) + Br(aq)$ Displacement; oxidation
8. $2CuO(s) + C(s) \rightarrow 2Cu(s) + CO_2(g)$ Displacement; redox
9. Methane + Oxygen → Carbon dioxide + steam
10. $Zn(s) + 2HCl(aq) \rightarrow ZnCl(aq) + H_2(g)$
11. Sodium chloride → sodium + Chlorine
12. $2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$
13. $Pb(NO_3)_2 + KI \rightarrow CuO + CO_2(g)$ thermal decomposition

Appendix A3: Sample of Worksheet

1. Powdered Zn is added to blue aq copper (11) sulphate and shaken. The blue colour gradually fades to colourless, while a reddish brown ppt is produced.
   Rxn: $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$. Why?
2. You have seen what happens when a colourless aqueous solution of potassium iodide is added from a dropping pipette, with shaking, to some aqueous lead (II) nitrate in a test-tube, until no further change occurs. A bright yellow precipitate is instantly produced. On allowing standing for a while, the yellow precipitate settles to the bottom, with a colourless solution above. The changes that occur are represented by the chemical equation:
   $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

   a) : Name the yellow precipitate produced.
   b) : What does the chemical equation tell you about the changes that have occurred?

Using your knowledge about atoms, molecules and ions, answer Questions c – h.

   c) : Name the particles present in aqueous lead (II) nitrate.
   d) : Name the particles present in aqueous potassium iodide
   e) : Name the particles present in the yellow precipitate
   f) : Name the particles present in the colourless solution finally produced.
   g) : Name the particles that have remained unchanged in solution.
   h) : Deduce the ionic equation for the changes that have occurred.

   When the experiment is repeated using colourless aqueous solutions of lead (II) ethanoate, $(CH_3COO)_2Pb$, and sodium iodide, a yellow precipitate and a colourless solution are again produced.

   i) : Write a balanced chemical equation for the changes that occur, indicating all state symbols.
   j) : Write a balanced ionic equation for the changes that occur, indicating all state symbols.
   k) : On allowing the yellow precipitate to settle, what colourless solution is formed? Name the ions that will be found

Appendix B: Retention Test

Write formula equations for the reactions below (1-4) and write the names of the resulting compound. Explain why you have formed your products of choice.

1. Trioxonitrate (v) acid reacts with aqueous calcium hydroxide.
   ....
   ....

From items 5-8, fill in the missing species and explain your written answer

4. Zinc carbonate + ... → Zinc sulphate
   I write this answer because ....

For items 9-10, choose one of the answers given and explain your choice

9. What are the products of the reaction between aqueous barium hydroxide and hydrochloric acid?
   a. Barium chloride and water c. barium chloride and barium hydroxide
   b. Barium hydroxide and water d. hydrochloric acid and barium

I make this choice because ………………………………………………………… H_2SO_4 is added to black copper (11) oxide powder and warmed. The copper (11) oxide disappears and forms a blue solution. Why? *$CuSO_4$ is produced. Cu^{2+} ions cause blue colour*

Appendix C: Observation Schedule

No.	Demonstrative skills	Observed	Not sure	Not observed
1	Manipulative skill			
2	Process skill			
3	Measurement skills			
4	Collaborative skills			
5	Deductive skills			
6	Analytical skills			
7	Reflective skills			
8	Interpretive skills			
9	Critical thinking skills			
10	Imaginative (of mental model) skills			